LOW VOLUME SHORT DURATION HIGH-INTENSITY INTERVAL TRAINING AND REPEATED SPRINT ABILITY IN GAELIC FOOTBALL PLAYERS

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Declaration

I hereby certify that this material, which I now submit for assessment on the programme of study leading to the award of PhD is entirely my own work, that I have exercised reasonable care to ensure that the work is original, and does not to the best of my knowledge breach any law of copyright, and has not been taken from the work of others save and to the extent that such work has been cited and acknowledged within the text of my work.

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Abstract

Kelly, David T. Low Volume Short Duration High-intensity Interval Training and Repeated Sprint Ability in Gaelic Football Players

Gaelic Football is the most popular sport in Ireland and is characterized by irregular changes of pace and high-intensity efforts interspersed with periods of light to moderate intensity activity. Speed, power and aerobic capacity are essential fitness components for optimal performance during match play. A high level of aerobic conditioning is required to generate and maintain power output during repeated high intensity activities.

Study 1: Anthropometric, physiological, metabolic and endurance exercise performance were evaluated in club level Gaelic football players (n=15) in response to 2 weeks of low volume short duration high-intensity interval training (LS-HIT) or high volume endurance training (HVET). Six sessions of LS-HIT and HVET induced similar improvements in endurance exercise performance. $\dot{V}O_2$max was increased significantly in the LS-HIT group only. There was no change in running economy or v$\dot{V}O_2$max following LS-HIT or HVET.

Study 2: This study compared the effect of 6 weeks of LS-HIT and HVET on anthropometric, physiological, metabolic and performance indices in club level Gaelic football players (n=25). Both groups had a similar significant increase in $\dot{V}O_2$max, v$\dot{V}O_2$max, Wingate anaerobic performance and endurance exercise performance. Running speed and jump performance did not change following LS-HIT and decreased significantly in response to HVET.

Study 3: The construct validity and determinants of repeated sprint ability (RSA) tests were evaluated in club and county level Gaelic football players (n=30). The RSA test involving 8 maximal 30 m sprints on a 22.5 sec cycle demonstrated construct validity. The ability to perform repeated sprints has a greater relation to running speed and power and blood lactate levels than indices of endurance performance.

Conclusion: LS-HIT is a time efficient strategy to induce aerobic adaptations normally associated with traditional HVET and maintain indices of speed and power in club level Gaelic football players. An RSA test involving 8 x 30 m sprints on a 22.5 sec cycle was superior in county than club level Gaelic football players.

Abbreviations

ADP	Adenosine diphosphate
AFL	Australian Football League
AMP	Adenosine monophosphate
ATP	Adenosine triphosphate
Ca_2^+	Calcium
CHO	Carbohydrates
CK	Creatine kinase
CMJ	Counter-movement jump
CO_2	Carbon dioxide
COX	Cytochrome c oxidase
Creatine	Methyl guandino-acetic acid
CS	Citrate synthase
DJ	Drop jump
ETC	Electron transport chain
FAD^+	Oxidised from FADH
FADH	Flavin adenine dinucleotide
$FADH_2$	Reduced form of FADH
FI	Fatigue index
GAA	Gaelic Athletic Association
H_2O	Water
HAD	Beta-Hydroxyacyl-CoA-dehydrogenase

HIT	High-intensity interval training
HK	Hexokinase
HRmax	Maximal heart rate
HVET	High volume endurance training
IDH	Isocitrate dehydrogenase
LDH	Lactic dehydrogenase
LS-HIT	Low volume short duration high-intensity interval training
LT	Lactate threshold
MCTs	Monocarboxylate transporters
MDH	Malate dehydrogenase
MPO	Mean power output
NAD^+	Oxidised form of NADH
NADH	Nicotinamide adenine dinucleotide
$NADH_2$	Reduced form of NADH
O_2	Oxygen
OBLA	Onset of blood lactate accumulation
PCr	Phosphocreatine
PDH	Pyruvate dehydrogenase
PFK	Phosphofructokinase
P_i	Phosphate
PPO	Peak Power Output
RE	Running economy

RSA	Repeated sprint ability
SD	Standard Deviation
SDH	Succinate dehydrogenase
TCA	Tricarboxylic acid cycle
VJ	Vertical jump
$\dot{V}O_2$	Oxygen uptake
$\dot{V}O_2max$	Maximal aerobic capacity
$\dot{V}O_2peak$	Peak aerobic capacity
$v\dot{V}O_2max$	Velocity at maximal oxygen uptake

Chapter I

Introduction

The Gaelic Athletic Association (GAA) was established in 1884 with the aim of promoting the traditional games of hurling, handball, Gaelic football and rounder's. It is Ireland's largest sporting organisation and is celebrated as one of the great amateur sporting associations in the world. Community based clubs form the basic unit of the organisation and competitions are organised from underage to senior level. There is a hierarchical competitive structure with elite players selected to represent their county team.

Gaelic football is a field based sport played by two teams of 15 players. It can be described as a hybrid of soccer, rugby and basketball. Each team consists of a goalkeeper, 6 defenders, 2 midfield players and 6 forwards. The ball is round and is slightly larger and heavier than that used in soccer, and may be caught, and/or kicked from the ground or hands. A point is awarded when the ball is kicked or hand passed over the crossbar and a goal, which is worth 3 points, is awarded when the ball passes between the posts underneath the crossbar. Adult club level and inter-county games are 60 min and 70 min in duration, respectively.

Like a number of other field-based invasive team sports, Gaelic football is characterised by irregular changes of pace and anaerobic efforts interspersed with periods of light to moderate aerobic activity. Club level players cover approximately 7.0 km during a game, the majority of which is spent jogging (24%) and walking (48%) [1]. The aerobic energy

system contributes significantly to these low to moderate intensity level activities. Many of the important events during the course of a game involve single or repeated short duration bouts of activity lasting ~3-4 sec, involving high running velocities (6.5 – 7.5 $m \cdot sec^{-1}$) and muscle power. These high intensity activities rely on the phosphagen system and anaerobic glycolysis and the relative contribution of each system is dependent, in large part, on the intensity and duration of the high intensity activity and the recovery intervals.

The duration of recovery periods following high intensity activities is however, largely unpredictable, due to the fact that they are imposed by the pattern of play and can vary greatly from player to player and from one game to another. Many are separated by rest periods long enough to allow complete or near complete recovery and therefore subsequent sprint performance is not significantly impaired. At other times the high-intensity bouts are separated by short rest periods (<10 sec) which may negatively affect subsequent sprint performance. The ability to perform short-duration sprints with a short recovery time is called repeat sprint ability (RSA) and is an important fitness component for Gaelic football [2]. The ability to perform repeated bouts of high intensity exercise depends on the number of repetitions, duration of work periods and the nature, duration and intensity of the recovery period [3]. This emphasizes the need for a selection of appropriate RSA protocols that will match work-rest pattern and physiological demands of Gaelic Football. To date, no specific RSA protocol has been developed for use in Gaelic football.

Since PCr resynthesis occurs primarily by oxidative processes, a high maximal aerobic capacity ($\dot{V}O_2max$) enhances the replenishment of phosphagen stores, during single and repeated bouts of high intensity activity. Studies involving soccer players have also found

that a high $\dot{V}O_2$max is also associated with a higher playing intensity, increased number of repeated sprints, increased involvement with the ball and greater distance covered in a game.

The primary purpose of any training program is to optimize performance during competition. To accomplish this goal, the coach needs to design and implement a comprehensive conditioning program that allows players to cope with the physical demands of the game. Cellular, organ and systemic alterations occur in a relatively predictable and uniform manner when conditioning programs are appropriately designed and implemented. High volume endurance training (HVET), a form of training that involves continuous running undertaken at low to moderate intensities has been traditionally used to improve aerobic capacity in club level Gaelic football players. A large number of laboratory-based studies have found that one to six months of HVET results in significant improvements in $\dot{V}O_2$max and endurance performance[4–6]. While HVET can develop aerobic capacity, it is time consuming, may lack the specificity required to develop or maintain running speed and muscle power and may result in neuromuscular and endocrine adaptions that are detrimental to their development and maintenance [7].

Low volume short duration high-intensity interval training (LS-HIT) involves repeated short duration bouts (<30 sec) of high intensity exercise interspersed with periods of active or passive recovery. Compared to HVET, this type of training is less time consuming, allows players to undertake a greater volume of high intensity activities and improves aerobic capacity. Burgomaster *et al*., (2008) found that 6 weeks of LS-HIT on a cycle ergometer elicited similar improvements in $\dot{V}O_2$max despite a much lower training volume and time

commitment. By design, weekly training volume was 90% lower in the LS-HIT group and necessitated a training time commitment that was only one-third of that of the HVET group (9 h vs. 27 h). Most of the training time in the LS-HIT group was spent in recovery between short, intense bursts of all out cycling and actual weekly exercise time was approximately 10 min, as compared to 4.5 h of continuous moderate-intensity cycling in the HVET group [8].

A number of recent studies [9–12] have also found that brief repeated sessions of LS-HIT, elicits physiological and metabolic adaptations that resemble traditional HVET. Given the markedly lower training volume involved with LS-HIT, this form of training may be used as a potential time-efficient strategy to increase $\dot{V}O_2$max and endurance performance and induce specific metabolic adaptations during exercise that are comparable to traditional HVET. In addition, LS-HIT may induce neuromuscular and endocrine adaptions that assist with the development or maintenance of running speed and muscle power.

The following series of studies will investigate the effects of 2 and 6 weeks of LS-HIT and HVET on anthropometric, physiological, metabolic and performance indices and compare performance and evaluate determinants in 4 different RSA tests in Gaelic football players.

Study Aims

1. Compare the effects of 2 weeks of LS-HIT and HVET on anthropometric, physiological, metabolic and performance indices in club level Gaelic football players
2. Compare the effects of 6 weeks of LS-HIT and HVET on anthropometric, physiological, metabolic and performance indices in club level Gaelic football players

3. Compare the construct validity of 4 different RSA tests in club and county level Gaelic football players
4. Evaluate the determinants of RSA performance in Gaelic football players

Study Hypotheses

Null Hypothesis

1. Anthropometric, physiological, metabolic and endurance performance responses will be similar in club level Gaelic football players following 2 weeks of LS-HIT and HVET
2. Anthropometric, physiological, metabolic and speed and power and performance responses will be similar in club level Gaelic football players following 6 weeks of LS-HIT and HVET
3. Performance in 4 different RSA tests will be similar in club and county level Gaelic football players

Alternate Hypothesis

4. $\dot{V}O_2max$, $v\dot{V}O_2max$, running economy and blood lactate concentration will account for most of the variation in RSA performance

Chapter II

Review of Literature

Gaelic football is the most popular team sport in Ireland. It is organized and promoted by the GAA. It is an invasion team sport that can best be described as a hybrid of soccer, rugby, basketball and Australian rules league, although it predates all of these games. It is a fast, physical contact game and at adult level is played between two teams of 15 players on a rectangular playing area that is approximately 135 m long and 80 m wide. Goalposts with a crossbar are located on both end lines. Each team has a goalkeeper and 14 "outfield" players. The exact positioning of each player may vary depending on the tactics employed. The ball which is similar in size but slightly heavier than that used in soccer can be played over any distance by foot or hand, and can be carried using the accepted solo running technique. This involves kicking the ball from foot to hand while moving.

The primary objective of the team in possession is to create and exploit space in order to score. A team is awarded a point when the ball is kicked or hand-passed between the posts and over the crossbar and a goal is awarded when the ball crosses the end line between the goal posts and under the crossbar. Three points are awarded for a goal. When the opposition has possession, the primary aim is to decrease the time and space available in order to prevent them from scoring and to regain possession of the ball.

While performance in Gaelic football is dominated by technical and tactical proficiencies, successful players must also have highly-developed, specific, physical capacities. Gaelic football is characterized by irregular changes of pace and anaerobic

efforts superimposed on a backdrop of sustained light-to-moderate aerobic activity [13]. Club and inter-county level Gaelic football players cover an average distance of 7.0 km and 8.5 km respectively, during the course of a game [1,13,14]. The majority of this distance involves low to moderate intensity activity with <1.7% of total playing time involving sprinting (figure 2.1) [1]. The average sprint duration is approximately 5.7 sec in duration [15]. However, these short duration bouts of high intensity sprinting, are predominantly the most decisive and important actions during the course of a game.

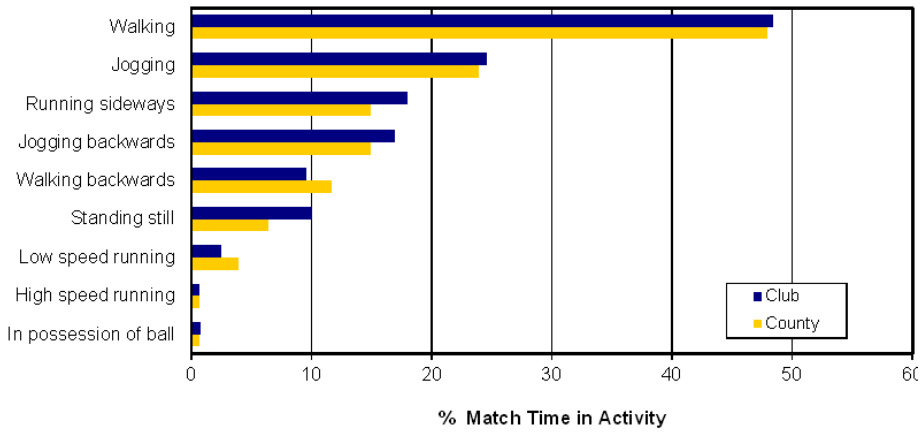

Figure 2.1: Gaelic football match time activity [14]

Bioenergetics

Human locomotion and other physical activities involve the extraction and transfer of energy from food nutrients to the contractile elements in skeletal muscle in order to generate force and create bodily movement. The process of converting the chemical energy of food nutrients into adenosine triphosphate (ATP), the common chemical intermediate used to power all forms of biological work is called bioenergetics or metabolism.

ATP is one of a group of compounds called nucleotides that contains a nitrogenous purine base (adenine), attached to the first carbon atom of ribose, and three phosphates ($P_{i)}$ attached to the fifth carbon atom of the pentose sugar (figure 2.2).

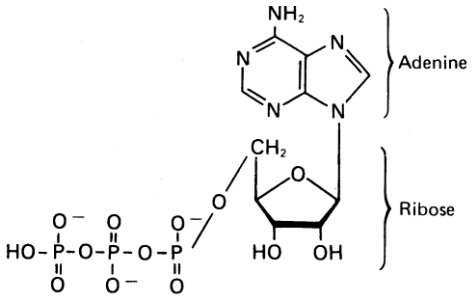

Figure 2.2: The structure of adenosine triphosphate

Hydrolysis of the anhydride bond between the final two P_i groups releases high amounts of stored energy resulting in the formation of adenosine diphosphate (ADP) and the release of an inorganic P_i. This reaction is catalyzed by the enzyme ATPase and the standard free energy change ($\Delta G°$) during the hydrolysis of 1 moll ATP to ADP *in vitro* is -7.3 kcal·mol^{-1}. However, in living cells the $\Delta G°$ is closer to -11.0 kcal·mol^{-1}. Skeletal muscle typically stores 6.0 mmol·kg^{-1} muscle of ATP, which at peak ATP turnover rates is enough to fuel 1-2 sec of maximal work. Maintaining muscle ATP homeostasis during match play is vital to delay the onset of muscle fatigue.

Metabolic processes involving the integration of aerobic and anaerobic (phosphagen system and anaerobic glycolysis) metabolism provide the energy used to rephosphorylate ADP during match play [16]. The relative contribution of each metabolic system is dependent on a number of factors including the intensity and duration of exercise, recovery interval between bouts of high intensity activity, fitness levels, nutritional status and genetics. The

phosphagen system along with anaerobic glycolysis, are the primary energy sources used during high-intensity, short-duration activity.

Phosphagen System

Phosphocreatine (PCr) (also called creatine phosphate) can be considered an intramuscular reservoir of high energy P_i bonds. It is made up of the amino acid derivative, methyl guandino-acetic acid (creatine) linked to P_i by a high energy anhydride bond (figure 2.3). The PCr concentration in resting muscle is ~18-20 mmol·kg^{-1}·muscle, which is three to four times greater than ATP [17].

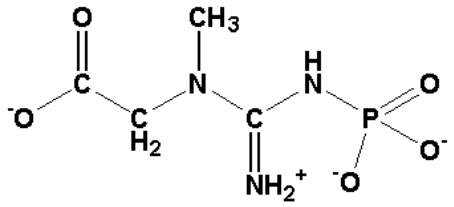

Figure 2.3: The structure of Phosphocreatine

Hydrolysis of ATP during a single short duration bout of high intensity exercise is rapidly compensated for by cytoplasmic PCr stores. The energy released from the breakdown of PCr is coupled to the synthesis of ATP in a reversible reaction catalyzed by the non-mitochondrial from of creatine kinase (CK) in skeletal muscle. The forward direction is favored during muscle contraction and during recovery the reverse reaction is favored to regenerate PCr.

The high activity of CK allows the phosphagen system to resynthesize ATP at a maximum rate of ~8.6 mmol·kg^{-1} dry weight^{-1}·sec^{-1} during short-duration (2-6 sec) bouts of

high-intensity exercise. Muscle levels of PCr can decrease by almost 90% during exercise and the decrease is proportional to the relative exercise intensity [18–20].

PCr restoration occurs in the mitochondria through the action of mitochondrial CK. It involves the hydrolysis of ATP produced from the metabolism of carbohydrates (CHO) and fats in the presence of molecular oxygen (O_2) [21,22] and the transfer of a P_i group from ATP to creatine. Creatine phosphate then diffuses from the mitochondria to the myofibrils of the working muscles to provide the energy for muscle contraction.

The term high-energy phosphates or phosphagens is used to describe the combined intramuscular stores of ATP and PCr. The ability to provide ATP rapidly for short periods of time makes the phosphagen system important for performance during high-intensity, short-duration match activities such as jumping to catch a ball, evading an opponent, sprinting etc.

Dawson *et al*., (1997) compared the repletion rate of PCr following a single 6 sec sprint and after 5 x 6 sec sprints. Muscle PCr was 70% replenished 30 sec following the 6 sec sprint and was complete after 3 min of recovery. In contrast, muscle PCr was only 50% replenished 30 sec after completion of the 5 x 6 sec sprints and 80% complete following 3 min of recovery [19] (figure2.4).

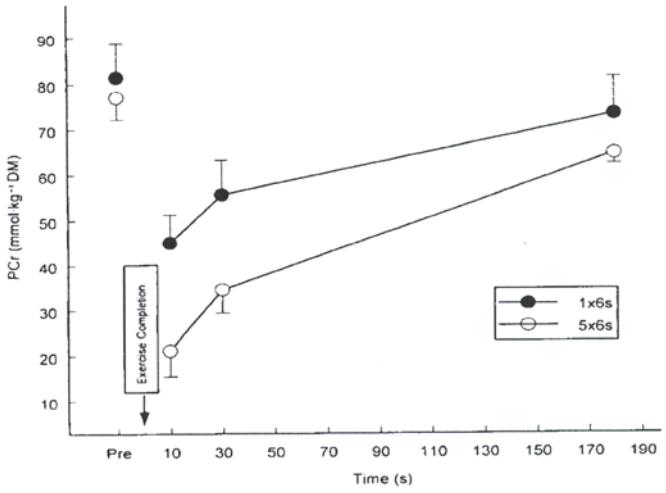

Figure 2.4: Repletion of PCr after 1 x 6 sec and 5 x 6 sec sprints [19]

Anaerobic Glycolysis

Glycolysis involves the breakdown of a single molecule of glucose into 2 molecules of pyruvate in a series of sequentially enzymatically catalyzed reactions that occur in the cytosol (figure 2.5).

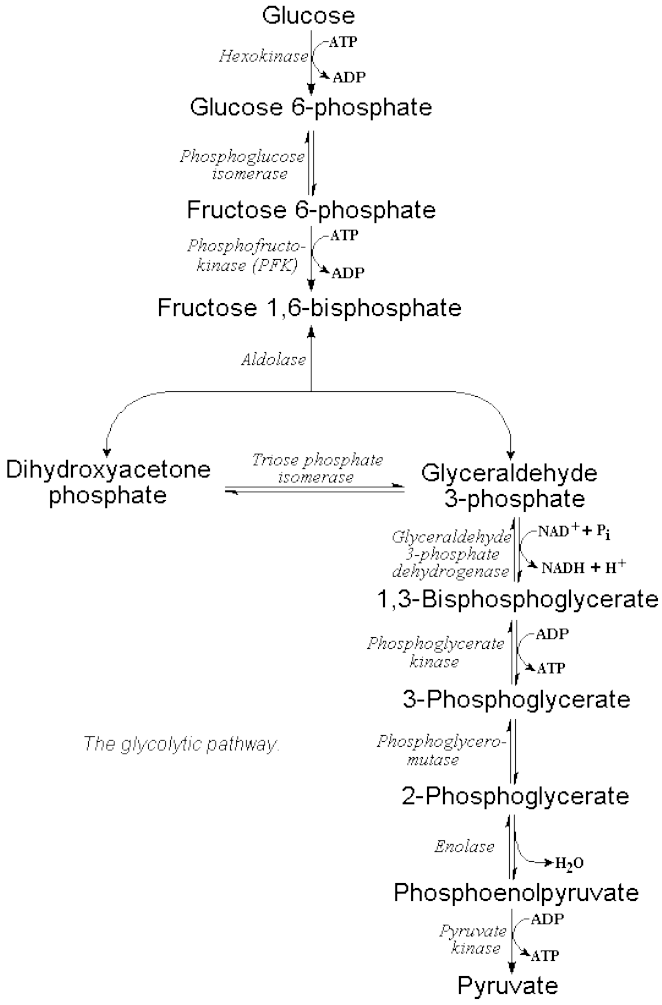

Figure 2.5: Summary of the glycolytic pathway in which glucose is degraded to pyruvate

Two substrate level phosphorylations result in the production of ATP by the direct transfer of a high-energy P_i group from 1,3-bisphosphoglycerate to 3-phosphoglycerate and phosphoenolpyruvate to pyruvate. The glyceraldehyde-3-P dehydrogenase reaction involves two coupled reactions. Firstly, a pair of hydrogen atoms are transferred from

glyceraldehyde 3-phosphate to NAD^+ to produce NADH and secondly, energy is released to add a P_i to carbon 1 producing 1,3-bisphosphoglycerate. At rest and during light to moderate submaximal exercise, NADH is shuttled to the mitochondria where it is oxidized.

Since the oxidized form of nicotinamide adenine dinucleotide is required for the glyceraldehyde 3-phosphate reaction, it must be continually replenished to maintain flux through glycolysis. When the O_2 supply is unable to meet the demand, the coenzyme remains in its oxidized form and pyruvate accumulates. Lactic dehydrogenase (LDH) has the highest rate of functioning of any of the glycolytic enzymes. Any increase in pyruvate further increases the activity of LDH. Under these conditions, pyruvate is reduced to lactate and oxidized NAD^+ is formed. The NAD^+ allows the 3-glyceraldehyde phosphate dehydrogenase reaction and the two subsequent substrate level phosphorylations to proceed.

Compared to aerobic metabolism, both anaerobic energy-producing systems have a high rate of ATP production, but a low capacity (table 2.1).

Table 2.1: Estimated maximal power and capacity in untrained males [52]

	Power		**Time**		**Capacity**
Energy system	$kcal \cdot min^{-1}$	$Kj \cdot min^{-1}$	hr:min:sec	kcal	kj
Phosphagen	72	300	:09 - :10	11	45
Anaerobic glycolysis	36	150	1:19.8	48	200
O2 (fuel = CHO)	7.2 - 19.1	30 – 80	2:21:00	359 - 1268	1500 – 5300

The maximal turnover rate of ATP production by anaerobic glycolysis is approximately 5-9 $mmol \cdot kg^{-1}$ dry $muscle \cdot sec^{-1}$. However, both anaerobic energy producing systems combine to maintain a ATP turnover rate of 11-14 $mmol \cdot kg^{-1}$ dry $muscle \cdot sec^{-1}$ [22].

The drop in PCr, along with the rise in metabolite accumulation, stimulates the rapid activation of anaerobic glycolysis at the start of high intensity exercise.

The glycolytic system is rather inefficient in terms of ATP production derived from each molecule of glucose. One glucose molecule produces 4 molecules of ATP. However, one ATP is used for activation if the initial fuel is glycogen and 2 ATPs are used if the initial fuel is glucose. Therefore, a net production of 3 ATP and 2 ATP molecules of ATP are produced if the initial fuel is glycogen and glucose respectively. Although this process is not energy efficient it has the advantage of replenishing ATP more rapidly than the oxidative pathway, which makes it particularly important during high intensity exercise.

It has been shown that anaerobic glycolysis supplies up to 40% of the total energy during a single 6 second sprint, with a progressive inhibition of glycolysis as sprints are repeated [18,20]. Gaitanos *et al*., (1993) found an 8-fold decrease in ATP production from anaerobic glycolysis from the first to the last sprint of a 10 x 6 sec protocol with 30 sec recovery. Power output decreased by 27% and blood lactate levels increased by 11.3 $mmol \cdot L^{-1}$. PCr and anaerobic glycolysis contributed 50% and 44% of the energy respectively for the first 6 sec sprint and 80% and 16% respectively for the 10^{th} sprint [18] (figure 2.6).

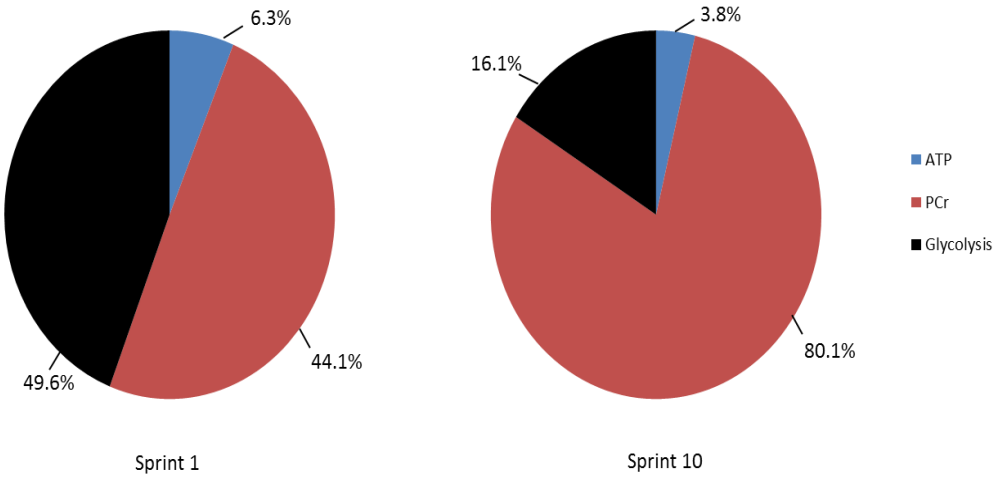

Figure 2.6: Anaerobic adenosine triphosphate (ATP) production (excluding energy provision related to lactate efflux) during the first and tenth sprints of 10 x 6 sec maximal sprints interspersed with 30 sec recovery periods [18].

Aerobic Metabolism

Aerobic metabolism refers to the breakdown of primarily CHO and fat in the presence of O_2. Under normal dietary conditions protein contributes little to energy production during team sports. Pyruvate, the end product of glycolysis undergoes irreversible oxidative decarboxylation to acetyl CoA and the formation of reduced NADH in a reaction catalyzed by the pyruvate dehydrogenase complex (PDH). The breakdown of fatty acids in the β-oxidation cycle, results in the formation of acetyl CoA and reduced NADH, and flavin adenine dinucleotide (FADH). The reduced NADH, and FADH produced during glycolysis and β-oxidation are transported to the mitochondria. The acetyl CoA produced during glycolysis and β-oxidation condenses with oxaloacetate to form citrate the first intermediary in the tricarboxylic acid (TCA) cycle.

The TCA cycle also known as the Krebs cycle is a series of enzyme-catalyzed chemical reactions used to generate energy through the oxidization of acetyl Co-A (figure 2.7). Hydrogen atoms and associated energy are removed from the various intermediates involved in the cycle using NAD^+ and FAD^+ as electron carriers. The reducing equivalents transport the energy derived from the TCA cycle through a series of protein complexes embedded within the inner mitochondrial membrane [23].

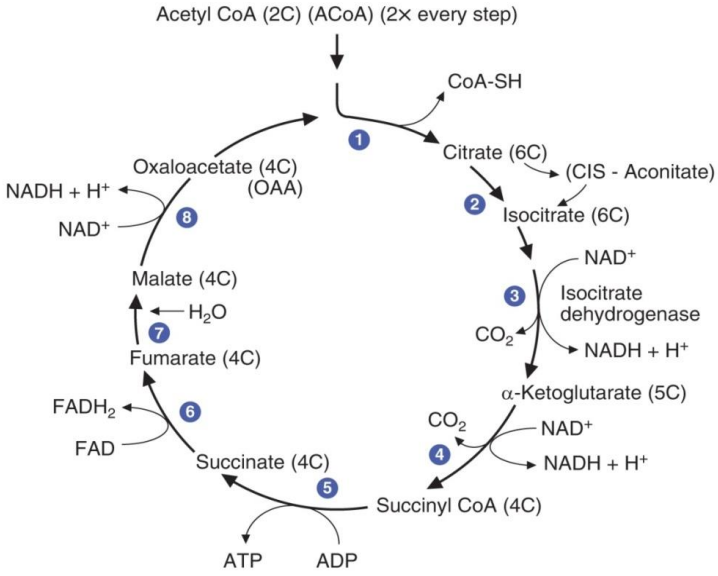

Figure 2.7: Overview of the tricaboxylic acid cycle (TCA cycle)

The condensation of oxaloacetate with acetyl CoA to form citrate is catalyzed by citrate synthase (CS) [24]. This enzyme is an important control point in the TCA cycle, and is allosterically inhibited by ATP. With the exception of succinate dehydrogenase (SDH) which is bound to the inner mitochondrial membrane the other enzymes catalyzing the reactions of the TCA cycle are located in the mitochondrial matrix. The CS, isocitrate dehydrogenase (IDH) and α-ketoglutarate dehydrogenase reactions operate with large negative free energy changes under the concentrations of products and reactants in the matrix of the mitochondria. These reactions are irreversible and rate limiting.

Regulation of the TCA cycle ensures that the rate of flux through the pathway provides optimal concentrations of ATP and $NADH_2$. Substrate availability limits the rate of citrate synthase activity. Because the TCA cycle is linked to O_2 consumption to regenerate NAD^+, it is regulated primarily by product feedback inhibition. The principle signals are

acetyl-CoA, succinyl-CoA, ATP, ADP, Adenosine monophosphate (AMP), NAD^+ and NADH. For example, high ratios of either ADP:ATP or NAD^+:NADH allosterically activate the key regulatory enzymes.

Oxidative phosphorylation is the process in which ATP is formed as a result of the transfer of electrons from $NADH_2$ and $FADH_2$ to O_2 by a series of electron carriers. The electron carriers transport the energy derived from glycolysis, β-oxidation and the TCA cycle through a series of protein complexes embedded within the inner mitochondrial membrane. These protein complexes constitute the electron transport chain (ETC), where oxidative phosphorylation takes place (figure 2.8).

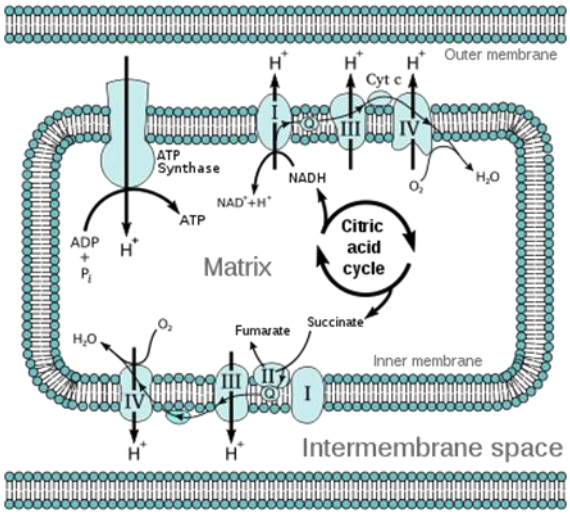

Figure 2.8: Overview of oxidative phosphorylation

NADH enters the ETC at complex I (NADH dehydrogenase), and transfers a pair of electrons to the protein complex. The electrons are then shuttled through the mitochondrial membrane to complex III, (cytochrome bc) by co-enzyme Q also called ubiquinone. From complex III, the electrons are transported to complex IV (cytochrome oxidase) where they are transferred to O_2 [24]. Coupled with the transfer of electrons at

complex I, III, IV is the pumping of hydrogen ions into the inter-membrane space. This process creates an electrochemical gradient across the inner mitochondrial membrane. The potential energy in this proton gradient is captured by complexes V (ATP synthase) and is used to rephosphorylate ADP [24].

FADH enters the ETC at complex Q. However, unlike NADH, the transfer of electrons from $FADH_2$ to co-enzyme Q is not coupled to the pumping of H^+ into the inter-membrane space at complex II. The subsequent passing of electrons through complex III and IV, however, yields free energy. Oxidation of $FADH_2$ and NADH results in the formation of 2 and 3 molecules of ATP, respectively [23].

Mitochondrial respiration is tightly controlled and is regulated by the presence of ADP. The rate of O_2 consumption increases with an increase in ADP concentration, electrons flow down the ETC chain allowing ATP to be produced. This mechanism ensures that electrons flow down the ETC only when ATP is required. The contribution of oxidative phosphorylation to total energy expenditure during a single short sprint is limited (<10%). This equates to an ATP turnover rate of approximately 1.3 $mmol \cdot kg^{-1}$ dry $muscle \cdot sec^{-1}$. Furthermore, the maximal rate of ATP formation from fat oxidation is too low to match the rate of ATP utilization during high-intensity exercise.

Although oxidative phosphorylation is not the dominant energy system during short-duration, high-intensity exercise bouts, O_2 availability limits the ability to replenish PCr stores. This is due to the fact the PCr resynthesis occurs primarily by oxidative processes [25]. The greater the phosphagen depletion during exercise, the greater the O_2 required for the

restoration during recovery. The half-time for recovery of PCr during rest periods is ~30 sec and can vary with fitness level [26].

A number of studies have found an association between O_2 availability and PCr recovery kinetics [27,28]. A higher PCr availability at the onset of each sprint as a result of hyperoxia reduces the demand on anaerobic glycolysis to maintain the required rate of ATP turnover and performance during 15 x 6 sec sprints (~250% $\dot{V}O_2$max) interspersed with 24 sec recovery [29,30]. In contrast, the ability to repeat 10 x 6 sec sprints interspersed with 30 sec recovery under hypoxic conditions was associated with increased anaerobic metabolites and muscle fatigue combined with a reduced $\dot{V}O_2$max [30]. Aerobic capacity is therefore an important determinant in recovery rate from intense activity. It assists power maintenance during high intensity exercise and decreases the demand on anaerobic glycolysis resulting in lower levels of circulating blood lactate.

According to the Fick equation, O_2 uptake is the product of cardiac output and arterio-venous O_2 across the body. This implies that both O_2 delivery (central) and O_2 extraction (peripheral) factors are important in ensuring that the muscle receives an adequate supply of O_2 [31]. $\dot{V}O_2$max is an integrative measure of the maximal ability of the lungs to supply O_2, the cardiovascular system to pump and transport oxygenated blood to the exercising muscle, and the ability of the working muscles to utilize O_2 [31]. Individuals with greater aerobic fitness exhibit higher concentrations of aerobic enzymes, increased mitochondrial number, size and surface area and increased myoglobin leading to improved O_2 extraction by the exercising muscle. These individuals also have greater cardiac output,

increased capillarisation of muscle tissue and a greater vasodilatory response during exercise than individuals with low fitness levels.

A high $\dot{V}O_2$max is widely accepted as a strong predictor of endurance running performance [32]. This is not surprising considering that a major part of the energy requirement in endurance events is provided by aerobic metabolism [33]. In addition to being the major source of energy during low to moderate intensity game activities with low levels of muscle and blood lactate accumulation, an individual with a high $\dot{V}O_2$max will have a higher capacity for oxidative ATP formation and should theoretically recover PCr stores at a faster rate than an individual with a low $\dot{V}O_2$max.

The majority of studies that have examined the relation between $\dot{V}O_2$max and performance during invasive team sports have involved soccer and the findings have been equivocal. Elite junior level Norwegian players with the highest $\dot{V}O_2$max, had a greater number of ball touches during a game, made a greater number of sprints and covered a larger distance than players with a lower $\dot{V}O_2$max [34]. In contrast, Roi *et al.,* (1993) found no relation between $\dot{V}O_2$max and the final position in the Italian soccer league [35]. Aziz *et al*., (2007), examined the relation between aerobic fitness levels and positional ranking among professional soccer teams in Singapore from 2002 – 2004, and found a significant relation between aerobic fitness and positional ranking during the 2003 season, but not during the 2002 or 2004 season [36].

Repeated Sprint Ability

Gaelic football players are required to repeatedly produce maximal or near maximal effort sprints with varying recovery periods. The ability to undertake multiple short duration intermittent bouts of high intensity exercise, interspersed with short duration recovery periods is termed repeated sprint ability (RSA) [2] and requires that the depleted PCr stores be rapidly re-synthesised [16] during recovery periods involving rest or low intensity activity. A high $\dot{V}O_2$max may allow for greater aerobic contribution to repeated sprints, and enhance ability to resist fatigue during repeated bouts of short-duration high-intensity activity [37].

A number of scoring methods have been used to assess RSA. Total sprint time and average sprint time are the most common and accurate measures of RSA performance. Fatigue index (FI) is also used in scoring RSA and is calculated in a number of ways: a) difference between the slowest and fastest sprint, b) percentage change from first to last sprint and c) 'ideal total' time minus total sprint time (where ideal total is best sprint score x number of sprints in the test). While RSA is often equated with a low FI, it is important to note that a good RSA is better described by a high average sprint performance, with or without a low FI [2].

Findings from studies that have examined the relation between $\dot{V}O_2$max and RSA performance are equivocal (table 2.2). Professional basketball players have a higher $\dot{V}O_2$max than amateur players and are able to repeatedly produce short, maximal bouts of exercise more often than amateur players [38]. Da Silva *et al*., (2010), found a significant inverse relation between $\dot{V}O_2$max and RSA FI using a protocol consisting of 7 x 34.2 m

sprints with 25 sec recovery on trained soccer players [39]. Bishop *et al*., (2004) also found a significant inverse relation (r= -0.62) between $\dot{V}O_2$max and RSA FI in untrained females, using a 5 x 6 sec protocol on a 30 sec cycle [40]. An inverse relation was found between $\dot{V}O_2$max and RSA total sprint time, in hockey and soccer players [41] and between $\dot{V}O_2$max and both RSA mean sprint time (r = -0.655) and total sprint time (r = -0.591) in professional soccer players [42]. In contrast, Bishop *et al*., (2003) found no significant relation between peak aerobic capacity ($\dot{V}O_2$peak) and FI in a 5 x 6 sec RSA test in elite female hockey players [43]. Similarly, Aziz *et al*., (2007) found no relation between any RSA parameter and $\dot{V}O_2$max in elite adolescent soccer players using a 6 x 20 m protocol (20 sec recovery) [44].

The conflicting findings regarding the relation between $\dot{V}O_2$max and RSA performance and may be due in part to the differences in fitness levels, the nature of the RSA test, and the use of relatively homogenous samples [3]. However the small variance in sprint decrement explained by $\dot{V}O_2$max suggests that other factors also contribute [45].

Table 2.2: $\dot{V}O_2$max and RSA performance

Journal	Level	N	Mode	Protocol	Rest	Results
Jones *et al.,* (2013) [42]	Professional soccer players	41	Running	6 x 40 m (20 + 20 m)	20 sec active recovery	Neg. *C* between RSA (MT & TT) and $\dot{V}O_2$max (r= -0.655 & r= -0.591)
Aziz *et al.,* (2000) [41]	National team hockey & soccer players	40	Running	8 x 40 m	30 sec	Neg. *C* between RSA (TT) and $\dot{V}O_2$max (r= -0.35)
Bishop *et al.,* (2006) [45]	Female Team sport athletes	16	Cycling	5 x 6 sec sprints (50 m)	30 sec cycle	Neg. *C* between RSA (FI) and $\dot{V}O_2$max (r= -0.50)
Da Silva *et al.,* (2010) [39]	Well trained soccer players	29	Running	7 x 34.2 m	25 sec	Neg. *C* between RSA FI and $\dot{V}O_2$max, (r= -0.39). No *C* between RSA (MT) and $\dot{V}O_2$max
Aziz *et al.,* (2007) [44]	Elite adolescent soccer players	37	Running	6 x 20 m	20 sec	No *C* between RSA and $\dot{V}O_2$max
Bishop *et al.,* (2003) [43]	Elite Female hockey players	14	Cycling	5 x 6 sec (50 m)	30 sec cycle	No *C* between RSA and $\dot{V}O_2$max
Meckel *et al.,* (2009) [46]	Trained adolescent soccer players	33	Running	1. 12 x 20 m 2. 6 x 40 m	20 sec cycle 30 sec cycle	Neg. *C* between RSA (FI) and $\dot{V}O_2$max in protocol 1 (r= -0.60). No *C* in protocol 2
Bishop *et al.,* (2004) [40]	Untrained Females	34	Cycling	5 x 6 sec (50 m)	30 sec cycle	*C* between RSA total work and $\dot{V}O_2$peak (r= 0.60), Neg.*C* between RSA FI and $\dot{V}O_2$peak (r=-0.62)

C = Correlation, MT = mean sprint time, TT = total time, FI = fatigue Index, Neg. = Negative/inverse,

High Volume Endurance Training and $\dot{V}O_2$max

HVET involving continuous exercise undertaken at low to moderate intensities has traditionally been used to improve aerobic capacity in Gaelic football players. A large number of laboratory-based studies have found that 1-6 months of HVET results in significant improvements in $\dot{V}O_2$max and endurance performance [53,54,91,159]. These improvements are related to both central and peripheral adaptations and allow individuals to sustain a given submaximal workload for a longer duration or to achieve a higher average power output over a fixed distance or time [47].

An increase in skeletal muscle oxidative capacity following endurance exercise training was first established over 40 years ago [48]. Holloszy *et al.*, (1967) found an approximate two-fold increase in mitochondrial enzymes SDH, NADH dehydrogenase and cytochrome c oxidase (COX) activities per gram of muscle and in the capacity of skeletal muscle to oxidize pyruvate in rats following 12 weeks of treadmill running 5 $d \cdot week^{-1}$ [48]. Furthermore, the skeletal muscle mitochondria of the exercised rats possessed a superior level of respiratory control and tightly coupled oxidative phosphorylation indicating that the increase in mitochondrial enzymes of the ETC is associated with an increased capacity to synthesis ATP. Exercise at the same absolute exercise intensity following endurance training requires a lower percentage of $\dot{V}O_2$max, which in turn minimizes disturbances in homeostasis [49]. This is evident by a smaller decrease in PCr and ATP and smaller increases in ADP and AMP, P_i and lactate, and a lower rate of glycogen breakdown at the same absolute exercise intensity.

The ETC is tightly coupled to ATP synthesis and is limited by the availability of ADP. The concentration of ATP decreases during exercise and the concentration of ADP and P_i increase until respiration is sufficiently activated to balance the rate of ATP utilisation during muscle contraction. ATP production per mitochondrion is less at the same submaximal work rate in trained than untrained individuals due the fact that they have a larger number of mitochondria. This results in a smaller decrease in ATP and PCr concentrations and a smaller rise in ADP, AMP and P_i in trained than untrained individuals in response to the same submaximal work rate [49]. Furthermore, phosphofructokinase (PFK) the rate limiting enzyme in glycolysis is inhibited by ATP and the availability of P_i is rate limiting for glycogen phosphorylase in glycogenolysis. As a consequence of the smaller reduction in ATP, ADP, AMP and P_i, glycogenolysis and glycolysis are activated to a smaller extent in trained than untrained individuals at the same relative work rates.

High-intensity Interval Training and $\dot{V}O_2$max

While ideal for developing aerobic capacity, HVET is time consuming, may lack the specificity required to develop or maintain running speed and muscle power and may even be detrimental to their development and maintenance. High-intensity interval training (HIT) refers to a type of discontinuous physical training that involves alternating brief bouts of high intensity exercise with periods of active or passive recovery [50]. High-energy phosphagens, anaerobic glycolysis and oxidative metabolism all contribute to ATP turnover to supply energy during short-term bouts of brief maximal intensity exercise.

Depending on the specific intensity, a single effort may last from a few seconds up to several min in duration, with multiple efforts separated by up to a few min of rest or low-

intensity exercise for recovery. Interval training is based on the concept that more work can be performed at higher exercise intensities with the same or less fatigue than a single bout of continuous exercise [51] and has been used by track and field athletes for almost a century [52]. Prescription for HIT involves manipulating the intensity and duration of the work and relief intervals and the number of sets.

There is an extensive body of literature examining the effect of high-intensity interval training on endurance exercise performance. Using a combination of cycling and running 6 d·week^{-1}, Hickson *et al*., (1981) found a 44% increase in $\dot{V}O_2$max in sedentary and recreationally active individuals in response to 10 weeks of HIT [53]. This early study established the link between HIT and improvements in aerobic capacity. Over the past 35 years a large number of studies have shown comparable changes in cardiorespiratory and metabolic adaptations in skeletal muscle in response to both HIT and endurance training [54–59]. Both the HIT and endurance training groups were matched for total work/volume or caloric expenditure in the majority of these studies.

LS-HIT involves performing a relatively small number of short duration (10-30 sec) activities at maximal intensity ('all-out' effort) with a work to rest ratio ranging from 1:3 to 1:6. An upper cut off of 30 sec is based on the assumption that longer duration bouts would result in substantially increased aerobic contribution to ATP turnover resulting in a marked drop in intensity [60].

A consistent finding of LS-HIT studies has been an increase in aerobic capacity expressed as $\dot{V}O_2$max or $\dot{V}O_2$peak (table 2.3) and endurance performance [61,62]. The majority of studies have recruited healthy active young college age men and used a Wingate test

protocol consisting of 3-7 x 30 sec cycle sprints with a recovery period of 3.0 - 4.5 min performed 3 d·week^{-1} for between 2 and 8 weeks [47,59,61,63–66]. The Wingate test involves cycling at maximal effort against a resistance of 7.5% body mass for 30 sec. Despite varying lengths of the training programs the average increase in $\dot{V}O_2$max was 7.2% [66]. In contrast two studies by Burgomaster *et al*., (2005, 2006) found no significant difference in $\dot{V}O_2$max following two weeks of LS-HIT despite improved endurance exercise performance [63,67].

Surprisingly, few studies that have evaluated LS-HIT on $\dot{V}O_2$max and endurance performance have used a running protocol or trained athletes. Iaia *et al*., (2009) found no change in $\dot{V}O_2$max in endurance trained runners following 4 weeks of LV-HIT consisting of 8 – 12 x 30 sec running sprints with 3 min recovery performed 3 d·week^{-1} [68]. Using a similar protocol involving highly trained endurance athletes, Laursen *et al*., (2002) found a small but significant 3% increase in $\dot{V}O_2$max and a 4.3% improvement in 40 km time trial performance [69]. In a recent review of 16 randomized control trials, Gist *et al*., (2013), found an aggregate improvement in $\dot{V}O_2$max of 8% in response to LS-HIT programs [70].

Table 2.3: Training Studies – LSHIT (15-30sec Intervals)

Study	Level	(N)	Mode	Protocol	Intensity	Duration (weeks)	Baseline $\dot{V}O_2$ (ml/kg/min)	Physiological Adaptations	Performance
Macdougall *et al*., (1998) [71]	Healthy Males	12	Cycling	4-10 x 30 sec sprints 2.5 - 4.0 min rec	All out	7 (3d/week)	3.73 (L/min)	7.5% ↑ in $\dot{V}O_2$max	↑ PPO, MPO
McKenna *et al*., (1997) [72]	Healthy Males	8	Cycling	4-10 x 30 sec sprints 3 min rec	All out	7 (3d/week)	3.53 (L/min)	4.2% ↑ in $\dot{V}O_2$max	1.3% ↑ PPO, 1.6% ↑ MPO
Whyte *et al*., (2010) [65]	Healthy Males	10	Cycling	4-6 x 30 sec sprints 4.5 min rec	All out	2 (3d/week)	2.98 (L/min)	8.4% ↑ in $\dot{V}O_2$max	3.6% ↑ MPO
Burgomaster *et al*., (2007) [62]	Active Males	8	Cycling	4-6 x 30 sec sprints 4 min rec	All out	6 (3d/week)	41.0		250kj TT performance ↑

Table 2.3: Training Studies – LSHIT (15-30 sec intervals) - Continued

Study	Level	(N)	Mode	Protocol	Intensity	Duration (weeks)	Baseline $\dot{V}O_2$ (ml/kg/min)	Physiological Adaptations	Performance
Astorino *et al*., (2012) [64]	Active Male and Females	20	Cycling	4-6 x 30 sec sprints 4 min rec	All out	2 (3d/week)	43.6	6.4% ↑ in $\dot{V}O_2$max	9.8% ↑ PPO, 10.7% ↑ MPO
Bailey *et al*., (2009) [59]	Active Male and Females	16	Cycling	4-7 x 30 sec sprints 4 min rec	All out	2 (3d/week)	42.0	6.7% ↑ in $\dot{V}O_2$max	
Barnett *et al*., (2004) [66]	Recreationally Active Males	16	Cycling	3-6 x 30 sec sprints 3 min rec	All out	8 (3d/week)	3.78 (L/min)	7.6% ↑ in $\dot{V}O_2$max	7.7% ↑ PPO, 7.1% ↑ MPO
Burgomaster *et al*., (2006) [67]	Male	8	Cycling	4-7 x 30 sec sprints 4 min rec	All out	2 (3d/week)	3.72 ($\dot{V}O_2$peak L//min)	Lactate accumulation ↓, no change in $\dot{V}O_2$peak	↑ 9.6%, TT perfor., 5.4% ↑ PPO, 8.7% ↑ MPO

Table 2.3: Training Studies – LSHIT (15-30 sec intervals) - Continued

Study	Level	(N)	Mode	Protocol	Intensity	Duration (weeks)	Baseline $\dot{V}O_2$ (ml/kg/min)	Physiological Adaptations	Performance
Trilk *et al*., (2011) [73]	Obese women	28	Cycling	4-7 x 30 sec sprints 4 min rec	All out	4 (3d/week)	21.6	11.8% ↑ in $\dot{V}O_2$max	No change in peak lactate
Iaia *et al*., (2009) [68]	Endurance trained runners	17	Running	8-12 x 30 sec sprints 3 min rec	All out	4 (3d/week)	54.8	No change in lactate or $\dot{V}O_2$max	RE ↑ at 11, 13, 14.5 and 16 km/h
Laursen *et al*., (2002) [69]	Highly trained endurance athletes	21	Cycling	12 x 30 sec sprints 4.5 min rec	175% PPO	4 (2d/week)	4.91 (L/min)	3% ↑ in $\dot{V}O_2$max	↑ 4.3% 40km TT perfor., 3% ↑ PPO
Burgomaster *et al*., (2005) [63]	Healthy Individuals	16	Cycling	4-7 x 30 sec sprints 4 min rec	All out	2 (3d/week)	44.6 ($\dot{V}O_2$peak)	No change in $\dot{V}O_2$peak	Time to exhaustion ↑ 100%
Hazell *et al*., (2010) [61]	Young Adults	22	Cycling	4-6 x 30 sec sprints 4min rec	All out	2 (3d/week)	48.7	9.3% ↑ in $\dot{V}O_2$max	↑ TT, 9.5% & 12.1% ↑ PPO & MPO

TT = Time Trial, PPO = Peak Power Output, MPO = Mean Power Output, RE = Running Economy

Comparison of Physiological and Performance Response to HVET or LS-HIT

Maximal Aerobic Capacity

A number of recent studies have compared the changes in $\dot{V}O_2$max in response to HVET and LS-HIT (table 2.4). Helgerud *et al*., (2007) found a significantly greater increase in $\dot{V}O_2$max following LS-HIT than in high volume moderate and low intensity training [74]. Burgomaster *et al*., (2008) found a similar increase in $\dot{V}O_2$peak in untrained men in response to 6 weeks of LS-HIT (3 d·week^{-1}) or HVET (5 d·week^{-1}). LS-HIT consisting of 4-6 x 30 sec sprints with 4 min recovery between efforts on a cycle ergometer and HVET involved 40-60 min of running at 65%$\dot{V}O_2$peak [8]. The similar increase in $\dot{V}O_2$peak occurred despite the fact that the total training time and energy expenditure was 66% (1.5 h vs. 4.5 h) and 90% (225 vs. 2250 kj·week^{-1}) lower in LS-HIT than HVET, respectively. Using the same 6 week LS-HIT and HVET protocols Cocks *et al*., (2013) found that $\dot{V}O_2$peak increased by 8% and 15% respectively, with no significant differences between groups [10]. Macpherson *et al*., (2011) found a 11.5% and 12.5% increase in $\dot{V}O_2$max in college aged men, following a 6 week LS-HIT and HVET program respectively. Both groups trained 3 d·week^{-1}. The LS-HIT group completed 4-6 x 30 sec sprints with 4 min recovery between efforts on a cycle ergometer and the HVET completing 30-60 min of continuous running [75].

Siemens *et al*., (2013) found an increase in $\dot{V}O_2$peak of 3.7 % and 8.6 % after 4 weeks of LS-HIT (8 x 20 sec running sprints, 10 sec rest) and HVET (30 min continuous running at 85% maximal heart rate (HRmax), respectively. Both groups increased $\dot{V}O_2$peak significantly despite a total training time difference of 86% (64 min vs. 480 min) [11]. Sandvei *et al*., (2012),

found that 8 weeks of LS-HIT involving 5-10 x 30 sec sprints with 3 min recovery induced a similar increase in $\dot{V}O_2$max as 30 – 60 min of continuous running at 70-80%HRmax in healthy young males [12]. The total training volume was 42% lower in LS-HIT than HVET (280 min vs. 480 min). In collegiate level soccer players, 5 weeks of LS-HIT involving 5 x 30 sec sprints with 3.5 - 4.5 min recovery, elicited a similar increase (4.7%) in $\dot{V}O_2$max as 40 min of HVET at 80% $\dot{V}O_2$max (3.4%) [9]. In summary LS-HIT is an effective and time efficient method for enhancing $\dot{V}O_2$ peak/max in recreationally and/or inactive participants.

In a study comparing LS-HIT and HVET Gibala *et al*., (2006) found a similar increase in the maximal activities of COX and the protein content of COX subunits II and IV after 2 weeks of either LS-HIT (4-6 x 30 sec cycles at 250%$\dot{V}O_2$peak with 4 min rec.) or HVET involving 90-120 min of continuous cycling at 65%$\dot{V}O_2$peak. Total training time over the 2 weeks was approximately 2.5 and 10.5 h for the sprint and the endurance trained respectively, and total exercise volume was approximately 90% lower in the LS-HIT group [47].

Similar increases in the maximal activities of oxidative enzymes have also been found in recreationally active individuals following 6 weeks (5 d·week^{-1}) of LS-HIT and HVET (40-60 min of continuous cycling at 65%$\dot{V}O_2$ peak). Participants performed a constant load exercise test involving 1 h of cycling at 65%$\dot{V}O_2$ peak before and after 6 weeks of training. Glycogen and PCr utilisation during this exercise test was reduced after both HVET and LS-HIT training and calculated rates of whole body CHO and lipid oxidation were also decreased and increased respectively with no difference between groups [8].

Table 2.4: Training Studies – LSHIT (15-30 sec intervals) vs. HVET

Study	Level	(N)	Exercise Mode	Protocol	Intensity	Duration (weeks)	Period	Physiological Adaptation	Performance Changes
Cocks *et al*., 2013 [10]	Sedentary Males	16	Cycle ergometer	SIT: 4-6 30s sprints x 4min recovery ET: 40-60min of continuous running	SIT: >100% $\dot{V}O_2$peak ET: 65% $\dot{V}O_2$peak	6 SIT:(3d/w) ET:(5d/w)	~	SIT: 8% ↑ $\dot{V}O_2$peak ET: 15% ↑ $\dot{V}O_2$peak	SIT: 9% ↑ W_{max} ET: 16% ↑ W_{max}
Siemens *et al*., 2013 [11]	Sedentary male & females	42	Running	HIT: 8 x 20s sprints (10s rest) END: 30 min continuous running	HIT: Maximal sprint efforts END: 85% HRmax	4 (4d/week)	~	HIT: 3.7% ↑ $\dot{V}O_2$peak END: 8.6% ↑ $\dot{V}O_2$peak	HIT: ↑ 5 km TT performance END: ↑ 5 km TT performance
Sandvei *et al*., 2012 [12]	Healthy young males	23	Running	SIT: 5-10 30s sprints (3min rest) CT: 30-60min of continuous running	SIT: Maximal sprint efforts CT: 70-80% HRmax	8 (3d/week)	~	SIT: 5.3% ↑ $\dot{V}O_2$max CT: 3.8% ↑ $\dot{V}O_2$max	

Table 2.4: Training Studies – LSHIT (15-30 sec intervals) vs. HVET - Continued

Study	Level	(N)	Exercise Mode	Protocol	Intensity	Duration (weeks)	Period	Physiological Adaptation	Performance Changes
Rowan *et al*., 2012 [9]	Collegiate level soccer players	13	Running	SPR: 5 x 30s sprints x 3.5-4.5min active recovery ET: 40min of continuous running	SPR: Maximal sprint efforts ET: 80% $\dot{V}O_2$max	5	Pre-season	SPR: 4.7% ↑ $\dot{V}O_2$max ET: 3.4% ↑ $\dot{V}O_2$max	SPR: ET:
Macpherson *et al*., 2011 [75]	Recreational athletes	20	Running	SIT: 4-6 30s sprints x 4min recovery ET: 30-60min of continuous running	SIT: >100% $\dot{V}O_2$max ET: 65% $\dot{V}O_2$max	6	In season	SIT: 11.5% ↑ c ET: 12.5% ↑ $\dot{V}O_2$max	SIT: 4.6% ↑ in 2000m TT perf. ET: 5.9% ↑ in 2000m TT perf.
Burgomaster *et al*., 2008 [8]	Recreational	20	Cycle Ergometer	SIT: 4-6 30S sprints & 4.5min recovery ET: 40-60min continuous running	SIT: Maximal cycling efforts ET: 65% $\dot{V}O_2$peak	6 SIT: (3d/week) ET: (5d/week)	Out of season	SIT: ↑ $\dot{V}O_2$peak ET: ↑ $\dot{V}O_2$peak	SIT: 17% ↑ PeakP ET: 7% ↑ PeakP

Table 2.4: Training Studies – LSHIT (15-30 sec intervals) vs. HVET - Continued

Study	Level	(N)	Exercise Mode	Protocol	Intensity	Duration (weeks)	Period	Physiological Adaptation	Performance Changes
Helgerud *et al*., 2007 [74]	Moderately trained	40	Running	LSD: 45min run IR: 47x 15s bouts with 15s active recov.	LSD: 70% HR_{max} IR: 90-95% HR_{max}	8 (3 d/week)	In Season	LSD: IR: 5.5% ↑ $\dot{V}O_2max$	LSD: ↑ RE IR: ↑ RE
Gibala *et al*., 2006 [47]	Recreational athletes	16	Cycle Ergometer	HIT: 4-6 30s bouts & 4 min recovery ET: 90-120min continuous cycling	HIT: Maximal cycling efforts ET: 65% $\dot{V}O_2peak$	2 (3 d/week)	Out of season	HIT: ET:	HIT: 50 & 750 kj TT ↓ 4.1 & 10.1% ET: 50 & 750 kj TT ↓ 3.5 & 7.5%

HIT=High Intensity Training; SIT=Sprint Interval Training; HIIT= High Intensity Interval Training; IR=Interval Running; IT=Interval Training; SPR= Sprint Training; ET= Endurance Training; HVT=High Volume Training; LSD=Long Slow Distance running; CT= Continuous Training;TT = Time Trial; > = greater increases compared to other group; Wmax = maximal aerobic power output

Metabolic Adaptations

In contrast to endurance training involving continuous exercise undertaken at low to moderate intensities, HIT results in an up-regulation of a number of enzymes involved in both the glycolytic and aerobic pathways. Indeed, early studies [76–78] found that interval training had a greater effect on skeletal muscle glycolytic capacity and less of an effect on mitochondrial oxidative enzymes than endurance training. Studies comparing both interval training and ET found that HIT increases PFK and adenylate activities without increasing CS, SDH, PDH or Beta-Hydroxyacyl-CoA-dehydrogenase (HAD) mitochondrial enzyme activities [79–81].

MacDougall *et al*., (1998) examined the effect of 7 weeks of LS-HIT on muscle enzymatic activity and exercise performance in 12 active students [71]. Individuals performed 4 LS-HIT sessions per week involving 4 - 10 x 30 sec all-out cycle sprints. Recovery intervals were 4 min in duration during weeks 1–4 and were subsequently decreased by 30 sec each week for the remaining 3 weeks. The maximal activities of CS, PFK, SDH, hexokinase (HK) and malate dehydrogenase (MDH) were significantly increased following training. Similarly, Rodas *et al*., (2000) found a 38%, 45% and 106% increase in PCr, LDH and PFK, respectively following 2 weeks of repeated supra-maximal cycle exercise [82].

Burgomaster *et al*., (2005) found a 38% increase in CS activity and a 100% increase in cycle endurance capacity after only 6 sessions of LS-HIT in recreationally active individuals [63]. The total exercise time during the 2 week period was ~15 min.

Endurance Performance Test (Time trial)

A number of performance tests have been designed to measure endurance performance in response to LS-HIT and HVET. The majority of these tests involved completing a set distance (km) or workload (kj) in the fastest time possible. Other methods include exercising at a certain percentage of $\dot{V}O_2$max/HRmax until volitional fatigue. Tests are sometimes referred to as endurance performance, time trial or performance tests.

Several studies have reported a significant increase in 250 kj time trial performance in recreationally active young men after 2 and 6 weeks of LS-HIT involving 4-6 x 30 sec cycle sprints, with 4 min recovery [62,67,83]. Using the same training protocol Hazell *et al*., (2010) reported a significant increase in 5 km time trial performance in young adults [61] after two weeks of training. Similarly, in elite male distance runners, a 4 week LS-HIT protocol consisting of 12 x 30 sec sprints 2 d·week^{-1} improved time trial performance by 4.3% [69].

Gibala *et al*., (2006) found similar improvements in both a 750 kj and 50 kj time trial performance after 6 sessions of LS-HIT and HVET even though there was a 90% difference in training volume [47]. Macpherson *et al*., (2011) found that 2000 m time trial performance increased in college aged men in response to both 6 weeks (3 d·week^{-1}) of LS-HIT consisting of 4-6 x 30 sec sprints on a cycle ergometer with 4 min recovery between efforts, and 6 weeks of HVET involving 40-60 min of running at 65%$\dot{V}O_2$peak, [75]. A study by Siemens *et al*., (2013) reported a significant increase in 5000 m time trial performance (approx. 5.6% & 10%) after 4 weeks of LS-HIT involving 8 x 20 sec running sprints with 10 sec recovery and HVET consisting of 30 min continuous running at 85%HRmax. The similar increase in time

trial performance occurred despite a total training time difference of 86% (64 min vs. 480 min) between groups [11].

In addition to $\dot{V}O_2$max, running economy (RE), velocity at maximal oxygen uptake ($v\dot{V}O_2$max) and circulating levels of lactate threshold are the major factors that account for inter-individual variability in aerobic endurance performance [34,84]. It is therefore possible that running economy and lactate threshold, combined with $\dot{V}O_2$max may provide a more precise determination of endurance characteristics than $\dot{V}O_2$max alone.

Running Economy

RE is defined as the steady state O_2 uptake for a given running velocity [85]. A more economic athlete uses less energy at a given running velocity than their less economic counterpart. The standard method for measuring RE usually involves running at progressively increasing velocity in 3-8 min bouts until steady state O_2 uptake is achieved (figure 2.9)**.** The intensity of the running should be below the ventilatory threshold, since above this intensity, the oxygen uptake ($\dot{V}O_2$) slow component dictates that steady state conditions are unlikely to be achieved [86,87]. The majority of studies that have measured RE at absolute treadmill velocities in elite and non-elite endurance runners have used a $\dot{V}O_2$ value expressed relative to body mass ($ml \cdot kg^{-1} \cdot min^{-1}$). RE can also be expressed as a caloric unit cost ($Kcal \cdot kg^{-1} \cdot km^{-1}$) [88] and O_2 unit cost ($ml \cdot km^{-1} \cdot min^{-1}$) [89].

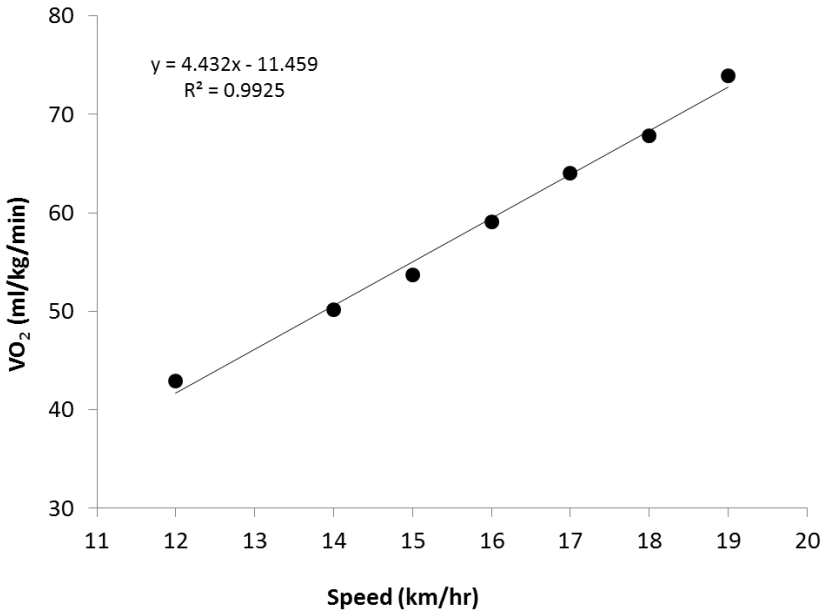

Figure 2.9: Running economy graph

Due to the complexity of RE, knowledge is limited compared with our understanding of other elements of running performance. Improved muscle oxidative capacity [90], reduced exercise ventilation and heart rate for the same intensity [87] or improved technique [91] have been found to influence RE. In addition, the ability of the muscles to store and release elastic energy, by increasing the stiffness of the muscles, and more efficient mechanics leading to less energy being wasted on braking forces may be associated with improved RE performance [92]. Biomechanical characteristics associated with improved RE include a narrow pelvis, smaller stature and feet, lower %body fat, and freely chosen stride length [86,93]. Fluctuations in physiological factors such as core temperature, heart rate, ventilation and lactate, may also be associated with changes in RE [94–97].

More efficient cyclists have been found to have a greater percentage of type I fibres, suggesting that the pattern of motor unit recruitment during exercise may be important in the determination of economy [98]. LS-HIT recruits a much greater volume of type II muscle

fibres than HVET, where type 1 fibres are primarily recruited [59]. Endurance training appears to induce fibre type remodelling resulting in type IIa fast twitch fibres taking on the morphologic and biochemical characteristics of slow twitch fibres. Therefore, as type I muscle fibres appear to be substantially more efficient than Type II muscle fibres, an endurance trained individual will have greater RE, possibly as a result of a lower rate of ATP turnover as reflected by a lower $\dot{V}O_2$, while performing exercise at a given power output [90]. Other factors that have been reported to influence RE, include genetics, fitness level, limb size and altitude [86,99,100]. Although RE has been extensively researched, there are still relatively few documented interventions that have shown improvements in trained populations. More precision measuring, that include both metabolic and mechanical aspects of RE are required, for a greater understanding on how to improve its performance.

RE has been reported as a better predictor of endurance exercise performance than $\dot{V}O_2$max in elite distance runners with similar $\dot{V}O_2$max values [92,101,102]. Considering that the range of $\dot{V}O_2$max values among outfield Gaelic football players is relatively small, it is therefore likely that RE may also account for inter-individual variance in aerobic endurance performance. This is supported by the fact that among soccer players with a similar $\dot{V}O_2$max those playing in the higher divisions were found to have a superior RE than players from lower divisions [103]. To date, no studies have evaluated RE in Gaelic football players.

The effect of exercise training and RE has also been extensively examined. Results from studies investigating the effect of medium to long duration (2-4 min) high-intensity interval training on RE have been equivocal [34,84,104]. Relatively few studies have compared the effect of LS-HIT and HVET on RE. A study on junior soccer players by Helgerud *et al*.,

(2007) compared the effect of 8 weeks of LS-HIT and HVET on RE. Participants in the endurance group ran for 45 min whereas the LS-HIT group completed 47 x 15 sec sprints. Even though there was a 74% difference in training volume, there was a similar increase in RE at 7 km·hr^{-1} (5.3% incline) in the LS- HIT (7.6%) and ET (7.5%) group [74].

v$\dot{V}O_2$max

The minimal velocity at which O_2 consumption starts to plateau despite an increase in running velocity is termed v$\dot{V}O_2$max. It is a composite variable that combines $\dot{V}O_2$max and RE into a single factor and is calculated by extrapolation from the sub-maximal $\dot{V}O_2$-velocity relation (figure 2.10). The accurate measurement of v$\dot{V}O_2$max therefore requires a valid measure of $\dot{V}O_2$max and RE at several moderate intensities below the LT [91 105].

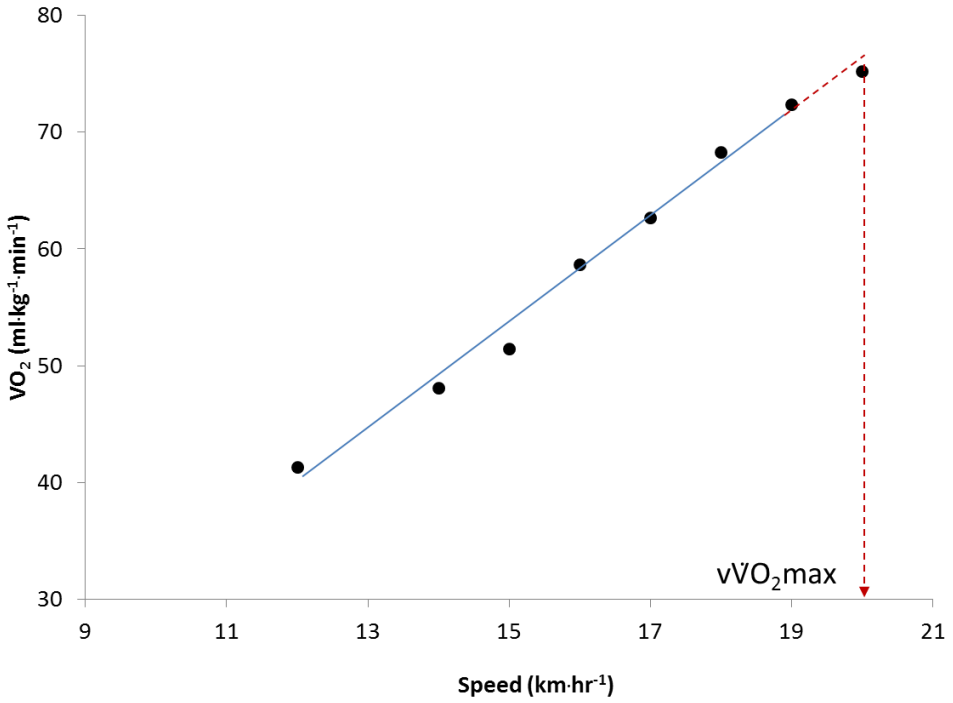

Figure 2.10: Determination of v$\dot{V}O_2$max

$v\dot{V}O_2max$ is an excellent predictor of endurance performance as it combines both aerobic capacity and RE. Changes in $v\dot{V}O_2max$ may be related to changes in endurance performance since $v\dot{V}O_2max$ measures are essentially performance measurements encompassing aerobic, anaerobic and neuromuscular aspects of performance. To date no published studies have evaluated $v\dot{V}O_2max$ in Gaelic Football or compared the effect of LS-HIT and HVET on $v\dot{V}O_2max$. However, both prolonged sub-maximal exercise and high-intensity interval training have been found to increase $v\dot{V}O_2max$ [106,107].

Blood Lactate Concentration

High blood lactate levels have a negative effect on muscle force production and are associated with the development of fatigue during high intensity exercise [31]. Increased blood lactate levels do not absolutely indicate a lack of O_2. Both resting and exercise blood lactate levels depend on the balance between production and clearance, i.e., turnover. When lactate production exceeds the rate of clearance, accumulation occurs. This is especially evident during short duration high-intensity exercise, when the O_2 supply is unable to keep up with the demand.

The increase in muscle contraction during exercise results in the release of calcium (Ca_2^+) from the sarcoplasmic reticulum. Ca_2^+ is not only involved in the coupling process of actin and myosin but also activates glycogen phosphorylase (GP), the key enzyme that regulates glycogenolysis. By binding to calmodulin, a subunit of phosphorylase kinase, Ca_2^+ activates GP without the need for its phosphorylation by protein kinase. Similarly, exercise induced activation of the sympathetic nervous system stimulates the release of epinephrine and glucagon which also activates GP.

The net result of the exercise induced activation of the sympathetic nervous system and increase in Ca_2^+ is an increase in the rate of glycogenolysis independent of the O_2 supply leading to increased flux through glycolysis and the production of pyruvate. High-intensity exercise also recruits fast twitch glycolytic muscle fibres which produce lactate when they contract, regardless of whether the O_2 supply is adequate. This is due to the fact that regardless of the availability of O_2, fast twitch glycolytic fibres have i) a predominance of LDH isozymes 4 and 5 that facilitate the reduction of pyruvate to lactate, ii) low mitochondrial density and a iii) large diffusion distance for O_2 .

Lactate clearance occurs primarily by oxidation (50-75%), gluconeogenesis/glyconeogenesis (10-25%) and transamination (5-10%). Each of these processes can involve the movement of lactate within or between cells. Lactate moves between lactate-producing and lactate-consuming sites through intracellular and extracellular lactate shuttles. This transport is provided by lactate transport proteins called monocarboxylate transporters (MCTs). Intracellular lactate transport involves movement of lactate by MCT1 transporters between the cytoplasm, where it is produced, and the mitochondria, where it can be oxidised to pyruvate and move through aerobic metabolism. Extracellular lactate transport involves the movement of lactate between tissues, primarily from fast twitch glycolytic muscle fibres to active slow twitch oxidative muscle fibres. This can happen through direct transport or via the circulation. Once in circulation, lactate can move to a number of different cells types where it can be oxidised to ATP, carbon dioxide (CO_2) and water (H_2O) through aerobic metabolism. Lactate returned to the liver can also undergo gluconeogenesis. Both oxidative and glycolytic fibres can also clear lactate by

transamination and a small amount of the lactate in the circulation moves from blood to the skin and is excreted in sweat.

Greater aerobic fitness results in lower blood and muscle lactate levels at the same absolute submaximal intensities due to decreased lactate production as a result of increased reliance on aerobic metabolism and/or increased lactate clearance. With reduced reliance on anaerobic glycolysis during exercise, less energy is required during the recovery periods to remove H^+, potentially speeding up the recovery process [22].

A number of submaximal blood lactate concentration markers are used to evaluate the effect of exercise training, prescribe exercise intensity and predict endurance exercise performance. The lactate threshold (LT), defined as the workload at which blood lactate begins to increase above baseline value and the fixed blood lactate concentrations such as 2.0 $mmol \cdot L^{-1}$ or 4.0 $mmol \cdot L^{-1}$, the so called 'onset of blood lactate accumulation' (OBLA), are the most commonly used blood lactate indices in performance physiology [101].

Exercise above the LT is associated with a nonlinear increase in metabolic and respiratory stress and with more rapid fatigue, either through the effects of metabolic acidosis on contractile function or through an accelerated depletion of muscle glycogen [108]. A rightward shift in the LT curve to a higher power output/running speed indicates an improved metabolic efficiency (figure 2.11). The training induced rightward shift in the LT curve is due in part to morphological and biochemical alterations in skeletal muscle that impacts on the rate of lactate production and clearance.

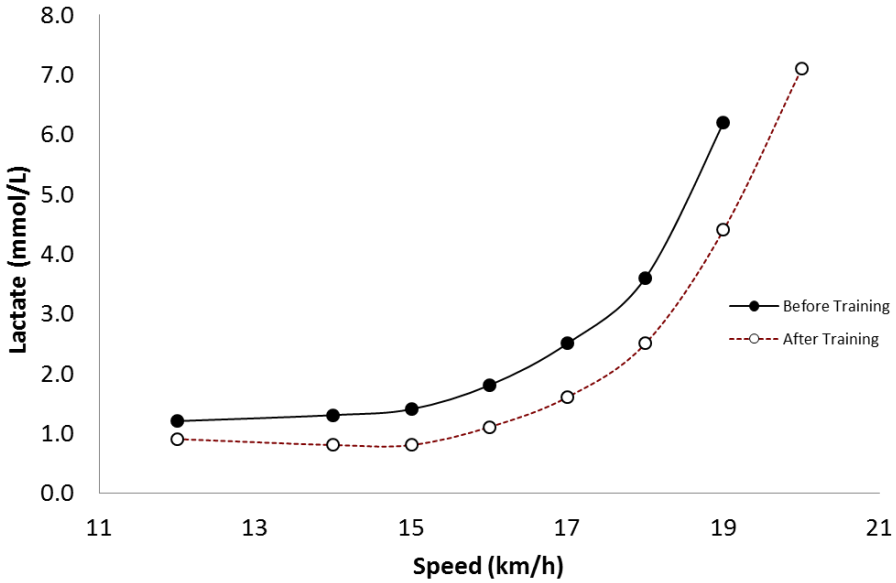

Figure 2.11: Lactate curve

An increase in the size and the number of mitochondria per unit area may help maintain cellular phosphorylation potential, improve the sensitivity of respiratory control and increase the capacity for aerobic ATP resynthesis during exercise in both type I and type II muscle fibres [91]. It is possible that a greater oxidative enzyme complement in type I muscle fibres might delay the point at which the type II muscle fibres are recruited during exercise, delaying the onset of lactate accumulation [109]. Furthermore, an increase in the oxidative potential of the type II fibres might reduce their reliance on anaerobic glycolysis for ATP production. The greater capacity of the TCA cycle to accept pyruvate following training may be important in reducing the production of lactate at the onset of exercise and during high intensity exercise [91].

It is well established that as few as 3-10 consecutive days of endurance training at approx. 60-70%$\dot{V}O_2$peak will reduce lactate accumulation compared with baseline values at the same absolute workload [91]. Endurance training has also been shown to be an effective method of improving an individual's LT, with as little as two weeks of HVET inducing positive

adaptations [110]. Endurance training at an intensity near lactate threshold is an adequate training stimulus for sedentary subjects to increase the LT, but a higher exercise intensity is needed for conditioned subjects [111].

High-intensity interval training has also been found to be an effective strategy to alter lactate metabolism. As little as 6 sessions of LS-HIT over a 2 week period decreases lactate accumulation during matched work exercise [67]. High-intensity interval training rapidly increases muscle oxidative potential and the proteins associated with lactate transport [62]. Interval training also stimulates the rate of lactate removal, which depends directly on its concentration, suggesting interval training that increases blood lactate concentrations will improve lactate removal [112]. Treadmill velocity at the LT increased to a similar extent (9.6%) in response to 8 weeks of LS-HIT or HVET in junior soccer players [74].

Bishop *et al*., (2004) found a significant relation between RSA % decrement and lactate threshold using a 5 x 6 sec sprint protocol on a 30 sec cycle [40]. Da Silva *et al*., (2010) found that a RSA protocol consisting of 7 x 35m sprints with a 25 sec recovery period produced high values of lactate, demonstrating the large contribution of anaerobic glycolysis. This study found that RSA is more strongly correlated to velocity at lactate threshold than $\dot{V}O_2$max. Both RSA mean sprint time and FI were negatively correlated with velocity at the onset of blood lactate accumulation ($r = -0.49$ & $r = -0.54$) [39]. These findings indicate that an improvement in velocity at lactate threshold will lead to greater performance in RSA tests.

Speed and Power

Running speed is defined as movement distance per unit time and is typically quantified as the time taken to cover a fixed distance. It is a product of stride length and stride frequency with elite sprinters superior in both of these determinants [113]. Maximal linear running speed over distance between 5 m and 40 m has been identified as an important fitness characteristic of elite players in Australian football league (AFL), American football, and junior rugby league [114–117]. Indeed, performance in a 40 yard (36.6 m) sprint is one of the primary physiological characteristics that discriminates between drafted and non-drafted players across all positional categories in American football [116]. Similarly, drafted AFL players have significantly better 5 m, 10 m and 20 m sprint times than non-drafted players [117]. In addition, starters in an elite AFL team performed significantly better than non-starters in both standing 10 m and flying 30 m sprint times [118].

During soccer match-play 96% of sprint bouts are shorter than 30 m with 49% being shorter than 10 m [119]. The average distance per high intensity effort in Gaelic football is 10.6 - 13.5 m [120]. This is shorter than the 18.6 m reported for elite AFL players during match-play. In a recent study, Cullen *et al*., (2013) found a strong positive relation between 5 m and 20 m sprint time in elite level adolescent Gaelic football players. [120].

The ability to express high power outputs is important in activities that rely on jumping, change of direction, and/or sprinting performance [9,17,88]. Mechanical power refers to the ability to produce force at a rapid velocity of movement. It is a measure of work performed per unit time (force x distance/time) or force x velocity [121]. The ability to apply high levels of force rapidly and express high contraction velocities impacts a players ability

to generate high power outputs [122] and is a well-developed fitness attribute in invasion team sports such as rugby union, rugby league and American football [114–117].

The underlying mechanisms that mediate power involve a host of physiological characteristics within an individual's neuromuscular system. However, sustained aerobic exercise, or long, slow distance training that is a commonly used in preseason to develop $\dot{V}O_2$max and endurance capacity in Gaelic football players have been found to result in neuromuscular and endocrine adaptations that negatively impact on speed and power.

The peak force generated in a movement depends on the speed of muscle lengthening and shortening. The classic force-velocity curve demonstrates that muscle force decreases with increased velocity of contraction during concentric contraction whereas it increases with increased velocity of contraction during eccentric contraction (figure 2.12) [121].

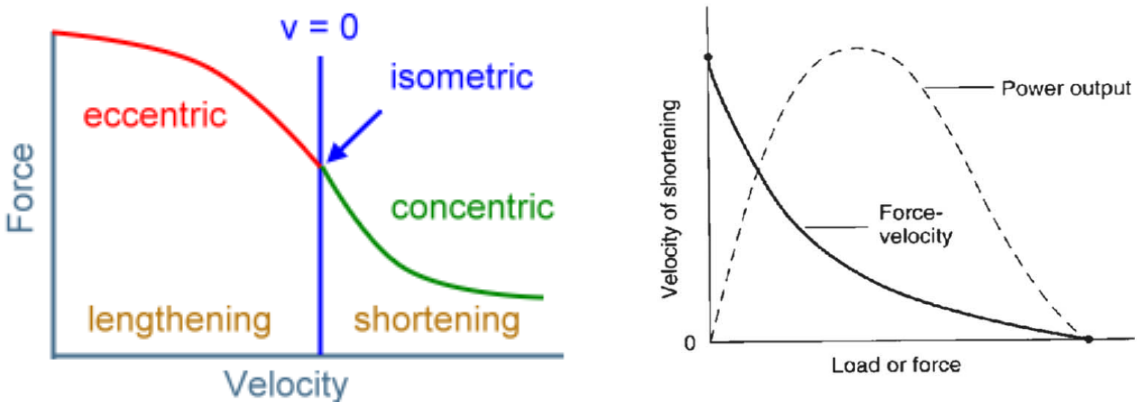

Figure 2.12: The maximal force-velocity relation for shortening (concentric) and lengthening (eccentric) muscle actions.

Rapid shortening velocities generate the least maximum force. Shortening velocities become zero (maximal isometric contraction) when the curves cross the y-axis. Force

generating capacity increases to its highest as the muscle lengthens at rapid velocities. Typically, power is evaluated during the concentric (shortening) muscle action and is achieved with moderate to minimal force at an intermediate velocity (figure 2.12) [121].

Slow, continuous exercise compromises the ability to produce force at the high velocity, low-frequency region of the force-velocity curve and therefore negatively impacts on the rate of force development. The number of motor units recruited for a movement is one of the most important determinants of the amplitude of power produced because it dictates the amount of muscle cross-sectional area and the corresponding number of actin-myosin cross bridges to be used in the movement [121]. Fast twitch muscle fibres containing myosin heavy chain types IIa and IIx are used in explosive, high intensity activities and are not recruited to the same extent during low-intensity exercise. Sustained aerobic exercise therefore, not only affects the rate of force development, but also decreases the rate of peak power development due to the low recruitment pattern of fast twitch muscle fibres. There is also evidence that sustained submaximal endurance training can also result in type IIa fibres taking on a morphological and biochemical characteristics of slow twitch fibres.

Endurance exercise training has been found to have a net catabolic effect on muscle tissue. This is due to a decrease in the release and/or activity of anabolic hormones and an sustained increase in release of catabolic hormones, particularly cortisol. Oxidative stress is also increased following prolonged endurance exercise and may negatively affect muscle protein turnover.

The Wingate anaerobic test is a laboratory based test that measures peak power output (PPO), mean power output (MPO) and fatigue Index (FI) [38]. The test involves cycling

at maximal effort against a resistance equal to a percentage of body mass for a fixed duration. The most popular protocol involves cycling against a resistance of 7.5% body mass for 30 sec. However, protocols involving multiple 10 sec bouts interspersed with short recovery periods may be more appropriate for assessing muscle power in Gaelic football players.

A number of explosive jump tests have been developed to assess lower limb muscular power. Each of the jump tests is performed from a stationary position and involves coordination of the upper and lower-body segments [123]. The stretch shortening cycle, trunk extension and head movements are initiated prior to each jump to develop maximum elastic and contractile energy in the muscles [124]. Upper body and abdominal strength are used to create good posture and act to conduct forces between the upper and lower body [125].

The counter-movement jump (CMJ) measures vertical displacement with both hands placed on the hips throughout the duration of the jump (figure 2.13). A CMJ with arm swing, commonly described in the literature as a vertical jump (VJ), permits a co-ordinated arm swing back to aid vertical displacement (figure 2.13) Studies in men and women found that the height attained in the VJ test was higher than the CMJ test [123,126]. Elevation of the arms in the VJ raises the centre of mass, and may contribute to the superior jump height achieved in the VJ than the CMJ. Furthermore, increased velocity at take-off may be elevated due to a series of events in which the arms build-up energy early in the jump which is then transferred to the rest of the body [123].

Figure 2.13: (A) VJ and (B) CMJ

VJ performance is significantly related to PPO and MPO during a 30 sec Wingate test [38]. VJ height ranges from 50 - 65 cm in Gaelic football players [127–129]. Performance in the VJ differentiates between elite and sub-elite rugby league players [114]. Among professional AFL players, starters perform better than non-starters in the CMJ test [118] and CMJ and VJ discriminated between starters and non-starters in elite junior level players [130,131].

In the majority of LS-HIT studies, the improvements in $\dot{V}O_2$max and endurance exercise performance have coincided with improvements in anaerobic power indices. The average increase in MPO and PPO during the Wingate test following LS-HIT is ~8% [61,64,66,67]. In contrast, other studies have found an increase in MPO and PPO of only 2-4% during the Wingate test following a similar LS-HIT protocol [65,72].

Considering that both speed and power are essential fitness components for players in many invasion field games, it is surprising that relatively few published studies have simultaneously evaluated the effect of LS-HIT and HVET on indices of speed and power. Burgomaster *et al*., (2008) measured PPO using the Wingate test in recreational men and women after 6 weeks of either LS-HIT or HVET. The LS-HIT group performed 3 training sessions·week^{-1}, consisting of 4 to 6 x 30 sec sprints on a cycle ergometer and the HVET

group undertook 40-60 min of continuous cycling at 65%$\dot{V}O_2$max. There was a significant improvement in PPO in both the LS-HIT (17%) and HVET (7%). There was no significant difference in PPO between groups despite the considerable difference in training volume. MPO increased by 7% in the LS-HIT group with no significant change in the HVET group [8].

RSA Determinants

Speed

Performance in short distance sprints of 10-60 m are strongly related to laboratory measures of anaerobic power such as vertical jump, Margaria-Kalamen stair test and the Wingate test [132]. The Margaria-Kalamen stair test uses the time required for a participant's movement through a fixed vertical distance to calculate anaerobic power. Using a 6 x 30 m protocol off a 20 sec cycle, Pyne et al., (2008) found that RSA total time correlated better with 20 m speed (r= 0.66) than endurance performance (r = 0.22) [133]. Similarly, Wadley et al., (1998), using a 12 x 20 m protocol off a 20 sec cycle, reported that both RSA total time and fatigue index correlated significantly with 20 m sprint speed [132]. A study by Oliver et al., (2009) found a significant relation between maximal running velocity speed (r = 0.72) and total work performed using an RSA protocol consisting of 7 x 5 sec sprints with 20 sec of recovery [134]. RSA (total time) performance and 15 m speed were found to be highly related among elite youth soccer players between the age of 13 and 18 years [135]. Mendez-Villanueva *et al*., (2011) also found a relatively strong correlation between both 10 m running speed (r = 0.55 to 0.79) and 20 m flying (r = 0.74 to 0.96) speed and RSA (mean sprint time) performance [136]. A study by Zagatto *et al*., (2009) on armed forces personnel using a 6 x 35 m protocol off a 10 sec cycle found a significant negative correlation between

RSA (PPO, MPO & FI) and 35 m speed (r = -0.99, -0.86 & -0.47) [137]. Studies that examined the relation between running speed and RSA performance are summarised in table 2.5.

Table 2.5: Running speed and RSA performance

Journal	Level	N	Mode	Protocol	Rest	Results
Pyne *et al.,* (2008) [133]	Well trained Junior AFL players	60	Running	6 x 30m	20 sec cycle	*C* between RSA (TT) and 20 m speed (r = 0.66)
Wadley *et al.,* (1998) [132]	AFL Players	17	Running	12 x 20m	20 sec cycle	*C* between RSA (TT & FI) and 20 m speed (r = 0.83 & r = 0.72)
Oliver *et al.,* (2009) [138]	School soccer & rugby teams	18	Treadmill running	7 x 5 sec	20 sec	*C* between max speed (r = 0.72) and RSA (total work)
Spencer *et al.,* (2011) [135]	Highly trained youth soccer players	119	Running	6 x 30m	30 sec cycle	*C* between RSA (TT) and 15 m speed (r = 0.81 to 0.95)
Mendez-Villanueva *et al.,* (2011) [136]	Highly trained youth soccer players	61	Running	10 x 30m	30 sec active	*C* between RSA (MT) and 10 m speed (r = 0.55 to 0.79) and 20 m flying speed (r = 0.74 to 0.96)
Zagatto *et al.,* (2009) [137]	Armed forces	40	Running	6 x 35m	10 sec	C between RSA (PPO, MPO & FI) and 35 m speed (r = - 0.99, -0.86 & -0.47)

C = Correlation, MT = mean sprint time, TT = total time, FI = fatigue Index, PPO = peak power output, MPO = mean power output

Power

Previous research into the relation between the Wingate anaerobic sprint test and tests of RSA performance has been equivocal (table 2.6). As the Wingate and RSA tests are designed to measure the same anaerobic capabilities of the participants, it is surprising that the results are not more comparable. Both tests also measure similar performance indices such as mean power/average time, peak power/total time and fatigue index reflecting similar physiological properties. However despite the similarity between the two tests in terms of reference values, the Wingate is a cycle ergometer based test while the majority of RSA tests are weight bearing running tests. This implies the Wingate and RSA tests impose varying physiological stress on the participant reflecting a different performance capability. Meckel *et al*., (2009) found that the Wingate anaerobic test significantly correlated with the fastest and total sprint time of a 6 x 40m protocol (r = 0.42 & 0.45) and with the total time of a 12 x 20m protocol (r= 0.47) [46]. Zagatto *et al*., (2009) found that RSA (total time) had significant correlations with the Wingate test (PPO r = 0.46; MPO r = 0.53; FI r = 0.63) [137]. Zacharogiannis *et al*., (2004) had similar findings, with significant correlations between RSA and Wingate anaerobic test PPO and MPO (r = 0.82 & 0.75) [139]. In contrast, Keir *et al*., (2012) found no correlations between a Wingate anaerobic test and the same RSA protocol consisting of 6 x 35m sprints with 10 seconds recovery [140]. Aziz *et al*., (2004) found modest correlations between the Wingate anaerobic test (MPO) and RSA (total time & FI) (r = 0.46 & 0.46) (172) (8 x 40m 30 sec recovery) [141].

Spencer *et al*., (2011) found moderate to large correlations between CMJ power (r = 0.34 to 0.82) and RSA (total time) performance for all of the age group, apart from U14, in

highly trained youth soccer players. Similarly, moderate to large correlations were reported between VJ power (r = 0.35 to 0.75) and RSA (total time) performance for all of the age group, again with the exception of the U14 age group [135]. Stojanovic *et al*., (2012), also reported inverse relations between countermovement jump height (r = -0.74) and RSA total time using a similar protocol in elite basketball players [142].

Table 2.6: Power and RSA performance

Journal	Level	N	Mode	Protocol	Rest	Results
Meckel *et al.,* (2009) [46]	Adolescent soccer players	33	Running	1. 6 x 40m 2. 12 x 20m	30 sec cycle 20 sec cycle	1. Neg. *C* between RSA (TT) and Wingate MPO (r = -0.42) 2. Neg. *C* between RSA (TT) and Wingate MPO (r = -0.47)
Keir *et al.,* (2012) [143]	Collegiate level soccer Players	8	Running	6 x 35m	10 sec	No significant *C* between Wingate and RSA test
Zagatto *et al.,* (2009) [137]	Armed forces	40	Running	6 x 35m	10 sec	C between RSA (PPO, MPO & FI) and Wingate (PPO, MPO & FI) (r = - 0.46, -0.53 & -0.63)
Zacharogiannis *et al.,* (2004) [139]	Active men and women	11	Running	6 x 35m	10 sec	*C* between RSA and Wingate (PPO, r = 0.85) & (MPO, r = 0.75)
Aziz *et al.,* (2004) [141]	Hockey and Soccer team players	26	Running	8 x 40m	30 sec	Neg. *C* between RSA (TT r = 0.46 and FI r = 0.46) and Wingate (MPO)
Spencer *et al.,* (2011) [135]	Highly trained youth soccer players	119	Running	6 x 30m	30 sec cycle	Neg. *C* between RSA (total time) and CMJ (r = -0.34 to -0.82) and VJ (r = -0.35 to -0.75)

C = Correlation, MT = mean sprint time, TT = total sprint time, FI = fatigue Index, PPO = peak power output, MPO = mean power output, CMJ = counter-movement jump, VJ = vertical jump

Muscular Strength

Muscular strength is generally accepted to be a major component of fitness influencing success in field based team sports such as soccer. Cometti *et al*., (2001) concluded that elite soccer players had higher hamstring torque than amateur players at multiple angular velocities [144]. Oberg *et al*., (1986) reported differences in isokinetic peak torque of the quadriceps and hamstring muscles between the highest and the lowest Swedish soccer divisions and concluded that high level soccer players had greater strength because training intensity increased with increasing playing category [145].

Specifically, explosive muscular contractions have been identified as a crucial factor in determining sprint performance [146]. Dowson *et al*., (1998) provided evidence supporting the notion that the magnitude of force generated during dynamic muscle actions relates to the amount of speed an athlete can produce during a sprint performance [147]. Although these studies demonstrate that muscular strength is related to the speed an athlete can produce during a single sprint [146], it tells us nothing about its influence on repeated sprints. To our knowledge, only one study has investigated the relationship between leg strength and RSA [146]. Newman et al., (2004) found no relation between isokinetic strength (expressed as peak isokinetic knee extension/flexion torque) and repeated sprint performance.

Chapter III

General Methodology

Training Intervention Design

At present, the majority of LS-HIT protocols have been performed on a cycle ergometer and have been found to significantly improve aerobic and anaerobic capacity, and skeletal muscle mitochondrial protein content [64, 66, 69, 71, 72]. Recent studies have found that when adapted to whole-body training, similar protocols continue to improve these indices [8, 11, 12, 68]. While many studies have examined the efficacy of LS-HIT in sedentary and recreationally active populations, invasive field based team sport athletes have received much less attention in the LS-HIT literature.

By design, the protocols used in study 1 and study 2 differed substantially in terms of total training volume and time commitment in order to evaluate adaptations to two diverse training programmes. It is well documented that continuous exercise at an intensity corresponding to 50-80% $\dot{V}O_2$max results in a significant improvement in endurance performance in both trained and untrained individuals [8, 9, 75]. Considering that the participants were young, physically active men who were playing Gaelic football at club level, a training intensity was selected that could initially be sustained for 40-50 min (75% $\dot{V}O_2$max). The LS-HIT programme was modelled on recent training studies involving primarily cycle ergometry [8,47]. Substantial pilot work was undertaken to develop a protocol with a duration $\leq$ 30 sec and blood lactate levels $\geq$ 10 mmol·L^{-1} that replicated the movement patterns of the Gaelic football.

RSA Test Design

Many of the important events during Gaelic football match play involve repeated bouts of high intensity running, called RSA. The duration of these high intensity activities is largely unpredictable, due to the fact that they are imposed by the pattern of play. The ability to recover and to reproduce performance in subsequent sprints is an important fitness requirement for optimal performance in Gaelic football. Fatigue during repeated sprints typically manifests as a decline in maximal and/or mean running speed and performance decrements during successive repeated sprints are inversely related to the initial sprint performance. The average sprint in Gaelic football is 5.7 sec in duration [15] and the high ATP turnover rate is supplied by a combination of the phosphagen system and anaerobic glycolysis. There is however, progressive inhibition of glycolysis in response to performing repeated short duration sprints [18].

The nature of the work/recovery intervals alters the relative contribution of the phosphagen system, anaerobic glycolysis and aerobic metabolism and the time course and magnitude of fatigue development. During Gaelic football match play the distance covered during high intensity bouts range from 10-40 m while the work to rest ratio is ~4:1. Following extensive pilot work 4 different RSA protocols were designed. Each protocol was 240 m in length and involved high-intensity sprints between 10-40 m with a standard work to rest ratio of ~4:1 that mimicked Gaelic football. The sprint distance, number of turns, number of repetitions, and recovery durations were altered to stress phosphocreatine hydrolysis, anaerobic glycolysis, oxidative metabolism or a combination of one of more energy systems while maintaining blood lactate between 8-10 $mmol \cdot L^{-1}$.

Prior to each RSA tests the participants performed a 5-10 min warm-up that involved progressing from low to high intensity running and included a number of accelerations. In addition, they performed a dynamic stretching routine that incorporated the major muscle groups.

Table 3.1: Average RSA test values

	RSA Test			
	RSA-1	RSA-2	RSA-3	RSA-4
No of trials (m)	6	8	12	24
Distance (m)	40	30	20	10
Total distance (m)	240	240	240	240
Sprint time (sec)	8.5	4.7	3.4	2.1
Recovery time (sec)	21.5	17.8	11.6	7.9
Sprint:Rest	4:1	4:1	4:1	4:1
Total running time (sec)	51	37.6	40.8	50.4
Sprint cycle (sec)	30.0	22.5	15.0	10.0
End Lactate ($mmol \cdot L^{-1}$)	8.9	7.6	8.4	8.3

Laboratory Procedures

Anthropometrics

Height and body mass were measured to the nearest 0.1 cm and 0.1 kg respectively, using a portable scale (Seca 707 Balance Scales, GmbH, Hamburg, Germany). Participants were instructed to wear a light top and shorts and to remove their shoes prior to the measurement.

Harpenden skin fold callipers (Baty International Ltd, West Sussex, UK) were used to measure double thickness subcutaneous adipose tissue on the right side of the body. The following anatomical sites were measured: triceps, pectoralis, subscapular, abdomen, midaxillary, suprailiac and thigh. A minimum of 2 measurements was taken at each site. If the measurements varied by more than 2 mm a third measurement was taken. Body density was calculated using the Jackson and Pollock equation [148] and body fat was determined using the Siri equation [149]

Running Economy (RE)

RE was determined on a treadmill (Woodway ELG 55, Waukesha, WI). Participants warmed up at 8 $km \cdot h^{-1}$ for 3 min at a 1% incline. Following the warm-up, the treadmill velocity was increased 1 $km \cdot h^{-1}$ every 3 min until the blood lactate concentration reached 4.0 $mmol \cdot L^{-1}$. All participants completed at least 4 sub-maximal stages (8, 9, 10, and 11 $km \cdot h^{-1}$) before reaching a blood lactate level of 4.0 $mmol \cdot L^{-1}$. Heart rate, expired O_2, CO_2, and ventilatory volume were continuously measured. Steady state expired O_2 ($ml \cdot kg^{-1} \cdot min^{-1}$ and $L \cdot min^{-1}$), CO_2 ($L \cdot min^{-1}$), ventilatory volume ($L \cdot min^{-1}$) and respiratory exchange ratio

(RER) were determined by averaging the final 60 sec of each exercise stage. RE was expressed in $ml \cdot kg^{-1} \cdot min^{-1}$, $ml \cdot kg^{-1} \cdot km^{-1}$ and $Kcal \cdot kg^{-1} \cdot km^{-1}$ at each submaximal speed. Caloric expenditure (was determined at each speed using the Brooks equation [150].

Maximal Aerobic Capacity ($\dot{V}O_2max$)

$\dot{V}O_2max$ was determined on a treadmill (Woodway ELG 55, Waukesha, WI) using a ramp protocol. Following the RE test, the treadmill velocity was set at 10 $km \cdot h^{-1}$ and the gradient at 4%. Treadmill velocity remained constant and the gradient was increased by 1% every min until volitional exhaustion. $\dot{V}O_2max$ was determined by averaging the two highest consecutive 30 sec values. Heart rate, ratings of perceived exertion (RPE), expired O_2, CO_2, and ventilatory volume were continuously recorded. RPE was obtained using the 15-point Borg category RPE scale. Heart rate was measured using telemetry (Polar Vantage NV™ Polar, Port Washington, NY).

$v\dot{V}O_2max$

Running velocity at $\dot{V}O_2max$ ($v\dot{V}O_2max$) was predicted from the RE and $\dot{V}O_2max$ measurements taken during the sub-maximal and maximal exercise tests respectively [105]. The linear relation between RE and $\dot{V}O_2$ during incremental exercise can be expressed as a simple linear regression equation ($y = mx + c$). Maximal treadmill velocity was the dependent or outcome variable (y) and was predicted from the measured $\dot{V}O_2$ max value. The terms c and m are the intercept, and slope of the line of best fit, respectively.

Cardiorespiratory and Metabolic Measures

Respiratory metabolic responses were determined using standard open-circuit spirometry techniques (Sensormedics Vmax 229, SensorMedics Corp., CA). Prior to testing, the gas analyzers were calibrated with standard gases of known concentration.

Mass Flow Sensor Heated wire Anemometer-Mode of Operation

A mass flow sensor (Sensormedics, Loma Linda, CA, USA) was used to collect breath-by-breath measurement of ventilation. The mass flow sensor is a low resistance tube with a tapered internal diameter extending from both ends of a laminar flow throat. Cold and hot stainless steel wires electrically heated to -180°C and -240°C respectively, are centered in the flow stream. These wires are elements in a servo-controller bridge circuit that maintains the resistance ratio of the two wires at a constant value. If only the temperature of the inspired gases changes, then both wires lose heat at the same rate and no current change is required to keep the bridge balanced. As air flows across the wires, the hot air loses heat more rapidly than the cold air and the current must be added to keep the bridges balanced at a 3:4 ratio. The amount of current required is proportional to the mass flow of the gas. This method ensures that the sensor measures only the heat loss from the molecular convection of the moving gas stream and not the artifact due to cooling of the gas as it passes through a breathing assembly.

The mass flow meter responds to instantaneous flow rates between 0-16 $L \cdot sec^{-1}$ and integrated flow between 0-350 $L \cdot min^{-1}$, with flow resistance <1.5 $cmH_2O \cdot L^{-1} \cdot sec^{-1}$. The mass

flow sensor was outputted to the analyser module of the Vmax 229 and was sampled at a rate of 125 Hz.

Mass Flow Sensor Calibration

A 3 L volume syringe (Sensormedics, Loma Linda, CA, USA) was used to calibrate the mass flow sensor prior to each test. The syringe was connected to the mass flow sensor and stroked four times in order to measure inspired and expired volumes. The volumes were calculated by expressing 3 L as a fraction of each measured inspired and expired volume achieved during calibration. An average correction factor was calculated for inspired and expired volumes and used to fine tune the volume measurement.

A verification procedure was performed. This involved stroking the 3 L volume syringe four times. Inspired and expired volumes were measured using the newly calculated correction factors. In order to pass the calibration procedure, one of the four strokes had to have an average flow rate <0.5 $L \cdot sec^{-1}$ and at least one of the four strokes had to have an average flow >3.0 $L \cdot sec^{-1}$.

Gas Analysers

The Vmax 229 utilizes a rapid response infrared measurement technique. An O_2 and CO_2 analyser is integrated with the Vmax 229. A small sample of inspired air is drawn through a sample cell and exposed to an infrared light through an optical that is passed through a band pass filter and the sample cell. An infrared detector responds to the amount of infrared light that passes through the sample cell. The amount of light that passes through the sample cell varies according to the concentration of CO_2 in the sample cell.

Based on measured levels of infrared light intensity, the analyser computes the PCO_2 in the gas sample. The CO_2 analyser is linearly scaled across the 0-100% range with a resolution of 0.01%CO_2 and a response time of <130 $m \cdot s^{-1}$ (10-90%) at 500 $ml \cdot min^{-1}$ flow. The O_2 analyser is based on the high paramagnetic susceptibility of O_2. A diamagnetic glass dumbbell suspended in a magnetic field rotates in proportion to the PO_2. The analyser is linearly scaled across the 0-100% range with a resolution of 0.01%O_2 and a response time of <130 ms (10-90%) at 500 $ml \cdot min^{-1}$ flow.

Calibration of CO_2 and O_2 Analysers

The gas analysers were calibrated with standard gases of known concentration (BOC gases, Dublin, Ireland). The first calibration gas contained 26.00 ± 0.02% O_2 and the balance nitrogen (N_2). The second calibration gas contained 4.00 ± 0.02% CO_2, 16.00 ± 0.02% O_2, and the balance N_2. A small bore drying tube connected to the CO_2 and O_2 analysers sampled the calibration gases. The absorption and evaporative properties of the drying tube ensured that the relative humidity of the calibration gas was equilibrated to ambient conditions prior to sampling by the O_2 and CO_2 analysers. The calibration gas was sampled at a rate of 125 Hz. The response time was similar between O_2 and CO_2 analyser.

Ratings of Perceived Exertion

RPE was obtained using the 16-point Borg category RPE scale. Prior to the maximal exercise test participants read a standard set of perceptual scaling instructions. These instructions followed an established format used in previous investigations. Low and high "perceptual anchors" were established during the maximal exercise test. This involved

asking participants to assign a rating of 6 (low anchor) to the lowest exercise intensity, and 20 (high anchor) to the highest exercise intensity. Participants were instructed to make their subjective assessments of perceived exertion relative to these minimum and maximum standards (perceptual anchors).

Blood Lactate Sampling and Measurement

Blood samples were drawn from the earlobe. Prior to each sample, the ear lobe was wiped with alcohol and allowed to dry thoroughly. The base of the ear lobe was jabbed with a lancet (Accu-Check Softclix, UK) and the first drop of blood was wiped away. Pressure was placed on the ear lobe with the thumb and forefinger in order to provide an appropriate sample. A 5 μL sample of whole blood was automatically aspirated into a single use, enzyme-coated electrode test strip (Lactate Pro Akray, Japan). The reagent strip fills by capillary action directly from the earlobe site.

Whole blood samples were analysed using a hand-held portable analyser (Lactate Pro Akray, Japan). The measuring range is 0.8 – 23.0 $mmol \cdot L^{-1}$. Lactate in the sample reacts with potassium ferricyanide and lactate oxidase to form potassium ferrocyanide and pyruvate. Upon the application of a given voltage, ferrocyanide is oxidised, releasing electrons and creating a current. This current is measured amperometrically and is directly proportional to the lactate concentration of the blood sample. The result is displayed after 60 sec. The Lactate Pro is supplied with a check strip and a calibration strip that provide a non-quantitative indication of instrument accuracy.

Blood Lactate Interpretation

Lactate threshold was determined subjectively from plots of the lactate concentration versus work rate, by visually identifying the treadmill velocity that best corresponds to a departure from a linear baseline pattern. Blood lactate markers at 2.0 mmol·L^{-1} and 4.0 mmol·L^{-1} were also identified from the treadmill velocity vs. blood lactate plot (figure 3.1)

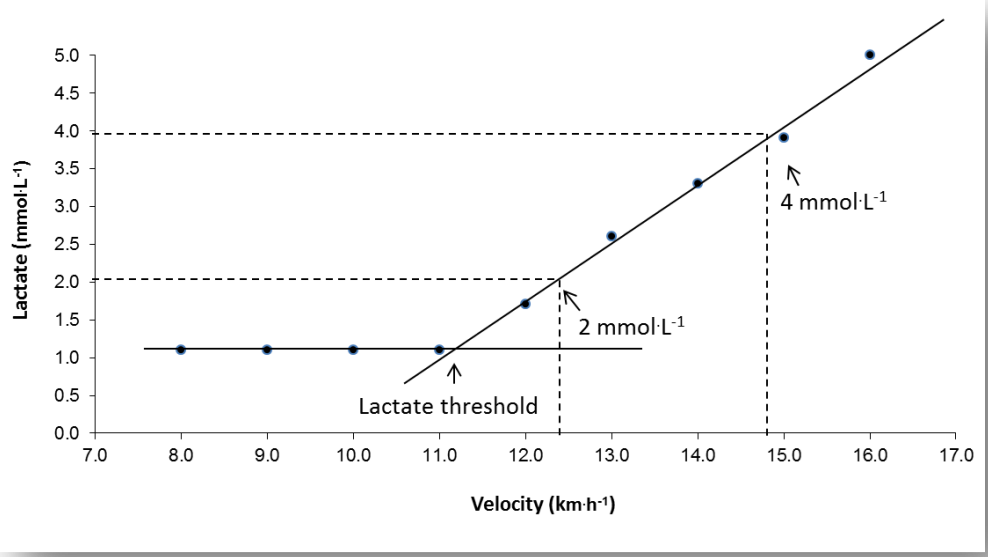

Figure 3.1: Blood Lactate Plot

Endurance Performance Test (Time Trial)

Participants warmed up for 5 min on a treadmill (Woodway ELG 55, Waukesha, WI) at 50% of v$\dot{V}O_2$max velocity. The treadmill velocity was then increased to 110% v$\dot{V}O_2$max and the participants ran until volitional fatigue.

Intermittent Endurance Performance

Endurance performance was determined using an intermittent treadmill (Woodway ELG 55, Waukesha, WI) running protocol. Following a 3 min warm-up at 50% $\dot{V}O_2$max, participants ran at 75%$\dot{V}O_2$max for 20 min after which they performed a series of alternating 1 min bouts of high intensity running at 100%v$\dot{V}O_2$max interspersed with 1 min bouts of recovery at 75%v$\dot{V}O_2$max until volitional fatigue.

Vertical Jump

The VJ was performed on a FSL JumpMat (FSL, Cookstown, UK) (Figure 3.2a). Participants stood on the JumpMat with their feet shoulder width apart and arms hanging loosely. When instructed, participants moved into a semi-squat position and then jumped as high as possible, landing on the mat. They were encouraged to use their arms to help propel their body upwards (figure 3.2b). Three trials were performed. Each trial was separated by a 60 sec rest period. The best score was recorded for statistical analysis.

The FSL JumpMat consists of a hand held electronic timer connected to a contact mat (Tapeswitch Signal Mat, model CVP 1723, Tapeswitch, Farmingdale, NY) measuring 584 x 432 x 2 mm. The system resolution is 1000 Hz with a threshold for operation of 2.3 kg. Jump height is calculated using the formula; h=g·t2/8 (where h is the jump height in metres; g is gravitation acceleration [9.81 m·s^{-2}]; t is the flight time in sec) [151].

Figure 3.2: (A) FSL JumpMat (B) VJ technique

Countermovement Jump

The countermovement jump was performed using the FSL JumpMat (FSL, Cookstown, UK). Participants stood on the JumpMat with their feet shoulder width apart with hands placed on the hips. When instructed, participants moved into a semi-squat position and then jumped as high as possible and landed on the mat. Participants were instructed to keep their hands on their hips throughout the jump. Three trials were performed with a 60 sec rest period between each trial. The best score was recorded for statistical analysis.

Drop Jump

Drop jump (DJ) was performed using the FSL JumpMat (FSL, Cookstown, UK) and a 30.48 cm high wooden box. Participants stood on the box with their feet shoulder width apart and hands placed on the hips. When instructed, participants stepped off the box with dominant leg first, into a semi-squat position on the jump mat and then jumped as high as possible and landed on the mat (figure 3.3). Participants were instructed to keep their hands on their hips throughout the jump. Three trials were performed with a 20 sec rest period between each trial. The best score was recorded for statistical analysis.

Figure 3.3: Drop Jump

5 m and 20 m sprint Speed

SMARTSPEED wireless electronic timing gates (Fusion Sport International) were used to measure 5 m and 20 m running speeds. The timing gates were placed at the start line and at 5 m and 20 m. Participants were instructed to start with their preferred foot forward and placed 50 cm behind the start line. The SMARTSPEED system has a special error correction technology that is programmed to interpret all events as an individual passes through the light beam. Timing commenced automatically as the torso passed through the beam that dissected the start line.

Participants commenced each sprint of their own volition and were encouraged to complete the 20 m run in the fastest possible time. Each participant performed 3 trials interspersed with a 2 min recovery period. The fastest 5 m and 20 m times were recorded to the nearest $m \cdot s^{-1}$ and were used for statistical analysis. Prior to the speed tests, participants performed a 5-10 min warm-up that involved progressing from low to high intensity running and included a number of accelerations. In addition, they performed a dynamic stretching routine that incorporated the major muscle groups.

Wingate Test

The Wingate test was undertaken on a Monark 894E cycle ergometer (Monark, Varberg, Sweden). The ergometer was calibrated prior to each test. The test was preceded by a 5 min warm-up at a self-regulated intensity against zero resistance. The warm-up was followed by a 3 min recovery period during which participants were permitted to dismount the bike and stretch.

During the first 5 sec of the test, participants cycled at 90 rpm against zero resistance. Following a 5 sec countdown a resistance equal to 7.5% body mass was applied and the participant exercised maximally for 10 sec. Participants were instructed to remain seated throughout the testing procedure. A total of 6 Wingate tests were performed and each test was separated by 50 sec of self-regulated active recovery. Verbal encouragement was given throughout each trial. Following completion of the test, participants continued cycling against zero resistance for 2-3 min to assist recovery.

PPO, MPO and FI were measured. PPO was defined as the maximum power exerted during a 5 sec period and was calculated using the formula; PP (kgm·5 sec^{-1}) = rev (max) in 5 sec x $D \cdot rev^{-1}$ sec x F, where D is the distance travelled by the flywheel in 1 revolution (6 m), and F is the force setting in kg. MPO was the average power exerted during the 10 sec work bout and was calculated using the formula; MP (kg 10·sec^{-1}) = rev (total) in 10 sec x D·rev^{-1} sec x F, where D is the distance travelled by the flywheel in 1 revolution (6 m), and F is the force setting in kg. The FI was defined as the power drop off during the 10 sec test and was calculated using the formula; FI (W) = (highest power kgm·kg^{-1}·sec^{-1} - lowest power kgm·kg^{-}

^{1}·sec^{-1}).

Margaria-Kalamen

The Margaria-Kalamen test was used to calculate power output during stair climbing at maximal speed. Participants ran up a flight of stairs at maximum speed taking three steps at a time. The starting line was placed 6 m from the base of the first step and participants commenced each sprint of their own volition. Timing gates were placed on the third and ninth steps (figure 3.4). Timing commenced when the participant's foot landed on the third step and ended when their foot landed on the ninth step. Following 2 familiarization practice runs, each participant performed 3 trials interspersed with a 2 min recovery period. The fastest time was recorded to the nearest m·s^{-1} and was used for statistical analysis. Prior to the test, participants performed a 5-10 min warm up that involved progressing from low to high intensity running and included dynamic stretching of the major muscle groups.

Figure 3.4: Margaria-Kalamen test

Muscle Strength

A Biodex Multi-joint System-3 dynamometer (Biodex Medical Instruments, Shirley, NY) was used to assess muscle strength (peak torque) of both the dominant and non-

dominant legs (Figure 3.5). Isokinetic quadriceps and hamstring strength were first determined at 3 different angular velocities (60°·sec^{-1}, 180°·sec^{-1} and 300°·sec^{-1}). Maximum volitional isometric contraction force was then determined for the quadriceps femoris muscle (QFM) only. To permit graphical visualisation on the monitor during testing, the dynamometer data was transferred to a second computer using Biodex Advantage Software (Version 3.30, Biodex Medical Systems, Shirley, NY).

Figure 3.5: Isokinetic and Isometric test – dynamometer setup

Participants undertook a 5 min submaximal warm-up at a self-regulated intensity against zero resistance on a stationary bike. The warm-up was followed by a 3 min recovery period during which participants completed a pre-planned dynamic stretching routine. A 10 min rest period separated each test to minimise muscle fatigue. Standardised verbal instruction was given during each test.

Subject Positioning and Set-up

Participants were not permitted to visualise the monitor during testing. The dynamometer was oriented at 90° with 0° tilt. A hip angle of 110° was achieved by inclining

the seat to 70°. This ensured an optimal length-tension relation of both hamstring and quadriceps muscle groups resulting in improved muscle output and range of motion (ROM). The lower portion of the ankle force pad was positioned 5 cm above the medial malleolus and the fulcrum of the dynamometer lever arm, containing a force transducer, lined-up with the inferior aspect of the lateral epicondyle. To ensure correct sagittal alignment between the tibio-femoral joint and the dynamometers axis of rotation, the knee was extended from 90° to 0°. Correct axis alignment avoids stressful joint loading and avoids recruitment of other muscles.

Prior to testing, gravity correction was performed with the knee at 30° flexion. This is necessary since the QFM must overcome the weight of the leg before force is registered. In addition, a carpenter's level was used to ensure the lever arm of the dynamometer was vertical with the knee flexed to 90°. To minimise the effects of accessory muscles during knee flexion and extension participants placed both arms across their chest. In addition, waist, thigh and shoulder straps were used to further stabilise participants during testing (Figure 3.5).

Isokinetic Quadriceps Femoris and Hamstring Strength Assessment

Three sub-maximal warm-up repetitions and one maximal repetition were performed to familiarise participants with the testing protocol. This was immediately followed by 5 maximal concentric isokinetic repetitions performed at $60°\cdot sec^{-1}$, $180°\cdot sec^{-1}$ and $300°\cdot sec^{-1}$. A 60 sec rest period followed each testing speed. A set of repetitions was repeated if a correlation coefficient of more than 15% was observed in either quadriceps or

hamstring strength tests. A motion arc of 90° was required to complete the test. The maximum force (peak torque) determined was recorded and used for statistical analysis.

Maximum Volitional Isometric Contraction Force

Isometric peak torque was tested with the knee at 60° of flexion. Participants performed 3 submaximal and one maximal contraction to familiarise themselves with the procedure. The testing protocol consisted of 3 consecutive 5 sec trials of knee extension with the knee held in 60° flexion. There was a rest period of 50 sec between each attempt. The maximum force generated over the three trials was recorded as the peak torque and used for statistical analysis.

Training Indicators

Blood Lactate Measurements

During LS-HIT, lactate measurements were taken at baseline and after each set of repetitions. During HVET, lactate measurements were taken before and after exercise. Blood samples were drawn from the earlobe. Prior to each sample, the earlobe was wiped with alcohol and allowed to dry thoroughly. The base of earlobe was jabbed with a lancet (Accu-Chek Softclix, UK) and the first drop of blood was wiped away. Pressure was placed on the earlobe with the thumb and forefinger and a 5.0 μL sample of whole blood was automatically aspirated into a single use, enzyme-coated electrode test strip (Lactate Pro Akray, Japan). The reagent strip fills by capillary action directly from the earlobe site.

Blood samples were analysed using a hand-held portable analyser (Lactate Pro Akray, Japan). The measuring range is 0.8–23.0 $mm \cdot L^{-1}$. Lactate in the sample reacts with potassium ferricyanide and lactate oxidase to form potassium ferrocyanide and pyruvate. Upon the application of a given voltage, ferrocyanide is oxidised, releasing electrons and creating a current. This current is measured amperometrically and is directly proportional to the lactate concentration of the blood sample. The result is displayed after 60 sec. The Lactate Pro is supplied with a check strip and a calibration strip that provide a non-quantitative indication of instrument accuracy.

Performance Measurements

Wireless electronic timing gates (Fusion Sport International, Coopers Plains, AUS) were used to measure the time for each 110 m interval sprint. The timing gates were placed at the starting line. Participants were encouraged to complete each interval sprints in the shortest possible time.

Chapter IV

Study 1

Introduction

Gaelic football involves irregular changes of pace and high-intensity efforts interspersed with periods of light to moderate aerobic activity. Players are required to develop a number of fitness attributes including aerobic endurance, running speed and power. The aerobic energy system contributes significantly to the energy demands during low to moderate intensity level activities whereas the phosphagen system and anaerobic glycolysis are the primary sources of energy during high intensity activities. Since PCr resynthesis occurs primarily by oxidative processes a high aerobic capacity ($\dot{V}O_2max$) enhances the replenishment of phosphagen stores during single and repeated bouts of high intensity activity. A high $\dot{V}O_2max$ is also associated with a higher playing intensity, increased number of repeated sprints, increased involvement with the ball and greater distance covered during soccer.

Among individuals with similar $\dot{V}O_2max$ values RE may be a better predictor of endurance exercise [92]. Changes in $v\dot{V}O_2max$, a composite variable that combines $\dot{V}O_2max$ and RE may be related to changes in endurance exercise since it encompasses aerobic, anaerobic and neuromuscular aspects of performance. High blood lactate levels have a negative effect on muscle force production and are associated with the development of fatigue during high intensity exercise [31]. To date no published studies have evaluated RE,

vV̇O2max or blood lactate concentrations in Gaelic football players or have examined their response to LS-HIT or HVET.

HVET, characterised by repeated sessions of continuous moderate intensity exercise, induces numerous physiological and metabolic adaptations that facilitate improved exercise capacity [4,5]. Although this type of training offers significant training adaptations it requires a large time commitment. LS-HIT consists of alternating brief bouts of high intensity exercise interspersed with periods of active or passive recovery. This type of training allows players to undertake a greater volume of high intensity activities and can elicit similar or even superior physiological adaptations and improvements in exercise performance normally associated with traditional high volume endurance training (HVET). The majority of previous studies that have compared LS-HIT to HVET have been matched for total work or caloric expenditure [55–57,152]. In contrast, low volume short duration interval protocols are not matched for energy expenditure, and therefore involve a substantially lower time commitment and reduced total exercise volume than HVET.

Brief repeated sessions of LS-HIT over as little as 2 weeks, induces changes in skeletal muscle energy metabolism that resemble endurance type training [63,153]. Gibala *et al*., (2006) found that 6 sessions of either LS-HIT or HVET induced similar improvements in muscle oxidative capacity, muscle buffering capacity and exercise performance. The total volume of training was 90% lower in the LS-HIT group than the HVET group indicating that LS-HIT is a time efficient strategy to produce physiological adaptations parallel to endurance training [47].

To date, the majority of studies that have compared the physiological and performance changes in response to LS-HIT and HVET have involved cycle exercise and healthy recreational athletes [60]. Gaelic football involves weight bearing short-duration, high-intensity sprints interspersed with periods of light to moderate aerobic activity consisting primarily of walking and jogging. To date, only one published study has used a running protocol to compare the effects of LS-HIT and HVET on physiological and performance parameters [9]. The study participants were adolescent soccer players competing in a collegiate league.

The purpose of this study was to evaluate the effect of two weeks of LS-HIT using a running protocol and HVET on physiological, metabolic parameters and endurance performance in club level Gaelic football players

Study Aims

1. To compare the effects of a 2 week HVET and LS-HIT program on $\dot{V}O_2max$, in club level Gaelic football players

2. To compare the effects of a 2 week HVET and LS-HIT program on RE in club level Gaelic football players

3. To compare the effects of a 2 week HVET and LS-HIT program on $v\dot{V}O_2max$ in club level Gaelic football players

4. To compare the effects of a 2 week HVET and LS-HIT program on circulating levels of blood lactate in club level Gaelic football players

5. To compare the effects of a 2 week HVET and LS-HIT program on endurance exercise performance in club level Gaelic football players

Study Hypotheses

Null Hypotheses

1. $\dot{V}O_2$max responses will be similar in club level Gaelic football players following 2 weeks of LS-HIT and HVET
2. RE responses will be similar in club level Gaelic football players in response to 2 weeks of LS-HIT and HVET
3. v$\dot{V}O_2$max responses will be similar in club level Gaelic football players in response to 2 weeks of LS-HIT and HVET
4. Blood lactate levels responses will be similar in club level Gaelic football players in response to 2 weeks of LS-HIT and HVET
5. Endurance exercise performance will be similar in response to 2 weeks of LS-HIT and HVET in club level Gaelic football players

Methodology

Participants

Fifteen apparently healthy men with a mean age of 23 years, currently playing Gaelic football at club level volunteered to participate in the study. Each player had a minimum of 3 years playing experience. During the season participants trained on average 2 $d \cdot week^{-1}$ and played a game on the majority of weekends. Participants were excluded if they were current smokers or had any medical conditions that contraindicated exercise participation. The nature and risks of the study were explained and written informed consent was obtained from each participant (appendix A). The experimental procedures were approved by the Research Ethics Committee at Dublin City University, Ireland.

Overview of Study Design

The study design is outlined in figure 4.1. The study took place in the School of Health and Human Performance at DCU. The training program was undertaken 3 $d \cdot week^{-1}$ for 2 weeks. Participant's made 2 separate visits to the Human Performance Laboratory, before the study and at the end of the 2 week training program. Each visit was separated by at least 24 h. Post-exercise measurements were taken 48 h after the last exercise session. Upon completion of baseline testing, participants were randomly assigned to a HVET or LS-HIT group. The study was undertaken during the competitive phase of the season.

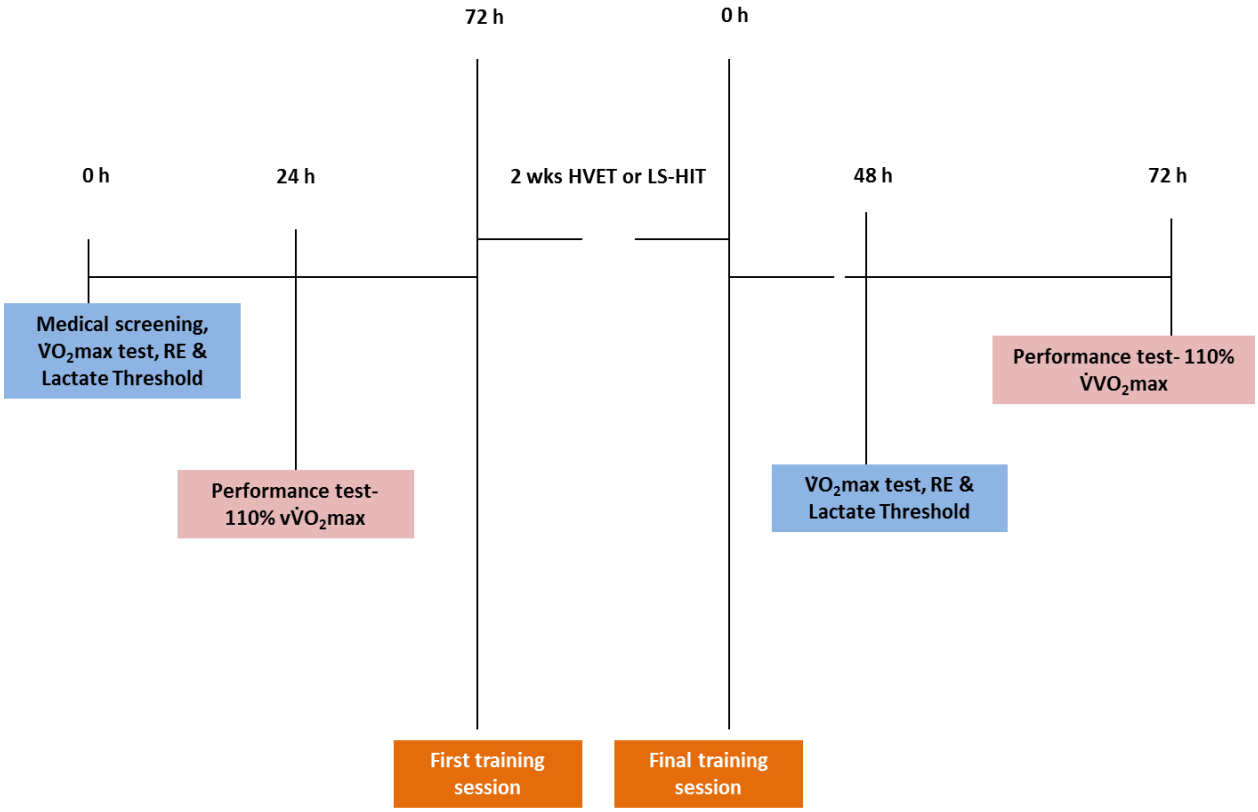

Figure 4.1: Study 1 – Research Design

Training Protocols

Low Volume Short Duration High-intensity Interval Training (LS-HIT) Protocol

The LS-HIT protocol involved 3 sets of high intensity running interspersed with short recovery periods (figure 4.2). Each interval run was 110 m in length and involved forward and backward sprints over distances ranging from 10-20 m. A set consisted of 3 x 110 m runs with a 20 sec recovery period between each run, and a 5 min recovery period between sets. At the end of each run a 5 μL blood sample was taken from the earlobe to determine whole blood lactate concentration.

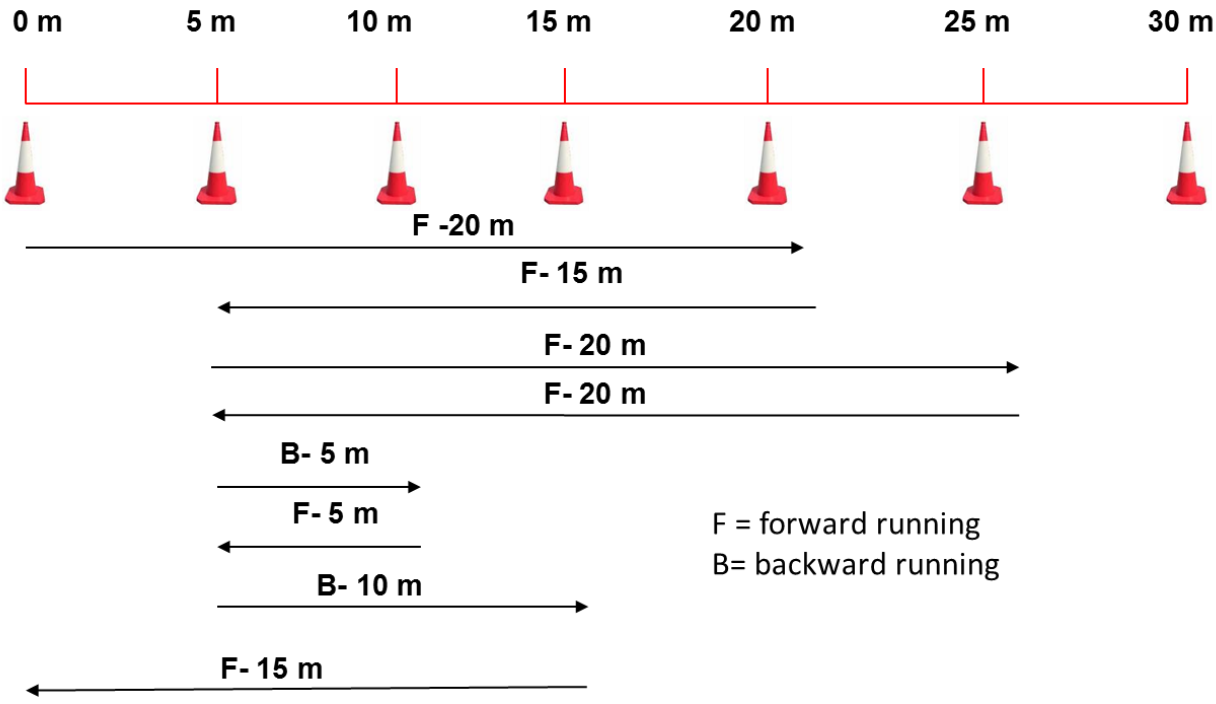

Figure 4.2: LS-HIT training protocol

High Volume Endurance Training (HVET) Protocol

Participants in the HVET group ran for 50 min on a treadmill (Woodway ELG 55, Waukesha, WI) at 75%$\dot{V}O_2$max.

Laboratory Procedures

Anthropometrics

Height and body mass were measured to the nearest 0.1 cm and 0.1 kg respectively, using a portable scale (Seca 707 Balance Scales, GmbH, Hamburg, Germany). Participants removed their shoes and stood with their feet together on the base plate with their arms loosely by their side. Each participant was asked to take a deep breath and to stand with their back as straight as possible against the vertical measuring rods and to look straight

ahead. Body mass was measured to the nearest 0.1 kg. Participants were instructed to wear a light top and shorts, and to remove their shoes prior to the measurement.

Running Economy (RE)

As described in the methods section of chapter 3 (pg. 63)

Maximal Aerobic Capacity ($\dot{V}O_2$max)

As described in the methods section of chapter 3 (pg. 64)

v$\dot{V}O_2$max

As described in the methods section of chapter 3 (pg. 64)

Cardiorespiratory and Metabolic Measures

As described in the methods section of chapter 3 (pg. 65)

Mass Flow Sensor Heated wire Anemometer-Mode of Operation

As described in the methods section of chapter 3 (pg. 65)

Mass Flow Sensor Calibration

As described in the methods section of chapter 3 (pg. 66)

Gas Analysers

As described in the methods section of chapter 3 (pg. 66)

Calibration of CO_2 and O_2 Analysers

As described in the methods section of chapter 3 (pg. 67)

Ratings of Perceived Exertion

As described in the methods section of chapter 3 (pg. 67)

Blood Lactate Sampling and Measurement

As described in the methods section of chapter 3 (pg. 68)

Blood Lactate Interpretation

As described in the methods section of chapter 3 (pg. 69)

Endurance Performance Test (Time Trial)

As described in the methods section of chapter 3 (pg. 69)

Training Indicators

Blood Lactate Measurements

As described in the methods section of chapter 3 (pg. 77)

Performance Measurements

As described in the methods section of chapter 3 (pg. 78)

Statistical Analysis

Where participants had incomplete data for a given variable, participants were excluded from analysis of this variable specifically. The data was checked for normality using the Shapiro-Wilk test. Since the majority of results did not meet normality assumption it was decided to use non-parametric statistics. It was attempted to log-transform the data, but even following this the majority of data did not meet normality assumption. Descriptive statistics and frequencies for all anthropometric, physiological, metabolic and performance indices were calculated. A paired-sample Wilcoxon signed rank test was used to compare within group differences in anthropometric, physiological, metabolic and performance indices. A Mann Whitney U test was used to compare anthropometric, physiological, metabolic and performance indices values between LS-HIT and HVET groups. Statistical significance was set at $p \leq 0.05$ level of confidence. SPSS for Windows statistical software (version 21) was used to perform the statistical analysis.

The aim of the study 1 was to test the null hypothesis that the impact of LS-HIT and HVET on VO_2max (pre training versus post training) would be identical in the two populations. The criterion for significance (alpha) was set at 0.05. The test was 1-tailed. A retrospective power analysis based on Wilcoxon signed rank test indicated that with sample size of 8 and effect size of 0.49 the study had power of 41% to yield a statistically significant result for the LS-HIT group and with a sample size of 7 and effect size of 0.36 the study had power of 22% to yield a statistically significant result for the HVET group.

Results

Blood Lactate Levels During Each Individual Training Session

Table 4.1 summarises the blood lactate concentration before, during and after each LS-HIT and HVET training session. With the exception of training session 4, baseline blood lactate concentration was similar in both the LS-HIT and HVET groups prior to training. Post exercise blood lactate values were significantly higher ($p < 0.05$) than baseline in both the LS-HIT and HVET group immediately after each training session. Post exercise blood lactate values were significantly higher ($p < 0.01$) after each LS-HIT session compared to each HVET session. (see appendix C, tables 7.5, 7.6, 7.7 & 7.8, pg. 229-232)

Table 4.1: Blood lactate concentration before, during, and after each LS-HIT and HVET training session

	Experimental Condition					
	LS-HIT				HVET	
	Pre Exercise	Set 1	Set 2	Post Exercise	Pre Exercise	Post Exercise
Training 1	1.20 ± 0.36	9.30 ± 2.43	10.70 ± 2.50	11.41 ± 0.50*[c]	1.03 ± 0.26	5.64 ± 3.36*
Training 2	1.03 ± 0.21	8.83 ± 3.13	11.64 ± 1.04	12.19 ± 1.32*[b]	1.09 ± 0.20	4.54 ± 3.30*
Training 3	1.23 ± 0.41	7.58 ± 3.32	12.06 ± 1.23	12.45 ± 1.59*[b]	0.97 ± 0.15	4.66 ± 3.51*
Training 4	1.29 ± 0.36[x]	7.63 ± 3.71	10.94 ± 2.96	11.88 ± 1.69*[c]	0.90 ± 0.17	2.97 ± 2.27*
Training 5	1.29 ± 0.39	6.84 ± 3.42	13.19 ± 2.08	13.26 ± 1.72*[c]	1.01 ± 0.38	3.64 ± 2.39*
Training 6	1.05 ± 0.31	7.46 ± 3.93	10.90 ± 3.30	12.90 ± 2.16*[c]	0.93 ± 0.34	3.94 ± 2.14*

Values are mean ± SD; *$p<0.05$ vs. pre-exercise within each experimental group; [x]$p<0.05$ pre LS-HIT compared to value pre HVET; [b]$p<0.01$ post LS-HIT compared to value post HVET; [c]$p<0.001$ post LS-HIT compared to value post HVET

Physiological Responses at Maximal Exercise

Table 4.2 summarises the physiological responses at maximal exercise before and after training. With the exception of HRmax there was no significant difference between the two experimental groups for any of the physical, perceptual, metabolic and performance indices before training. Following training, there was a significant increase in relative $\dot{V}O_2$max ($p<0.05$), absolute $\dot{V}O_2$max ($p<0.05$) and $\dot{V}_E$ ($p<0.05$) in the LS-HIT group only. HRmax decreased significantly ($p<0.05$) in the HVET group after training. (see appendix C, tables 7.1, 7.2, 7.3 & 7.4, pg. 225-228)

Table 4.2: Physiological responses at maximal exercise in the LS-HIT and HVET group before and after training

	Group			
	LS-HIT		**HVET**	
	Pre Training	**Post Training**	**Pre Training**	**Post Training**
Age (yr)	21.63 ± 2.13	-	21.86 ± 3.53	-
Height (cm)	177.11 ± 2.97	-	174.84 ± 7.20	-
Weight (kg)	74.80 ± 7.30	75.05 ± 6.87	75.14 ± 6.82	75.30 ± 6.64
$\dot{V}O_2max$ ($ml \cdot kg^{-1} \cdot min^{-1}$)	51.83 ± 4.33	55.56 ± 4.05*	51.27 ± 1.88	54.05 ± 4.50
$\dot{V}O_2max$ ($L \cdot min^{-1}$)	3.97 ± 0.50	4.26 ± 0.50*	3.85 ± 0.39	4.06 ± 0.48
Ventilation ($L \cdot min^{-1}$)	98.95 ± 17.42	113.52 ± 14.92*	99.57 ± 17.38	105.50 ± 20.64
RER	1.08 ± 0.64	1.10 ± 0.07	1.10 ± 0.06	1.04 ± 0.08
Heart rate ($b \cdot m^{-1}$)	184.50 ± 11.98^{x}	188.50 ± 9.13	200.43 ± 12.53	188.86 ± 10.51*
RPE	19.00 ± 1.31	19.75 ± 0.46	19.29 ± 0.76	20.00 ± 0.00
$v\dot{V}O_2max$ ($km \cdot hr^{-1}$)	14.68 ± 1.68	16.31 ± 2.82	14.66 ± 1.73	15.00 ± 1.62

Values are mean ± SD; *p<0.05 vs. pre-training within each experimental group; ^{x}p<0.05 pre LS-HIT compared to value pre HVET

Endurance Performance Test

Before training there was no significant group difference in endurance performance at $v\dot{V}O_2$ max. Time to exhaustion at $v\dot{V}O_2$ max significantly increased in both the LS-HIT ($p \leq 0.05$) and HVET group ($p \leq 0.01$) after training (figure 4.3). (see appendix C, tables 7.1, 7.2, 7.3 & 7.4, pg. 225-228)

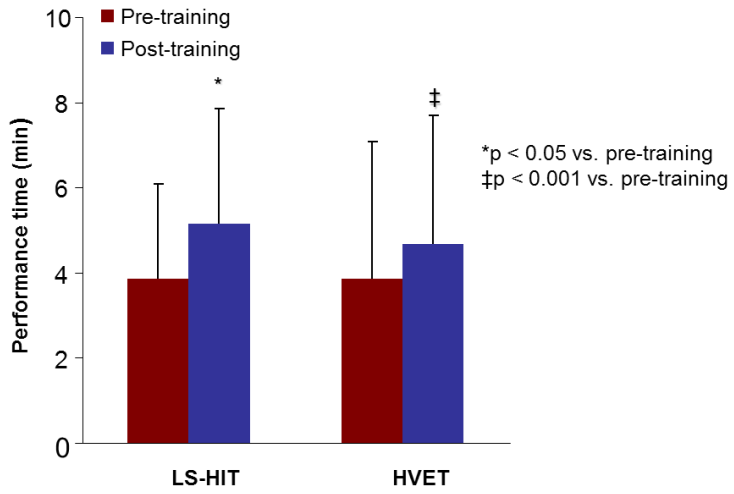

Figure 4.3: Endurance performance (min) before and after training

Blood Lactate Concentration

Table 4.3 summarises the treadmill velocity, $\%\dot{V}O_2$ and heart rate at the LT and 2.0 $mmol \cdot L^{-1}$ and 4.0 $mmol \cdot L^{-1}$ fixed blood lactate concentrations in the LS-HIT and HVET group before and after training. Before training, there was no difference between groups in treadmill velocity, $\%\dot{V}O_2$ and heart rate at the LT, 2.0 $mmol \cdot L^{-1}$, and 4.0 $mmol \cdot L^{-1}$ fixed blood lactate concentrations. Compared to pre-training, treadmill velocity and $\%\dot{V}O_2$ at 4.0 $mmol \cdot L^{-1}$ increased significantly ($p \leq 0.05$) in the HVET group following the 2 week training

program. There were no significant changes in blood lactate concentration following 2 weeks of LS-HIT. (see appendix C, tables 7.9, 7.10, 7.11 & 7.12, pg. 233-236)

Table 4.3: Treadmill velocity, %V̇O2 and heart rate at the LT and 2.0 mmol·L^{-1} and 4.0 mmol·L^{-1} fixed blood lactate concentrations in the LS-HIT and HVET group before and after training.

	Experimental Condition			
	LS-HIT		**HVET**	
	Pre-Training	**Post Training**	**Pre-Training**	**Post Training**
Treadmill velocity at LT	10.4 ± 1.3	10.8 ± 0.8	11.0 ± 0.7	10.7 ± 1.5
Velocity of treadmill at 2.0 mmol·L^{-1}	10.5 ± 1.7	10.3 ± 1.2	10.9 ± 0.2	10.7 ± 1.5
Velocity of treadmill at 4.0 mmol·L^{-1}	12.5 ± 1.4	12.2 ± 1.9	11.4 ± 1.4	12.8 ± 1.2*
%$\dot{V}O_2$ at LT	74.2 ± 11.0	67.8 ± 11.5	75.6 ± 8.8	75.0 ± 12.5
%$\dot{V}O_2$ at 2.0 mmol·L^{-1}	73.1 ± 13.7	68.9 ± 6.4	79.0 ± 13.1	73.2 ± 12.2
%$\dot{V}O_2$ at 4.0 mmol·L^{-1}	86.9 ± 8.5	77.5 ± 9.4	80.2 ± 11.6	86.1 ± 7.9*
%HR at LT	84.0 ± 6.4	83.1 ± 6.4	86.6 ± 8.3	84.9 ± 9.4
%HR at 2.0 mmol·L^{-1}	81.7 ± 9.6	82.8 ± 5.2	87.5 ± 2.6	83.2 ± 9.8
%HR at 4.0 mmol·L^{-1}	93.4 ± 3.4	93.4 ± 3.3	91.6 ± 9.9	94.3 ± 5.2

Values are mean ± SD; *p<0.05 vs. pre-training within each experimental group

Running Economy

Table 4.4 summarises RE expressed in $ml \cdot kg^{-1} \cdot min^{-1}$, $ml \cdot kg^{-1} \cdot km^{-1}$ and $Kcal \cdot kg^{-1} \cdot km^{-1}$ in the LS-HIT and HVET group before and after training. RE expressed in $ml \cdot kg^{-1} \cdot min^{-1}$, $ml \cdot kg^{-1} \cdot km^{-1}$ and $Kcal \cdot kg^{-1} \cdot km^{-1}$ was similar in both groups at baseline and did not change following training. (see appendix C, tables 7.13, 7.14, 7.15 & 7.16, pg. 237-240)

Table 4.4: RE expressed as $\dot{V}O_2$ in $ml \cdot kg^{-1} \cdot min^{-1}$, $ml \cdot kg^{-1} \cdot km^{-1}$, $kcal \cdot kg^{-1} \cdot km^{-1}$ in the LS-HIT and HVET group before and after training.

	Experimental Condition			
	LS-HIT		**HVET**	
	Pre Training	**Post Training**	**Pre Training**	**Post Training**
$ml \cdot kg^{-1} \cdot min^{-1}$				
8.0 ($km \cdot h^{-1}$)	30.7 ± 4.0	29.7 ± 4.3	29.3 ± 2.4	30.5 ± 3.1
9.0 ($km \cdot h^{-1}$)	34.9 ± 4.0	33.1 ± 3.9	32.9 ± 3.6	34.3 ± 3.7
10.0 ($km \cdot h^{-1}$)	35.5 ± 5.4	37.1 ± 5.0	36.9 ± 3.1	36.8 ± 3.8
11.0 ($km \cdot h^{-1}$)	40.3 ± 4.6	39.8 ± 5.3	39.7 ± 3.2	41.1 ± 2.9
$ml \cdot kg^{-1} \cdot km^{-1}$				
8.0 ($km \cdot h^{-1}$)	230.0 ± 30.1	222.4 ± 32.2	220.0 ± 18.3	228.8 ± 22.9
9.0 ($km \cdot h^{-1}$)	232.4 ± 26.6	220.8 ± 26.3	219.1 ± 24.2	228.8 ± 24.5
10.0 ($km \cdot h^{-1}$)	213.0 ± 32.4	222.8 ± 29.8	221.7 ± 18.5	220.5 ± 22.9
11.0 ($km \cdot h^{-1}$)	219.8 ± 24.9	217.2 ± 28.8	216.4 ± 17.7	224.2 ± 15.9
$kcal \cdot kg^{-1} \cdot km^{-1}$				
8.0 ($km \cdot h^{-1}$)	1.02 ± 0.13	1.03 ± 0.12	1.01 ± 0.08	1.07 ± 0.09
9.0 ($km \cdot h^{-1}$)	1.08 ± 0.07	1.04 ± 0.09	1.03 ± 0.08	1.09 ± 0.10
10.0 ($km \cdot h^{-1}$)	0.95 ± 0.11	1.03 ± 0.10	0.99 ± 0.06	1.07 ± 0.09
11.0 ($km \cdot h^{-1}$)	0.99 ± 0.06	1.01 ± 0.14	1.00 ± 0.07	1.08 ± 0.09

Values are mean ± SD

Summary

Following 2 weeks of training, there was a significant increase in absolute and relative $\dot{V}O_2$max in the LS-HIT group only. There was a significant increase in treadmill velocity and %$\dot{V}O_2$max at 4 $mmol \cdot L^{-1}$ following HVET. RE did not change and endurance performance increased in both LS-HIT and HVET following training. Post exercise blood lactate values at the end of each training session were significantly higher than pre-exercise values in both LS-HIT and HVET. Blood lactate values were significantly higher after each LS-HIT session than HVET session.

Chapter V

Study 2

Introduction

The present study sought to confirm and extend the findings from study 1 showing a significant increase in $\dot{V}O_2$max after 2 weeks of LS-HIT only. Study 1 was limited in that the duration of training was relatively short and it could be argued that the very intense nature of LS-HIT might stimulate rapid skeletal muscle remodelling, whereas adaptations to lower intensity HVET may accrue more slowly. In addition, study 1 involved laboratory tests of endurance performance, and did not provide any information on the effects of LS-HIT or HVET on speed and power, both important fitness characteristics for optimal performance in Gaelic football. While ideal for developing aerobic capacity, HVET may lack the specificity required to develop or maintain running speed and muscle power whereas LS-HIT may induce neuromuscular and endocrine adaptions that may have a positive effect.

Surprisingly, few published studies have examined the effect of HVET on indices of speed and power in athletes participating in field based invasion sports. A study by Sperlich *et al*., (2011) found that 5 weeks of endurance training and high intensity training induced similar improvements in 20 m, 30 m and 40 m sprint performance with no changes in jump performance in adolescent soccer players [154]. The study also found a 7% increase in $\dot{V}O_2$max and improved 1 km time trial performance after high intensity training only. These improvements were achieved with 90-120 min·week^{-1} less weekly exercise time. A

limitation of the study is the fact that both training programs were administered as an extension of a regular soccer-specific training session.

The purpose of the study was to compare the effects of 6 weeks of LS-HIT and HVET on anthropometric, physiological, metabolic and performance indices in club level Gaelic football players.

Study Aims

1. To compare the effects of a 6 week HVET and LS-HIT program on $\dot{V}O_2max$, RE and $v\dot{V}O_2max$ in club level Gaelic football players

2. To compare the effects of a 6 week HVET and LS-HIT program on circulating levels of blood lactate in club level Gaelic football players

3. To compare the effects of a 6 week HVET and LS-HIT program on endurance exercise performance in club level Gaelic football players

4. To compare the effects of a 6 week HVET and LS-HIT program on running speed in club level Gaelic football players

5. To compare the effects of a 6 week HVET and LS-HIT program on lower body power in club level Gaelic football players

Study Hypotheses

Null Hypotheses

1. $\dot{V}O_2max$, RE and $v\dot{V}O_2max$ responses will be similar in club level Gaelic football players following 6 weeks of LS-HIT and HVET

2. Blood lactate levels will be similar in club level Gaelic football players following 6 weeks of LS-HIT and HVET

3. Endurance exercise performance will be similar in club level Gaelic football players following 6 weeks of LS-HIT and HVET

Alternate Hypotheses

4. Running speed will be maintained in club level Gaelic football players following 6 weeks of LS-HIT and will decrease following 6 weeks of HVET

5. Lower body power will be maintained in club level Gaelic football players following 6 weeks of LS-HIT and HVET will decrease following 6 weeks of HVET

Methodology

Participants

Twenty five apparently healthy men with a mean age of 26 years, currently playing Gaelic football at club level volunteered to participate in the study. Each player had a minimum of 3 years playing experience. During the season participants trained on average 2 $d \cdot week^{-1}$ and played a game on the majority weekends. Participants were excluded if they were current smokers or had any medical conditions that contraindicated exercise participation. Individuals who met the entry criteria and who received medical clearance to participate were randomly assigned to the HVET group (n = 12) or LS-HIT (n = 13) group. The nature and risks of the study were explained and written informed consent was obtained from each participant (appendix A). The experimental procedures were approved by the Research Ethics Committee at Dublin City University, Ireland.

Overview of Study Design

The study took place in the School of Health and Human Performance at DCU. The training program was undertaken 3 $d \cdot week^{-1}$ for 6 weeks. Participants made 3 separate visits to the Human Performance Laboratory, before the study and at the end of the 6 week training program. Each visit was separated by at least 24 h. Participants refrained from strenuous physical activity for 24 h prior to each visit. The study was undertaken during the competitive phase of the season.

The research design is outlined in figure 5.1. During the first laboratory visit participants completed a physical activity readiness (PAR-Q) and general health

questionnaire (appendix B), and their blood pressure, height and body mass measured. They then underwent a Wingate test. During the second visit participants performed a countermovement and vertical jump, had their 5 m and 20 m running speed assessed and underwent a treadmill exercise test to determine RE, blood lactate concentrations and to measure aerobic capacity ($\dot{V}O_2max$). The final visit was used to measure endurance performance.

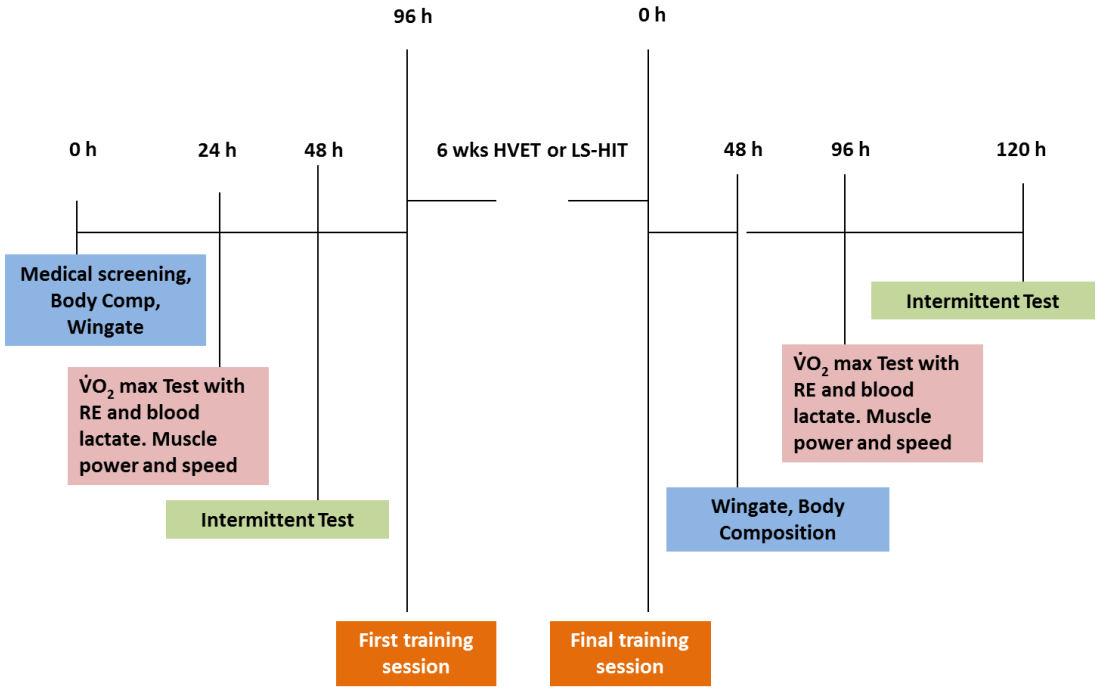

Figure 5.1: Study 2 - Research Design

High Volume Endurance Training (HVET) Protocol

During the first two weeks participants ran continuously on a treadmill (Woodway ELG 55, Waukesha, WI) for 40 min at 75%$\dot{V}O_2max$. The duration was increased to 50 min at the beginning of week 3 and remained constant thereafter.

Low Volume Short Duration High-intensity Interval Training (LS-HIT) Protocol

A simplified version of the study 1 LS-HIT programme was used while maintaining a duration ≤ 30 sec and blood lactate levels ≥10 mmol·L^{-1}. Participants sprinted 100 m with a change of direction at 50 m (figure 5.2). Each sprint was followed by a 50 m jog recovery with a change of direction at 25 m (figure 5.2). Each sprint and recovery period was 40 sec in duration. On average, participants completed the 100 m sprint in 17-20 sec, allowing for a 20-23 sec recovery period. A single set was comprised of 4 x 100 m sprints, each interspersed with a 50 m jog recovery. Each set was followed by a 3 min recovery period. Participants completed 3 sets (12 sprints) during the training sessions in week 1 and 2, and the number of sets was increased to 4 for the remaining 4 weeks of the study.

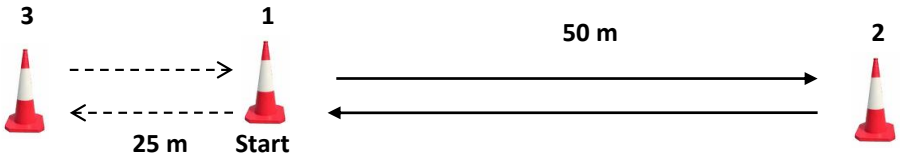

Figure 5.2: LS-HIT training protocol

Laboratory Procedures

Anthropometrics

As described in the methods section of chapter 3 (pg. 63)

Running Economy

As described in the methods section of chapter 3 (pg. 63)

Maximal Aerobic Capacity

As described in the methods section of chapter 3 (pg. 64)

v$\dot{V}O_2$max

As described in the methods section of chapter 3 (pg. 64)

Intermittent Endurance Performance

As described in the methods section of chapter 3 (pg. 70)

Cardiorespiratory and Metabolic Measures

As described in the methods section of chapter 3 (pg. 65)

Mass Flow Sensor Heated wire Anemometer-Mode of Operation

As described in the methods section of chapter 3 (pg. 65)

Mass Flow Sensor Calibration

As described in the methods section of chapter 3 (pg. 66)

Gas Analysers

As described in the methods section of chapter 3 (pg. 66)

Calibration of CO_2 and O_2 Analysers

As described in the methods section of chapter 3 (pg. 67)

Ratings of Perceived Exertion

As described in the methods section of chapter 3 (pg. 67)

Blood Lactate Sampling and Measurement

As described in the methods section of chapter 3 (pg. 68)

Blood Lactate Interpretation

As described in the methods section of chapter 3 (pg. 69)

Vertical Jump

As described in the methods section of chapter 3 (pg. 70)

Countermovement Jump

As described in the methods section of chapter 3 (pg. 71)

5 m and 20 m sprint Speed

As described in the methods section of chapter 3 (pg. 72)

Wingate Test

As described in the methods section of chapter 3 (pg. 73)

Statistical Analysis

Prior to statistical analysis the data was checked for normality using the Shapiro-Wilk test. A group (HVET and LS-HIT) x time (baseline and week 6) repeated measures ANOVA was used to compare anthropometric, physiological, metabolic and performance indices, mean differences within and between the LS-HIT and HVET groups. SPSS for Windows statistical software (version 21) was used to perform the statistical analysis. Statistical significance was accepted at the $p<0.05$ level of confidence.

The aim of the study 2 was to test the null hypothesis that the impact of LS-HIT and HVET on VO_2max (pre training versus post training) would be identical in the two populations. The criterion for significance (alpha) was set at 0.05. The test was 1-tailed. A retrospective power analysis based on repeated measures ANOVA indicated that with sample size of 25, the study had power of 95% to yield a statistically significant result. The calculation is based on an effect size of 0.39.

Results

Anthropometrics

Table 5.1 summarises anthropometric characteristics in the LS-HIT and HVET group before and after training. There were no within or between group differences in any of the anthropometric characteristics at baseline or week 6. (see appendix D, table 7.17, pg. 241)

Table 5.1: Anthropometric characteristics before and after training

	Group			
	LS-HIT		**HVET**	
	Pre Training	**Post Training**	**Pre Training**	**Post Training**
Age (y)	27.2 ± 3.6		24.7 ± 4.0	
Height (cm)	1.8 ± 0.1		1.8 ± 0.1	
Weight (kg)	79.7 ± 9.6	79.7 ± 9.8	76.6 ± 9.7	76.6 ± 10.4
BMI ($kg \cdot m^{-2}$)	25.3 ± 1.6	25.3 ± 1.5	23.6 ± 2.8	23.5 ± 2.9
Body fat (%)	16.9 ± 4.6	16.2 ± 5.0	13.5 ± 4.3	13.0 ± 4.6

Values are mean ± SD

Physiological Responses at Maximal Exercise

Table 5.2 summarises the physiological responses at maximal exercise in the LS-HIT and HVET group before and after training. Compared to pre training, $\dot{V}O_2max$ and $v\dot{V}O_2max$ increased significantly ($p<0.05$) in both the LS-HIT and HVET groups following the 6 week training program. HRmax was significantly lower at week 6 than baseline in both the LS-HIT ($p \leq 0.01$) and HVET ($p \leq 0.05$) group. RPE increased significantly in the LS-HIT group after training ($p \leq 0.05$). (see appendix D, table 7.18, pg. 241)

Table 5.2: Physiological responses at maximal exercise in the LS-HIT and HVET group before and after training

	Group			
	LS-HIT		HVET	
	Pre Training	Post Training	Pre Training	Post Training
$\dot{V}O_2$ max ($ml \cdot kg^{1} \cdot min^{1}$)	52.5 ± 5.3	56.0 ± 4.7*	52.8 ± 5.5	56.4 ± 4.1*
Ventilation ($L \cdot min^{1}$)	108.5 ± 10.3	115.6 ± 18.1	111.8 ± 16.6	116.5 ± 13.7
Heart rate ($beats \cdot min^{1}$)	197.7 ± 7.9	192.0 ± 7.6†	196.8 ± 6.7	193.6 ± 5.6*
RPE	18.1 ± 1.9	19.1 ± 1.0*	18.9 ± 1.3	18.9 ± 1.3
Lactate ($mmol \cdot L^{1}$)	7.5 ± 2.5	8.4 ± 2.2	7.6 ± 2.3	8.4 ± 1.6
$v\dot{V}O_2$ max ($km \cdot h^{1}$)	14.1 ± 1.2	15.1 ± 1.7*	13.7 ± 1.0	15.3 ± 2.3†

Values are mean ± SD, *p<0.05 vs. pre-training within each experimental group; †p<0.01 vs. pre-training within each experimental group

Blood Lactate Concentration

Table 5.3 summarises the treadmill velocity, %$\dot{V}O_2$ max and %heart rate max at the LT and 2.0 $mmol \cdot L^{-1}$ and 4.0 $mmol \cdot L^{-1}$ fixed blood lactate concentrations in the LS-HIT and HVET group before and after training. Compared to pre-training, %$\dot{V}O_2$ at LT ($p \leq 0.05$), %$\dot{V}O_2$ at 4.0 $mmol \cdot L^{-1}$ ($p \leq 0.01$), %HR at LT ($p \leq 0.05$) and %HR at 4.0 $mmol \cdot L^{-1}$ ($p \leq 0.05$) decreased significantly in the LS-HIT group following the 6 week training program. Treadmill velocity at LT was significantly higher in the HVET at week 6 than baseline ($p \leq 0.05$). There was a significant difference in treadmill velocity and %$\dot{V}O_2$ max at a fixed blood lactate concentration of 4.0 $mmol \cdot L^{-1}$ between LS-HIT and HVET after training ($p \leq 0.05$). (see appendix D, table 7.19, pg. 242)

Table 5.3: Treadmill velocity, %$\dot{V}O_2$ max and %HR max at the LT and 2.0 mmol·L^{-1} and 4.0 mmol·L^{-1} fixed blood lactate concentrations in the LS-HIT and HVET group before and after training

	Group			
	LS-HIT		**HVET**	
	Pre-Training	**Post Training**	**Pre-Training**	**Post Training**
Treadmill velocity at LT	10.4 ± 0.9	10.0 ± 0.9	9.8 ± 1.3	10.5 ± 1.1*
Treadmill velocity at 2.0 mmol·L^{-1}	11.0 ± 2.0	10.2 ± 1.3	10.1 ± 1.3	11.0 ± 1.2
Treadmill velocity at 4.0 mmol·L^{-1}	12.2 ± 2.0	12.1 ± 0.9[a]	12.2 ± 0.9	13 ± 1.1
%$\dot{V}O_2$ at LT	76.0 ± 12.2	67.1 ± 7.2*	71.0 ± 14.2	70.4 ± 7.2
%$\dot{V}O_2$ at 2.0 mmol·L^{-1}	77.2 ± 12.9	65.4 ± 7.9	73.0 ± 14.1	73.6 ± 8.8
%$\dot{V}O_2$ at 4.0 mmol·L^{-1}	88.5 ± 11.7	78.8 ± 6.4†[a]	88.2 ± 10.4	88.1 ± 10.4
%HR at LT	88.5 ± 5.1	83.9 ± 5.4*	73.6 ± 25.0	76.3 ± 27.1
%HR at 2.0 mmol·L^{-1}	89.2 ± 7.9	62.7 ± 37.0	70.2 ± 37.9	77.7 ± 26.8
%HR at 4.0 mmol·L^{-1}	94.5 ± 5.5	77.9 ± 32.6*	84.0 ± 28.8	85.1 ± 28.9

Values are mean ± SD; *p<0.05 vs. pre-training within each experimental group, †p<0.01 vs. pre-training within each experimental group.
[a]p<0.05 post LS-HIT compared to value post HVET

Running Economy

Table 5.4 summarises RE at 4 different running velocities in the LS-HIT and HVET group before and after training. There was no significant difference in pre-training RE expressed in $ml \cdot kg^{-1} \cdot min^{-1}$, $ml \cdot kg^{-1} \cdot km^{-1}$, or $kcal \cdot kg^{-1} \cdot km^{-1}$ between the LS-HIT and HVET groups. Compared to pre training, RE at 10 $km \cdot h^{-1}$ expressed as $kcal \cdot kg^{-1} \cdot km^{-1}$ decreased significantly following 6 weeks of HVET training ($p \leq 0.05$). (see appendix D, table 7.20, pg. 243)

Table 5.4: RE expressed as $\dot{V}O_2$ in $ml \cdot kg^{-1} \cdot min^{-1}$, $ml \cdot kg^{-1} \cdot km^{-1}$, $Kcal \cdot kg^{-1} \cdot km^{-1}$ before and after training

	Group			
	LS-HIT		**HVET**	
	Pre Training	**Post Training**	**Pre Training**	**Post Training**
$ml \cdot kg^{-1} \cdot min^{-1}$				
8.0 ($km \cdot h^{-1}$)	32.7 ± 4.1	30.1 ± 8.2	31.81 ± 2.1	31.7 ± 2.9
9.0 ($km \cdot h^{-1}$)	36.7 ± 4.9	33.8 ± 6.5	36.4 ± 3.5	36.1 ± 2.7
10.0 ($km \cdot h^{-1}$)	39.6 ± 5.6	38.3 ± 4.7	40.8 ± 3.6	39.6 ± 3.0
11.0 ($km \cdot h^{-1}$)	44.0 ± 5.2	41.0 ± 5.5	44.1 ± 4.1	43.0 ± 3.8
$ml \cdot kg^{-1} \cdot km^{-1}$				
8.0 ($km \cdot h^{-1}$)	244.9 ± 30.4	225.9 ± 61.4	238.6 ± 15.6	237.5 ± 21.9
9.0 ($km \cdot h^{-1}$)	244.7 ± 32.9	225.7 ± 43.3	242.4 ± 23.1	240.9 ± 18.0
10.0 ($km \cdot h^{-1}$)	237.9 ± 33.3	229.9 ± 28.0	244.6 ± 21.5	237.5 ± 17.7
11.0 ($km \cdot h^{-1}$)	239.8 ± 28.6	223.9 ± 29.9	240.5 ± 22.2	234.7 ± 20.9
$kcal \cdot kg^{-1} \cdot km^{-1}$				
8.0 ($km \cdot h^{-1}$)	1.2 ± 0.1	1.1 ± 0.3	1.2 ± 0.1	1.1 ± 0.1
9.0 ($km \cdot h^{-1}$)	1.2 ± 0.2	1.1 ± 0.2	1.2 ± 0.1	1.1 ± 0.1
10.0 ($km \cdot h^{-1}$)	1.2 ± 0.2	1.1 ± 0.1	1.2 ± 0.1	1.1 ± 0.1*
11.0 ($km \cdot h^{-1}$)	1.2 ± 0.2	1.1 ± 0.1	1.2 ± 0.1	1.1 ± 0.1

Values are mean ± SD; *p<0.05 pre-training within each experimental group

Running Speed and Jump Performance

Running speed and jump performance scores before and after training are summarised in Table 5.5. Compared to baseline, performance in the VJ was significantly lower in the HVET group after training ($p \leq 0.05$). The time required to complete the 20 m sprint was greater in the HVET group after training than baseline ($p \leq 0.05$). (see appendix D, table 7.21, pg. 244)

Table 5.5: Running speed and jump performance before and after training

	Group			
	LS-HIT		HVET	
	Pre Training	Post Training	Pre Training	Post Training
CMJ (cm)	35.9 ± 5.8	34.6 ± 3.5	33.7 ± 5.1	33.1 ± 4.9
CMJ flight time (sec)	0.5 ± 0.0	0.5 ± 0.0	0.5 ± 0.0	0.5 ± 0.0
VJ (cm)	39.5 ± 6.2	38.3 ± 3.7	38.5 ± 5.7	36.3 ± 5.0*
VJ flight time (sec)	0.6 ± 0.0	0.6 ± 0.0	0.6 ± 0.0	0.5 ± 0.0*
5 m (sec)	1.1 ± 0.1	1.1 ± 0.1	1.1 ± 0.1	1.2 ± 0.1
20 m (sec)	3.3 ± 0.2	3.3 ± 0.1	3.2 ± 0.1	3.3 ± 0.1†

Values are mean ± SD, *p<0.05 vs. pre-training within each experimental group; †p<0.01 vs. pre-training within each experimental group

Wingate Test

Performance scores in the Wingate test before and after training are summarised in Table 5.6. There were no significant group differences in any of the pre-training Wingate test scores. MPO and PPO were significantly higher in both the LS-HIT and HVET after training than baseline ($p \leq 0.05$ to 0.01). Compared to baseline values, there was no significant change in fatigue index in either group following the 6 week training program. (see appendix D, table 7.22, pg. 245)

Table 5.6: Wingate test scores before and after training

	Group			
	LS-HIT		HVET	
	Pre Training	Post Training	Pre Training	Post Training
Mean power (W)	637.8 ± 87.8	688.5 ± 90.2*	600.3 ± 73.5	652.2 ± 114.2*
Peak power (W)	858.9 ± 121.6	916.2 ± 145.9*	809.5 ± 96.3	895.9 ± 150.3†
Fatigue index (W)	273.0 ± 45.6	269.3 ± 77.0	257.6 ± 49.5	270.3 ± 65.8

Values are mean ± SD; *p<0.05 vs. pre-training within each experimental group, †p<0.01 vs. pre-training within each experimental group

Endurance Performance

The number of intervals completed and the blood lactate levels during the endurance test are summarised in Table 5.7. Both the LS-HIT ($p \leq 0.05$) and HVET ($p \leq 0.001$) group completed a significantly greater number of high intensity intervals after training than before training. Peak levels of blood lactate were significantly lower in the HVET at the end of the endurance test after training compared to baseline ($p \leq 0.05$). (see appendix D, table 7.23, pg. 245)

Table 5.7: Endurance performance before and after training

	Group			
	LS-HIT		HVET	
	Pre Training	Post Training	Pre Training	Post Training
Number of intervals (N)	10.2 ± 5.9	13.6 ± 6.7*	8.0 ± 2.6	15.4 ± 5.0‡
Baseline lactate ($mmol \cdot L^{-1}$)	1.0 ± 0.3	0.9 ± 0.4	1.2 ± 0.5	1.2 ± 0.4
Peak lactate ($mmol \cdot L^{-1}$)	4.5 ± 1.8	4.2 ± 1.8	5.6 ± 1.6	4.7 ± 1.5*

Values are mean ± SD, *p<0.05 vs. pre-training within each experimental group; ‡p<0.001 vs. pre-training within each experimental group

Summary

Compared to pre-training, there was a significant increase in $\dot{V}O_2max$, $v\dot{V}O_2max$, MPO and PPO and the number of intervals completed during the endurance test and a significant decrease in HRmax in both groups after training. Following the 6 week training program, the treadmill velocity at a fixed blood lactate of 4.0 $mmol \cdot L^{-1}$ was greater in HVET than LS-HIT. RE at 10 $km \cdot hr^{-1}$ expressed as $kcal \cdot kg^{-1} \cdot km^{-1}$, vertical jump, 20 m running speed and peak blood lactate levels decreased and treadmill velocity corresponding to the LT increased in the HVET group after training. There was a significant decrease in %HR and $\%\dot{V}O_2$ at 4.0 $mmol \cdot L^{-1}$ and at LT in the LS-HIT group after training.

Chapter VI

Study 3

Introduction

The ability to perform repeated sprints at the highest possible running velocity is termed repeated sprint ability (RSA), and is a crucial physical component of team-sport performance [2]. In study 2 a modified Wingate anaerobic test involving 6 x 10 sec bouts of maximal effort cycling against a resistance of 7.5% body mass with 50 sec recovery was used to assess RSA. The fact that no relation was found between $\dot{V}O_2$max and power output averaged across the 6 trials may be due to the fact that the test lacked specificity as it involved non-weight bearing exercise.

In recent years a number of different exercise protocols have been developed to measure RSA in invasive field-based team sports [39,42,46,133,141]. The protocols differ in terms of exercise mode, sprint duration, number of sprint repetitions and type of recovery in order to match the work-rest pattern during match play. To date, no study has evaluated the validity of RSA tests among Gaelic football players. Logical validity indicates that the test is appropriate to what you want to measure. Although RSA test protocols in the current study were derived directly from the time motion analysis of Gaelic football match play, and hence the tests characteristic itself provides sufficient logic in doing the test, assessing the validity of RSA performance in a team-sport athlete is complex because repeated sprinting activity contributes to, rather than being a primary determinant of the player's overall performance.

Criterion validity refers to how well the test scores compares or correlates to another test that is deemed to be a gold standard or criterion [155]. RSA testing is considered to be an anaerobic-type of performance test. However, there is currently no established "gold standard" anaerobic test that can be used for comparison. Construct validity refers to the properties of the test in allowing to discriminate between different groups of people performing the same test [155]. Previous studies have found significantly better RSA performance in adult professional vs. amateur players as well as in elite vs. sub-elite junior players [170, 171]. These findings indicate that RSA performance is superior in teams performing at a relatively higher standard of competitiveness. The present study evaluated the construct validity of 4 different RSA tests in Gaelic football players by comparing RSA performance between teams of different levels of competitiveness. Comparisons were made between county (elite) and club (sub-elite) level Gaelic football players. Furthermore, there is limited understanding of the determinants that predict RSA. Identification of these variables may help coaches and sport scientists to develop better training programs to improve RSA.

The purpose of the present study was to evaluate the validity of 4 different RSA tests and to examine the relation between selected physical and performance factors on RSA test scores among club and county level Gaelic football players.

Study Aims

1. To examine the construct validity of 4 different RSA tests in club and county level Gaelic football players

2. To examine the bivariate relation between selected physical, physiological and performance parameters on the RSA tests that demonstrated construct validity in club and county level Gaelic football players

Study Hypotheses

Alternate Hypotheses

1. Significant differences in performance in each of the 4 RSA tests between club and county level players will provide evidence of construct validity

2. There will be a significant bivariate relation between measures of speed, strength, power, endurance performance, $\dot{V}O_2max$, $v\dot{V}O_2max$, RE, and blood lactate indices and performance in RSA tests that demonstrate construct validity

Methodology

Participants

Thirty, apparently healthy males between the ages of 18 - 25 years currently playing Gaelic football at club (n= 15) or county (n=15) level volunteered to participate in the study. During the season participants trained on average 3 $d \cdot week^{-1}$ and played a game on the majority of weekends. Participants were excluded if they were current smokers or had any medical conditions that contraindicated exercise participation. The nature and risks of the study were explained and written informed consent was obtained from each participant (appendix B). The experimental procedures were approved by the Research Ethics Committee at Dublin City University, Ireland.

Overview of Study Design

The study design is outlined in figure 6.1. Participants made 3 visits to the High Performance Laboratory in the School of Health and Human Performance and 4 visits to the covered outdoor track in DCU. During the laboratory visits, they underwent a number of tests to measure body composition, running speed, power, leg strength, blood lactate levels, $\dot{V}O_2max$, and endurance performance. During visit 4 and visit 5 they performed 4 different RSA tests. The order of tests was randomly assigned. Each visit was separated by at least 24 h.

Study Visits

Visit 1: Participants completed a general health and physical activity readiness questionnaire (appendix A) after which body composition, countermovement, vertical and drop jump performance were assessed. Finally, they performed a combined submaximal/incremental exercise to measure RE, LT, fixed blood lactate concentration of 2.0 mmol·L^{-1} and 4.0 mmol·L^{-1} and $\dot{V}O_2$max.

Visit 2: Quadriceps and hamstring strength was assessed and anaerobic power was measured using the Wingate test.

Visit 3: 5 m and 20 m running speed, Margaria-Kalamen test and an endurance performance test were undertaken.

Visit 4 and 5: Participants performed two different RSA tests during each visit, and were separated by a minimum of 2 hrs recovery.

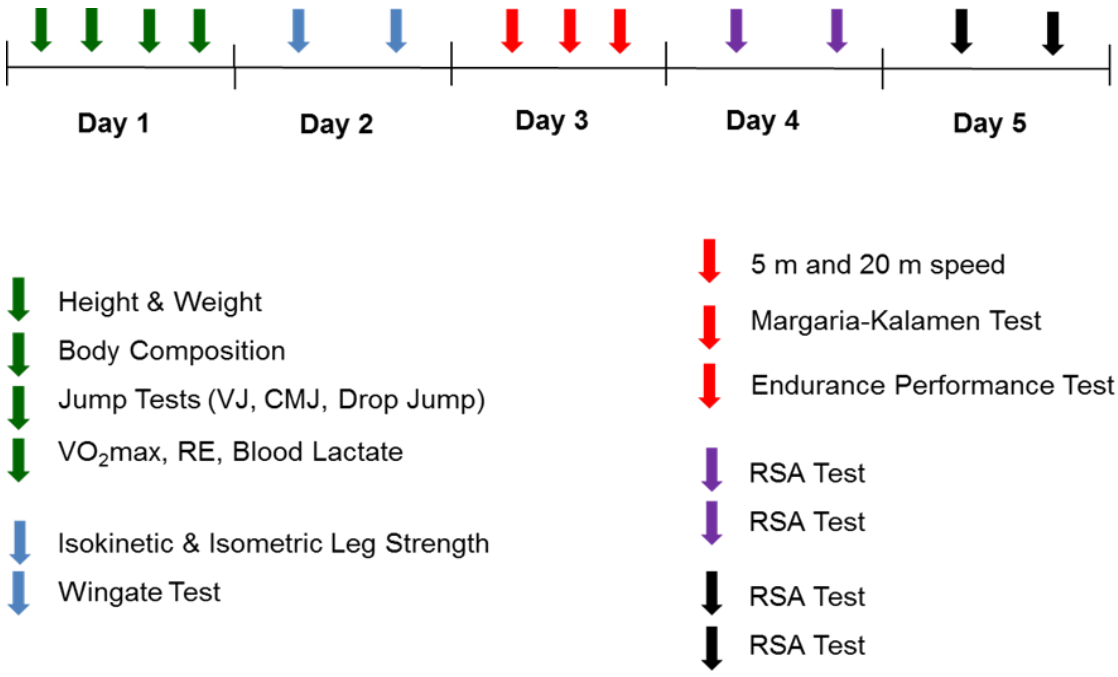

Figure 6.1: Study 3 – Research Design

RSA Test Design

RSA Test 1: Participants performed 6 maximal 40 m sprints with 3 changes of direction off a 30 sec cycle (sprint commenced every 30 sec). The testing protocol is illustrated in figure 6.2. Each sprint was timed using electronic timing gates (Smartspeed, Fusion Sport International) and a stopwatch was used to time each 30 sec sprint cycle.

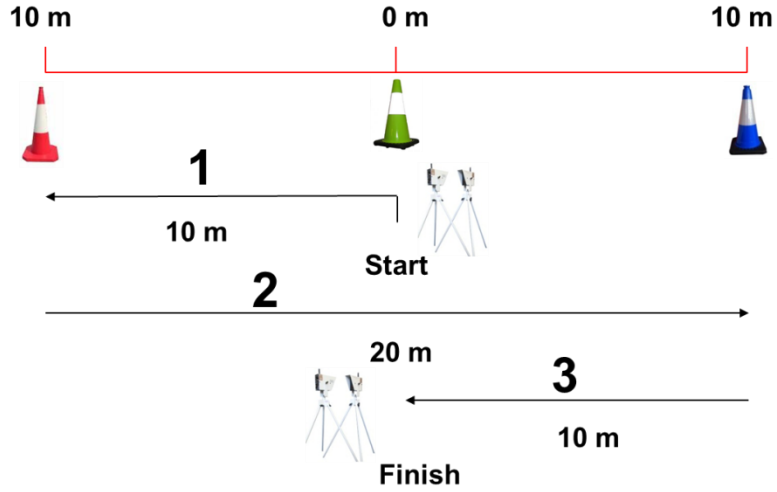

Figure 6.2: Testing protocol for RSA test 1

RSA Test 2: Participants performed 8 maximal 30 m sprints on a 22.5 sec cycle. The testing protocol is illustrated in figure 6.3. Each sprint was timed using electronic timing gates (Smartspeed, Fusion Sport International) and a stopwatch was used to time each 22.5 sec cycle.

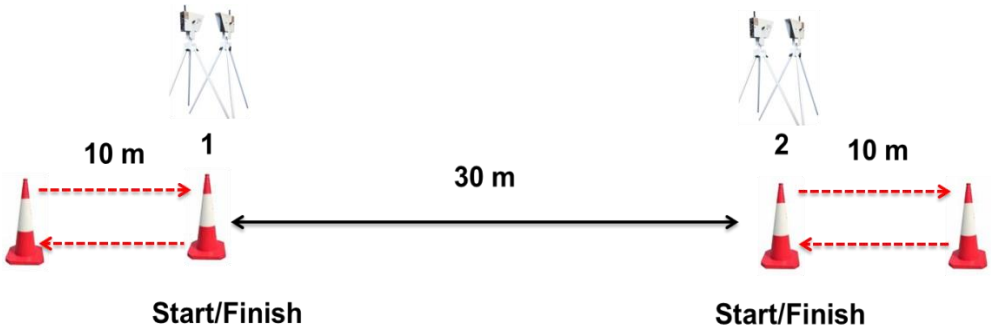

Figure 6.3: Testing protocol for RSA test 2

RSA Test 3: Participants performed 12 maximal sprints of 20 m on a 15 sec cycle. The testing protocol is illustrated in figure 6.4. Each sprint was timed using electronic timing gates and a stopwatch was used to time each 15 sec sprint cycle.

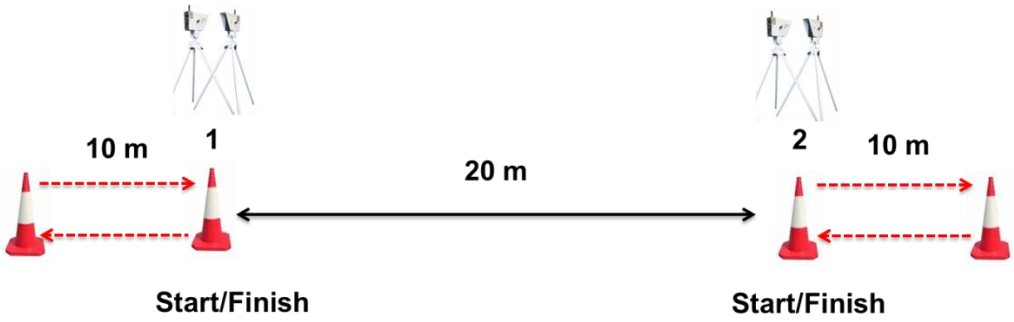

Figure 6.4: Testing protocol for RSA test 3

RSA Test 4: Participants performed 24 maximal sprints of 10 m on a 10 sec cycle. The testing protocol is illustrated in figure 6.5. Each sprint was timed using electronic timing gates and a stopwatch was used to time each 10 sec cycle.

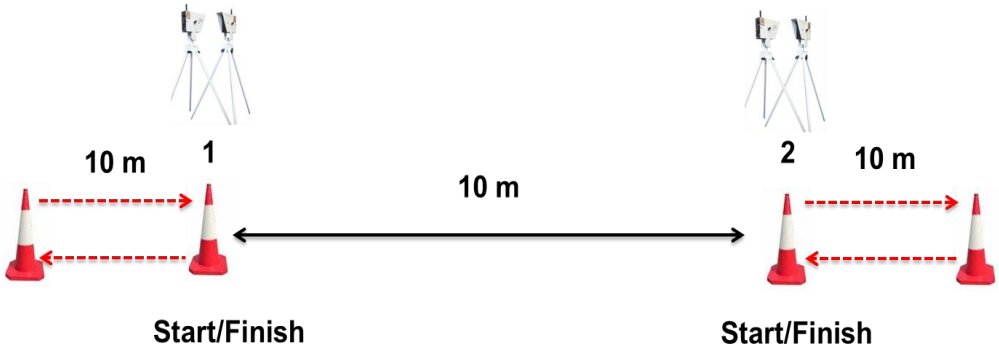

Figure 6.5: Testing protocol for RSA test 4

Laboratory Procedures

Anthropometrics

As described in the methods section of chapter 3 (pg. 63)

Running Economy

As described in the methods section of chapter 3 (pg. 63)

Maximal Aerobic Capacity

As described in the methods section of chapter 3 (pg. 64)

v$\dot{V}O_2$max

As described in the methods section of chapter 3 (pg. 64)

Cardiorespiratory and Metabolic Measures

As described in the methods section of chapter 3 (pg. 65)

Mass Flow Sensor Heated wire Anemometer-Mode of Operation

As described in the methods section of chapter 3 (pg. 65)

Mass Flow Sensor Calibration

As described in the methods section of chapter 3 (pg. 66)

Gas Analysers

As described in the methods section of chapter 3 (pg. 66)

Calibration of CO_2 and O_2 Analysers

As described in the methods section of chapter 3 (pg. 67)

Ratings of Perceived Exertion

As described in the methods section of chapter 3 (pg. 67)

Blood Lactate Sampling and Measurement

As described in the methods section of chapter 3 (pg. 68)

Blood Lactate Interpretation

As described in the methods section of chapter 3 (pg. 69)

Endurance Performance Test (Time Trial)

As described in the methods section of chapter 3 (pg. 69)

Vertical Jump

As described in the methods section of chapter 3 (pg. 70)

Countermovement Jump

As described in the methods section of chapter 3 (pg. 71)

Drop Jump

As described in the methods section of chapter 3 (pg. 71)

Speed

As described in the methods section of chapter 3 (pg. 72)

Wingate

As described in the methods section of chapter 3 (pg. 73)

Margaria-Kalamen

As described in the methods section of chapter 3 (pg. 74)

Muscle Strength

As described in the methods section of chapter 3 (pg. 74)

Subject Positioning and Set-up

As described in the methods section of chapter 3 (pg. 75)

Isokinetic Quadriceps Femoris and Hamstring Strength Assessment

As described in the methods section of chapter 3 (pg. 76)

Maximum Volitional Isometric Contraction Force

As described in the methods section of chapter 3 (pg. 77)

Statistical Analysis

Prior to statistical analysis the data was checked for normality using the Shapiro-Wilk test. Independent t-tests were used to compare selected physical (height, weight and body composition) and performance (VJ, DJ, CMJ, $\dot{V}O_2$max, RE, blood lactate concentration, isokinetic and isometric leg strength, wingate power, 5 and 20 m speed, Margaria-Kalamen power, endurance performance and RSA) parameters between club and county level players. The relation between RSA test performance and selected dependent variables (height, weight, body composition, VJ, DJ, CMJ, $\dot{V}O_2$max, RE, blood lactate concentration, isokinetic and isometric leg strength, wingate power, 5 and 20 m speed, Margaria-Kalamen power, endurance performance and RSA) was established using Pearson's product moment correlation. SPSS for Windows statistical software (ver. 21) was used to perform the statistical analysis. Statistical significance was accepted at the $p<0.05$ level of confidence.

Results

Anthropometrics

Table 6.1 summarises the anthropometric values for club and county level players. County level players were significantly older, taller and heavier than club level players ($p \leq 0.05$). (see appendix E, table 7.24, pg. 246)

Table 6.1: Anthropometric characteristics

	Playing Level	
	County	**Club**
Age (y)	21.1 ± 1.6*	19.9 ± 1.2
Height (cm)	1.9 ± 0.1*	1.8 ± 0.0
Weight (kg)	86.2 ± 8.2*	80.4 ± 6.0
BMI ($kg \cdot m^{-2}$)	25.0 ± 1.7	24.6 ± 1.6
Body fat (%)	10.0 ± 2.1	9.7 ± 3.4

Values are mean ± SD; *p<0.05 vs. club.

Physiological and Metabolic Responses at Maximal Exercise

Table 6.2 summarises the physiological and metabolic responses at maximal exercise in the club and county level players. HRmax was significantly lower in the county than club level players ($p \leq 0.01$). (see appendix E, table 7.25, pg. 246)

Table 6.2 Physiological and metabolic responses at maximal exercise

	Playing Level	
	County	**Club**
$\dot{V}O_2max$ ($ml \cdot kg^{-1} \cdot min^{-1}$)	53.5 ± 4.0	56.7 ± 4.7
Heart rate ($beats \cdot m^{-1}$)	184.7 ± 6.5†	193.6 ± 7.6
RPE	19.5 ± 0.7	19.6 ± 0.7
Peak lactate ($mmol \cdot L^{-1}$)	8.4 ± 2.2	8.0 ± 1.3
$v\dot{V}O_2max$ ($km \cdot h^{-1}$)	14.7 ± 1.6	15.1 ± 1.6
Performance test (sec)	342.9 ± 109.7	339.2 ± 211.3

Values are mean ± SD; †p ≤ 0.01 vs. club

Blood Lactate Concentration

Table 6.3 summarises blood lactate marker values in the club and county level groups. There was no significant difference between club and county level players. (see appendix E, table 7.26, pg. 246)

Table 6.3 Blood lactate concentration

	Playing Level	
	County	**Club**
Treadmill velocity at LT	11.0 ± 0.6	10.6 ± 0.8
Treadmill velocity at 2.0 $mmol \cdot L^{-1}$	11.6 ± 1.4	11.2 ± 0.7
Treadmill velocity at 4.0 $mmol \cdot L^{-1}$	13.1 ± 1.5	13.0 ± 1.2
%$\dot{V}O_2$ at LT	80.6 ± 9.1	74.0 ± 7.9
%$\dot{V}O_2$ at 2.0 $mmol \cdot L^{-1}$	82.6 ± 5.9	78.5 ± 7.0
%$\dot{V}O_2$ at 4.0 $mmol \cdot L^{-1}$	91.6 ± 6.5	89.0 ± 7.7
% HR at LT	85.8 ± 3.1	83.7 ± 4.6
% HR at 2.0 $mmol \cdot L^{-1}$	87.6 ± 4.7	86.4 ± 4.0
% HR at 4.0 $mmol \cdot L^{-1}$	94.0 ± 2.9	95.7 ± 1.7

Values are mean ± SD; †$p \leq 0.01$ vs. club

Running Economy

Table 6.4 summarises RE values in the club and county level players. There was no significant difference between club and county level players or any significant correlations between each RSA test and RE. (see appendix E, table 7.27, pg. 247)

Table 6.4: RE expressed as $\dot{V}O_2$ in $ml \cdot kg^{-1} \cdot min^{-1}$, $ml \cdot kg^{-1} \cdot km^{-1}$, $Kcal \cdot kg^{-1} \cdot km^{-1}$ before and after training

	$ml \cdot kg^{-1} \cdot min^{-1}$		**$ml \cdot kg^{-1} \cdot km^{-1}$**		**$Kcal \cdot kg^{-1} \cdot km^{-1}$**	
	County	**Club**	**County**	**Club**	**County**	**Club**
8.0 ($km \cdot h^{-1}$)	32.5 ± 0.8	33.1 ± 2.1	243.9 ± 5.6	248.1 ± 16.0	1.1 ± 0.1	1.1 ± 0.0
9.0 ($km \cdot h^{-1}$)	35.8 ± 1.3	37.6 ± 3.1	268.4 ± 9.7	282.0 ± 23.0	1.1 ± 0.1	1.1 ± 0.1
10.0 ($km \cdot h^{-1}$)	39.7 ± 3.9	40.2 ± 3.6	297.4 ± 29.2	301.8 ± 27.2	1.1 ± 0.1	1.1 ± 0.1
11.0 ($km \cdot h^{-1}$)	43.5 ± 4.2	44.1 ± 4.4	326.0 ± 31.4	330.8 ± 33.3	1.1 ± 0.1	1.1 ± 0.1

Values are mean ± SD

Power

Table 6.5 summarises the results of the jump tests, Margaria-Kalamen test and Wingate test. MPO and PPO attained during the Wingate test ($p \leq 0.05$) and VJ height ($p \leq 0.01$) were significantly greater in county than club level players. (see appendix E, table 7.28, pg. 248)

Table 6.5 Jump tests, Margaria-Kalamen test and Wingate test results

	Playing Level	
	County	**Club**
Vj (cm)	46.8 ± 2.5†	42.1 ± 4.9
Cmj (cm)	38.6 ± 4.3	36.9 ± 4.3
Dj (cm)	39.4 ± 4.1	38.0 ± 4.6
Djrsi (sec)	1.0 ± 0.3	1.0 ± 0.4
Margaria-Kalamen (sec)	0.6 ± 0.1	0.6 ± 0.1
Margaria-Kalamen (W)	1644.7 ± 198.4	1525.0 ± 193.6
Wingate -mean power (W)	1013.9 ± 118.7*	895.3 ± 120.6
Wingate - peak power (W)	1131.5 ± 123.5*	1010.4 ± 143.5
Wingate - fatigue Index (W)	318.4 ± 72.9	274.1 ± 74.0

Values are mean ± SD, *p ≤ 0.05 vs. club; †p ≤ 0.01 vs. club

Running Speed

There was no significant difference ($p \leq 0.116$) in 5 m running speed between club (1.1 ± 0.1 sec) and county (1.0 ± 0.1 sec) level players. In contrast, county level players were significantly ($p \leq 0.047$) faster than club level players over 20 m (3.0 ± 0.1 vs. 3.1 ± 0.1 sec).

Strength

Isokinetic Strength

Table 6.6 summarises isokinetic strength values at three different velocities in both dominant and non-dominant legs in the club and county level groups. Quadriceps and hamstring peak torque in both dominant and non-dominant leg at 60°·sec^{-1} and 180°·sec^{-1} was significantly greater in county than club level players ($p \leq 0.05$ to 0.01). Quadriceps and hamstring peak torque in the dominant leg at 300°·sec^{-1} was significantly greater ($p \leq 0.05$) in county than club level players. (see appendix E, table 7.29 and 7.30, pg. 249-250)

Table 6.6: Isokinetic strength

	County		Club	
	Quadriceps	**Hamstring**	**Quadriceps**	**Hamstring**
			60°·sec^{-1}	
Peak torque dom (N·m^{-1})	266.0 ± 40.0†	122.7 ± 18.3*	218.8 ± 50.2	107.3 ± 16.0
Peak torque non-dom (N·m^{-1})	260.7 ± 31.2†	116.8 ± 21.3*	210.6 ± 49.9	100.7 ± 18.2
Absolute difference PT (N·m^{-1})	5.3 ± 20.1	5.9 ± 14.1	8.3 ± 16.2	6.6 ± 17.6
Percentage difference PT (%)	1.3 ± 7.6	4.7 ± 12.0	3.7 ± 7.8	5.4 ± 16.5
			180°·sec^{-1}	
Peak torque dom (N·m^{-1})	188.0 ± 30.1*	104.9 ± 18.0	160.4 ± 30.4	90.8 ± 21.3
Peak torque non-dom (N·m^{-1})	178.8 ± 25.9*	98.1 ± 17.9	151.3 ± 33.5	89.8 ± 18.9
Absolute difference PT (N·m^{-1})	9.3 ± 15.3	6.9 ± 19.0	4.9 ± 11.9	4.8 ± 10.2
Percentage difference PT (%)	4.4 ± 8.0	8.9 ± 14.8	2.6 ± 8.0	4.9 ± 10.8
			300°·sec^{-1}	
Peak torque dom (N·m^{-1})	148.4 ± 24.4*	107.0 ± 18.8*	129.0 ± 25.8	90.8 ± 22.4
Peak torque non-dom (N·m^{-1})	143.0 ± 23.2	104.9 ± 19.6	127.7 ± 31.6	91.7 ± 19.0
Absolute difference PT (N·m^{-1})	5.4 ± 17.0	2.1 ± 16.6	6.4 ± 15.8	0.8 ± 14.3
Percentage difference PT (%)	2.9 ± 12.1	0.8 ± 16.4	4.1 ± 12.3	4.5 ± 19.4

Values are mean ± SD: *p<0.05 vs. club, †p<0.01 vs. club

Isometric Strength

In regards to isometric strength, there were no significant differences between club and county level players. Table 6.7 summarises Isometric strength values in both dominant and non-dominant legs in the club and county level groups. (see appendix E, table 7.31, pg. 251)

Table 6.7 Isometric strength

	60°·sec^{-1}	
	Quadriceps	
	County	**Club**
Peak torque dom (N·m^{-1})	46.8 ± 2.5	46.8 ± 2.5
Peak torque non-dom (N·m^{-1})	38.6 ± 4.3	38.6 ± 4.3
Absolute difference PT (N·m^{-1})	39.4 ± 4.1	39.4 ± 4.1
Percentage difference PT (%)	1.0 ± 0.3	1.0 ± 0.3

Values are mean ± SD

RSA Test Correlation

There was a significant relation between the average sprint time in each RSA test (table 6.8).

Table 6.8: RSA average sprint time correlations

	Average Time			
	RSA-1	**RSA-2**	**RSA-3**	**RSA-4**
RSA-1		0.000 (0.613)	0.005 (0.507)	0.004 (0.519)
RSA-2	0.000 (0.613)		0.000 (0.669)	0.001 (0.600)
RSA-3	0.005 (0.507)	0.000 (0.699)		0.000 (0.727)
RSA-4	0.004 (0.519)	0.001 (0.600)	0.000 (0.727)	

Values are P<0.05 and r

There was a significant difference ($p \leq 0.05$) in average sprint time between county and club level players in RSA-2 (figure 6.6).

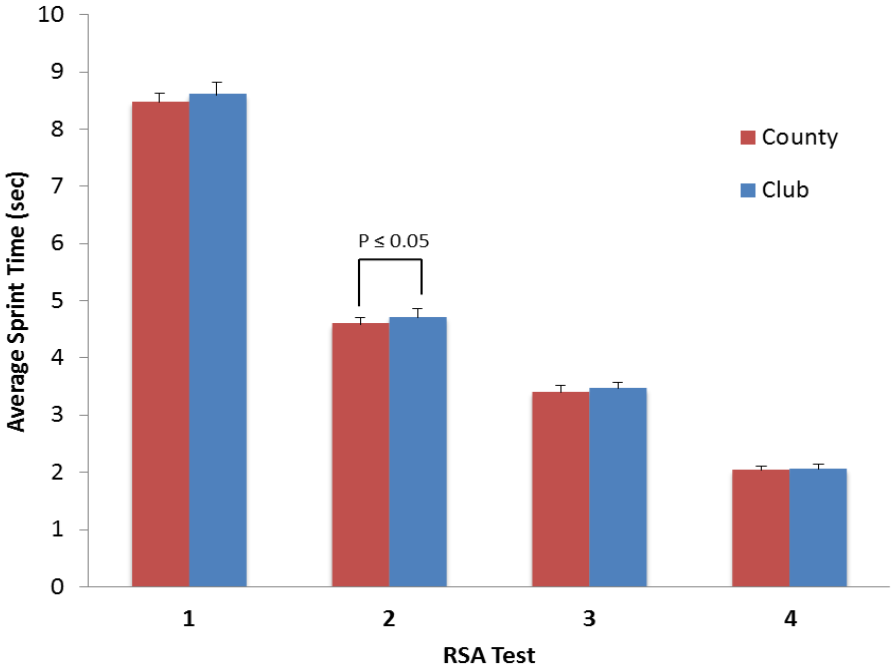

Figure 6.6: Average sprint time of club and county Gaelic football players in each RSA test.

Jump Performance

There was a significant inverse relation between the average sprint time in RSA-2 and performance in the CMJ and DJ (figure 6.7). (see appendix E, table 7.36, pg. 256)

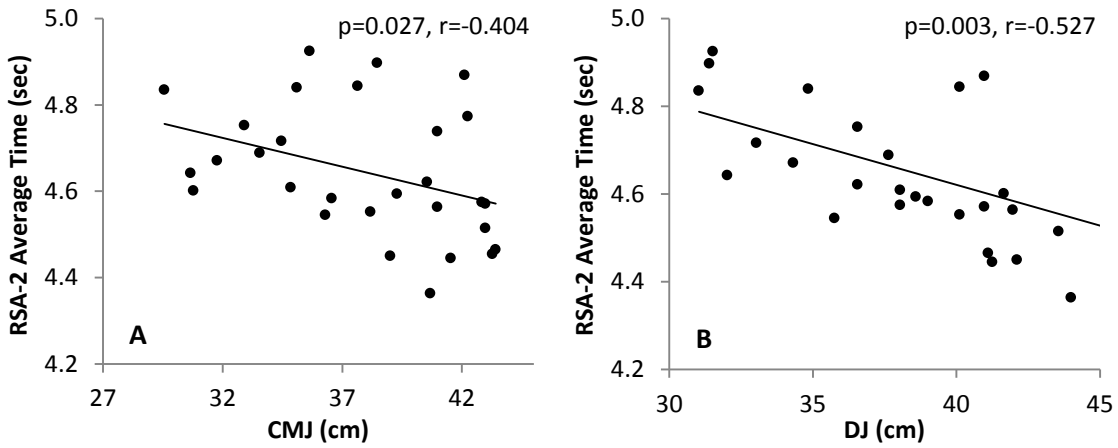

Figure 6.7 Relation between performance in the (A) CMJ and (B) DJ and average sprint time in RSA-2

Margaria-Kalamen Test

Time to complete the Margaria-Kalamen test was significantly related to the average sprint time for RSA-2 (figure 6.8). (see appendix E, table 7.36, pg. 256)

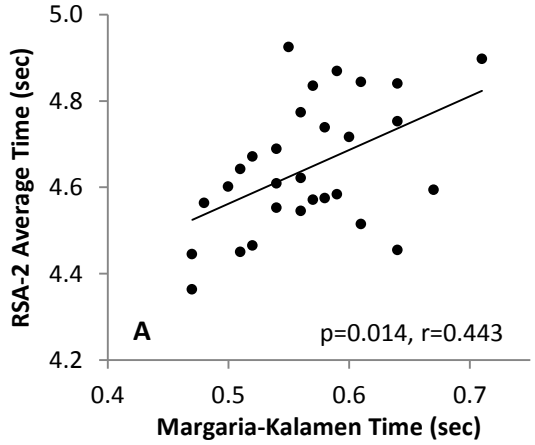

Figure 6.8 Relation between performance in the Margaria-Kalamen test and average sprint time for RSA-2.

Running Speed

There was a significant relation between the average time for RSA-2 and 5 m and 20 m running speed (figure 6.9). (see appendix E, table 7.36, pg. 256)

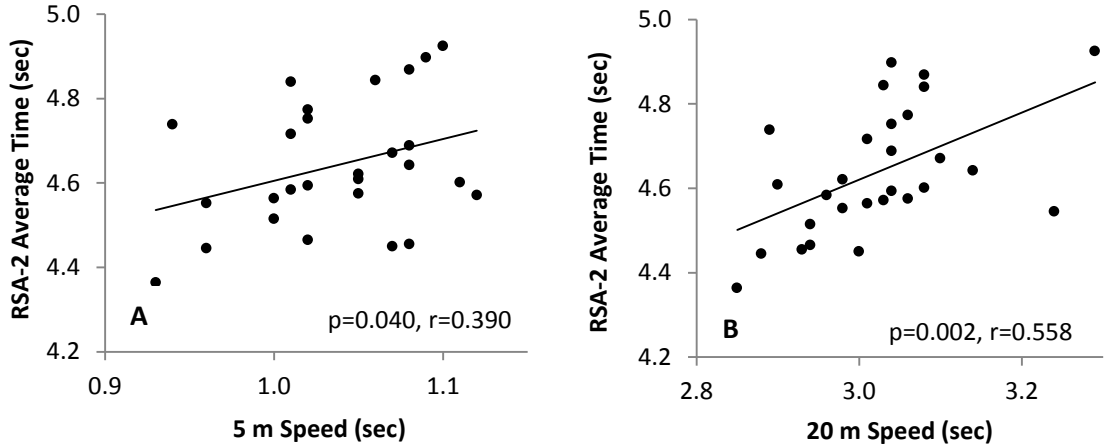

Figure 6.9 Relation between (A) 5 m running speed, (B) 20 m running speed and average sprint time for RSA-2

Blood Lactate Concentration

There was a significant relation between the average sprint time for RSA-2 and %HR at fixed blood concentration of 2.0 $mmol \cdot L^{-1}$ and the %HR at the fixed blood lactate concentration of 4.0 $mmol \cdot L^{-1}$ (figure 6.10). (see appendix E, table 7.34, pg. 254)

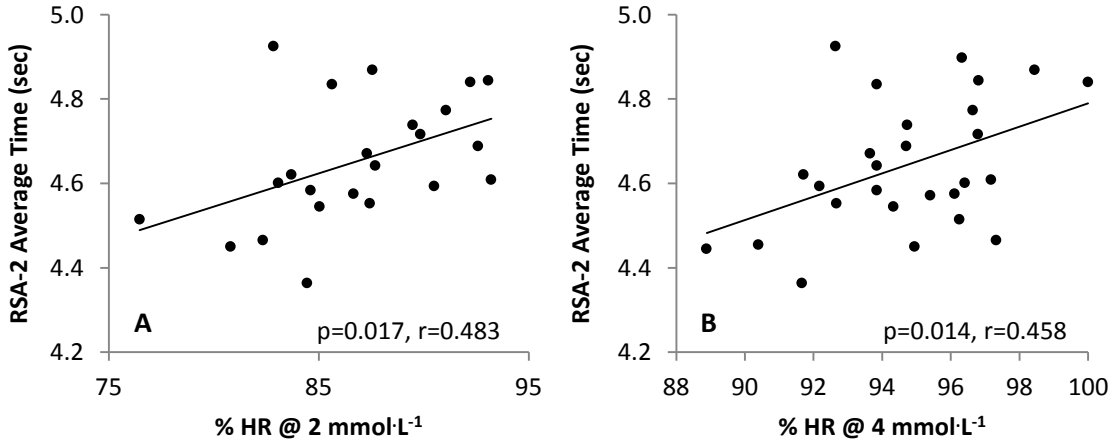

Figure 6.10 Relation between (A) %HR at the fixed blood concentration of 2.0 $mmol \cdot L^{-1}$ and (B) %HR at the fixed blood lactate concentration of 4.0 $mmol \cdot L^{-1}$ and average sprint time for RSA-2

Summary

County level players were significantly older and heavier than club level players. HRmax was significantly lower in the county than club level players. County level players were significantly ($p \leq 0.05$) faster than club level players over 20 m. MPO and PPO attained during the Wingate test, VJ height and quadriceps and hamstring peak torque in both dominant and non-dominant leg at $60°\cdot sec^{-1}$ and $180°\cdot sec^{-1}$were significantly greater in county than club level players. Quadriceps and hamstring peak torque in the dominant leg at $300°\cdot sec^{-1}$ was significantly greater in county than club level players.

Average sprint time in each RSA test was significantly related. There was a significant difference in average sprint time between county and club level players in RSA-2. CMJ and DJ were inversely related to average time in RSA-2. Margaria-Kalamen time, 5 m and 20 m running speed and %HR at 2.0 and 4.0 $mmol\cdot L^{-1}$ blood lactate concentration were significantly related to RSA-2 average time.

Chapter VII

Discussion

Overview

There is a growing body of evidence to indicate that LS-HIT has the potential to stimulate a number of physiological and metabolic adaptations similar to that associated with HVET. Previous studies have found that as little as 6 sessions of LS-HIT, totaling 15 min of exercise, improves both maximal and submaximal endurance performance [47,67]. Although LS-HIT is a research topic that is gaining popularity, the volume of research available on its benefits, especially in the trained athlete, is still very limited. To date, only one published study has compared the effects of both training methods in athletes involved in field based invasive team sports[9]. The ability to perform repeated high intensity sprints, termed repeated sprint ability (RSA), is an important physical component for optimal performance in Gaelic football. No information is currently available to coaches regarding RSA performance or its determinants among Gaelic football players. Large differences between RSA protocols and the repeated-sprint activity patterns of team sports may impact the validity and sport specific relevance of many of these protocols.

A series of studies were undertaken to i) investigate the effects of LS-HIT and HVET on anthropometric, physiological, metabolic and performance indices, ii) compare the construct validity of a number of RSA tests and iii) examine the relation between selected physical and performance factors and RSA performance among Gaelic football players.

Studies 1 & 2

In addition to supplying the energy requirements for low to moderate intensity activities during Gaelic football match play, a high $\dot{V}O_2$max also helps to ensure the provision of ATP for the replenishment of phosphagen stores following short-duration bouts of high-intensity activities [156], and decreases reliance on anaerobic glycolysis during periods of play that involve repeated high-intensity sprints, with relatively short recovery intervals.

The magnitude of the increase in $\dot{V}O_2$max resulting from exercise training depends on a number of factors, including hereditary fitness level, age, gender, the duration of the training program and the intensity, duration and frequency of the individual training sessions. The genetic factors establish the limit for each individual, but training can push endurance performance to the upper limits of these boundaries. Studies involving monozygous and dizygous twins have found that genetics may account for approximately 25-50% of the variance in $\dot{V}O_2$max values [157,158]. In general, an average improvement of between 5% and 25% can be anticipated for healthy young adults in response to HVET ranging from 2 - 25 weeks [53,159–161].

LS-HIT induces physiological and biochemical adaptations that have been associated with improvements in $\dot{V}O_2$max and are typically associated with high volume endurance training. These include an increase in muscle oxidative capacity, muscle buffering capacity and nuclear abundance of PGC-1α, a transcriptional co-activator which plays a crucial role in co-ordinating mitochondrial gene transcription [8,47,162]. In addition, it is likely that the potency of LS-HIT is derived in large part from the high level of motor unit activation. While ideal for developing aerobic capacity, HVET may lack the specificity required to develop

and/or maintain running speed and muscle power whereas LS-HIT may induce neuromuscular and endocrine adaptions that may have a positive effect [7].

Study 1 and 2 pre-training $\dot{V}O_2$max values in LS-HIT and HVET were almost identical to values previously reported for club level Gaelic football players [128,163,164]. A major advantage of LS-HIT over HVET is the lower total time requirement. In study 1, the total time requirement over the 2 weeks was almost 3 times greater in HVET than LS-HIT (300 min vs. 102 min) (figure 7.1). The total actual exercise time was 12.5 times greater for HVET (300 min vs. 24 min). Despite the large difference in both total time and exercise time, $\dot{V}O_2$max increased significantly compared to baseline in response to LS-HIT only. Endurance performance involving continuous running to volitional exhaustion at 110%v$\dot{V}O_2$max increased significantly in both LS-HIT and HVET. It is interesting to note that the increase in endurance exercise performance following HVET occurred despite the fact that the increase in $\dot{V}O_2$max (5.5%) did not reach statistical significance.

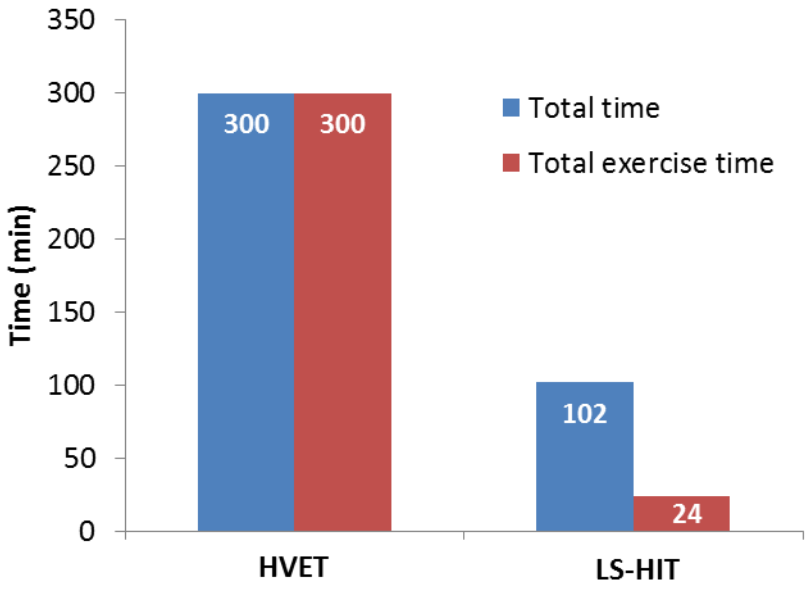

Figure 7.1: Total time and total exercise time during the 2 weeks of LS-HIT and HVET

In study 2, $\dot{V}O_2$max and endurance performance increased significantly following 6 weeks of LS-HIT and HVET. The total time requirement was 840 min in the HVET group and 374 min in the LS-HIT group. The total exercise time was 90% lower in LS-HIT than HVET (figure 7.2). The endurance test in study 2 involved alternating 1 min bouts of treadmill running between 75% and 100% $\dot{V}O_2$max and was more specific to the demands of Gaelic football than the continuous run to exhaustion at 110% v$\dot{V}O_2$max.

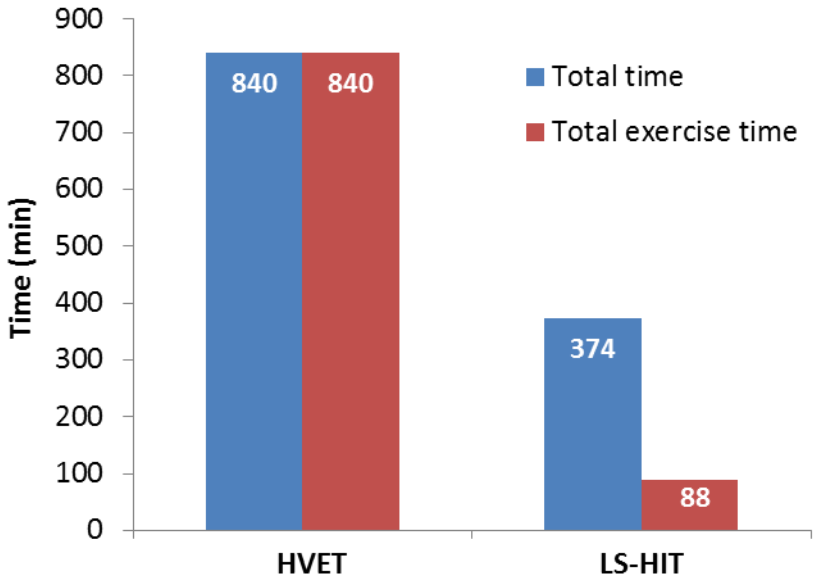

Figure 7.2: Total time and total exercise time during the 6 weeks of LS-HIT and HVET

HVET has traditionally been used to develop general fitness levels in club level players. This form of training is known to induce both central and peripheral adaptations that result in an increased $\dot{V}O_2$max [5,6]. The results from study 1 indicate that 6 sessions of HVET over a 2 week period may not be an adequate volume to significantly increase $\dot{V}O_2$max in club level players with a mean pre-training $\dot{V}O_2$max of 51.0 $ml \cdot kg^{-1} \cdot min^{-1}$. From a performance perspective the non-significant 5.5% increase in $\dot{V}O_2$max in HVET may still be a physiologically meaningful increase. The small sample size reduced the statistical power to find a significant increase in $\dot{V}O_2$max. However, even if the study had been powered to

detect a significant increase in $\dot{V}O_2$max in response to 2 weeks of HVET it would have involved 92% greater training volume and would therefore not have been as time efficient as LS-HIT. Compared to pre-training values (52.8 $ml \cdot kg^{-1} \cdot min^{-1}$), $\dot{V}O_2$max increased significantly following 18 sessions of HVET (study 2). Considering that the mean pre-training $\dot{V}O_2$max values were similar in study 1 and study 2, the results of study 2 would indicate that 3-6 weeks of HVET is required to significantly increase $\dot{V}O_2$max in club level Gaelic football players.

Maximal aerobic capacity and endurance exercise performance although related, are two distinct fitness attributes. Study 1 indicates that $\dot{V}O_2$max and endurance performance exhibit a different time course in their response to 6 sessions of HVET over a 2 week period. Endurance exercise performance but not $\dot{V}O_2$max increased significantly after 6 sessions of HVET. The improvement in endurance exercise performance would not have been identified, if as happens with most teams, only $\dot{V}O_2$max had been assessed. Coaches need to use an appropriate testing protocol when assessing $\dot{V}O_2$max or endurance exercise performance.

The increase in $\dot{V}O_2$max and endurance exercise performance was similar following 6 and 18 sessions of LS-HIT over 2 week and 6 weeks, respectively. Previous studies have also found similar increases in $\dot{V}O_2$max following 2 weeks [59,61,64,65,67] and 6-8 weeks of LS-HIT [9,10,12,75]. The major physiological and biochemical adaptations to LS-HIT may occur at an early stage of a training period and then plateau. Burgomaster *et al*., (2007) used changes in the protein content of COX4 as a marker of changes in muscle oxidative capacity, and

reported increases of approximately 35% after only 1 week of LS-HIT, without further increase after 6 weeks of training [62].

A similar trend involving early stage adaptation followed by a plateau phase has also been reported in some HVET studies. As little as 2 weeks of HVET was found to result in significant improvements in $\dot{V}O_2$max with no further increase evident after 3 weeks [99]. As little as 7-10 d of HVET resulted in significant increases in mitochondrial enzymes such as CS and HAD [110]. However, participants in both studies had a much greater training volume (120 min·session^{-1}) or frequency (12 sessions) over the 2 weeks compared to the participants in study 1.

Gaelic football players, especially club level players are amateurs and normally undertake collective training two times per week. Much of this time, particularly during the early part of the season is spent undertaking HVET to improve $\dot{V}O_2$max and submaximal endurance performance. The findings from study 1 and study 2 indicate that as little as 6 sessions of LS-HIT over a 2 week period is adequate to induce significant improvements in $\dot{V}O_2$max and endurance performance in club level players. The short duration of the LS-HIT sessions could potentially free-up considerable collective training time that could be used to develop technical and tactical aspects of play. It is possible that LS-HIT may be too intense at the beginning of the season and that HVET may be a more appropriate form of training at that time. However, a major disadvantage of HVET is the large time commitment involved. LS-HIT may be more appropriate when players attain a minimal level of aerobic fitness. Based on the findings in study 1 and study 2 the fitness threshold for LS-HIT could be set at a $\dot{V}O_2$max ≥ 50 ml·kg^{-1}·min^{-1}.

Peripheral adaptions including an increase in mitochondrial mass and associated increases in enzyme content and activity may account for some of the observed improvements in $\dot{V}O_2$max and aerobic performance in response to LS-HIT. Maximal activities of HK, CS, PFK, SDH and MDH have been found to significantly increase along with $\dot{V}O_2$max following 7 weeks of LS-HIT [71]. Similarly, a significant increase in PCr, LDH and PFK activity has been reported following as little as 2 weeks of repeated supra-maximal cycle exercise [82]. In a study comparing LS-HIT to HVET, maximal activities of COX and the protein content of COX subunits II and IV increased to a similar extent after 2 weeks of training [47].

Studies investigating the effect of LS-HIT on stroke volume and/or cardiac output, however findings are more limited and equivocal than changes in muscle oxidative capacity. Macpherson *et al*., (2011) examined the effect of 6 weeks of LS-HIT and HVET on $\dot{V}O_2$max, endurance performance, stroke volume and cardiac output in recreationally active men and women. There was no change in maximal cardiac output or stroke volume following 6 weeks of LS-HIT [75]. Although cardiac output increased by 9.5% in the HVET group, there was no significant difference between the two training groups. A-$\dot{V}O_2$ difference was significantly higher in LS-HIT than HVET after the training program. In contrast, Trilk *et al*., (2011) found that 4 weeks of LS-HIT increased stroke volume but had no effect on cardiac output and a-$\dot{V}O_2$ difference. This was surprising considering that the participants were sedentary overweight women with a very low level of fitness at the onset of exercise [73]. Consequently, it is still not clear if improved central function (SV) and/or peripheral adaptations (increased O_2 extraction) are responsible for the observed improvement in $\dot{V}O_2$max following LS-HIT.

With the exception of RE expressed as kcal·kg^{-1}·km^{-1} at 10 km·hr^{-1} in the HVET group (study 2) there was no change in RE expressed as ml·kg^{-1}·min^{-1}, ml·kg^{-1}·km^{-1}, or kcal·kg^{-1}·km^{-1} at 8, 9, 10, or 11 km·hr^{-1} following LS-HIT or HVET is study 1 or study 2. To date only one study has compared the effect of LS-HIT and HVET on RE [74]. Despite a difference in training volume of 74%, 6 weeks of LS-HIT and HVET in trained soccer players resulted in similar improvements in RE. Another recent study, reported substantial increases (5.7 - 7.6%) in RE at 11, 13, 14.5 and 16 km·hr^{-1} following 4 weeks of LS-HIT in highly trained endurance runners [68]. The equivocal evidence on RE may be related in part to genetic differences in the adaptive response to training, or the fact that participants in the above studies had higher aerobic capacity [68,74].

v$\dot{V}O_2$max is a composite variable that combines $\dot{V}O_2$max and RE into a single factor. In study 1, v$\dot{V}O_2$max remained unchanged following LS-HIT despite the significant increase in $\dot{V}O_2$max. In contrast, the significant increase in v$\dot{V}O_2$max following 6 weeks of LS-HIT and HVET coincided with increases in $\dot{V}O_2$max in both groups. Several studies have reported similar improvements in v$\dot{V}O_2$max following a HVET period of 4 to 6 weeks [91,104]. Although v$\dot{V}O_2$max has been shown to be an important determinant of endurance exercise performance [91], to our knowledge there are no available studies which have investigated the effects of LS-HIT or compared the effects of both LS-HIT and HVET on v$\dot{V}O_2$max performance.

Treadmill velocity and %$\dot{V}O_2$max at 4.0 mmol·L^{-1} increased significantly after 2 weeks of HVET, only. Treadmill velocity also increased following 6 weeks at HVET. Previous studies involving 2 weeks of HVET have also found lower blood lactate levels at the same absolute

workloads after than before training [110]. Exercise above the LT is associated with a nonlinear increase in metabolic and respiratory stress and with more rapid fatigue, either through the effects of metabolic acidosis on contractile function or through an accelerated depletion of muscle glycogen [108]. In previously sedentary individuals, endurance training at an exercise intensity close to the LT has been found to be an adequate training stimulus to increase the LT. Trained athletes need to exercise at a higher exercise intensity to increase LT [111]. The HVET group trained at a treadmill velocity (10.3 $km \cdot h^{-1}$) above the LT (9.8 $km \cdot h^{-1}$). The results in study 1 are consistent with previous studies that found a period of HVET induced improvements in velocity at LT [53,74,165]. Increased capillary density following endurance training, may increase the exchange area and decrease the distance between the site of lactate production and the capillary wall, leading to improvement in lactate exchange ability [49].

The fact that the treadmill velocity and relative HR and $\dot{V}O_2$ at LT and fixed blood lactate concentrations did not increase following 2 or 6 weeks of LS-HIT was surprising considering that LS-HIT has been found to be an effective strategy to alter lactate metabolism [67]. Indeed, a number of blood lactate parameters decreased in response to 6 weeks of LS-HIT. Previous LS-HIT studies have reported a decrease in lactate accumulation following 6 sessions of LS-HIT over 2 weeks [59,67].

The rate of lactate removal is directly related to its concentration in muscle or blood [112]. Increasing blood lactate levels should therefore improve lactate removal. The circulating levels of blood lactate following each LS-HIT session in study 1 ranged from 11-14 $mmol \cdot L^{-1}$. This compares to 2-6 $mmol \cdot L^{-1}$ following HVET. It is possible that the stimulus

experienced during LS-HIT may have been too short and that a minimum duration of exercise may be required to induce a significant decrease in blood lactate concentration. Although LS-HIT has been reported to elicit increases in both MCT1 and MCT4 content in human muscle [62], little is known about the stimulus for such muscle adaptations. Muscle fibre composition has been shown to influence the adaptive response of MCT1 to exercise training in rodents [166], and this may explain, in part, the variability associated with the human adaptive response to intense training.

Local production of H^+ and/or lactate within skeletal muscle during exercise may be an important stimulus for adaptations of the muscle pH-regulating systems. Despite a decrease in muscle buffering capacity and no change in the relative abundance of MCTs, Bishop et al., (2008) reported an increase in LT following a period of interval training [167]. Therefore, increases in muscle buffering capacity and MCT abundance are not concomitant to the degree of muscle lactate and H^+ accumulation during training. There is a need to better understand the complex intramuscular signalling pathways that are responsible for training-induced changes in the pH-regulating systems of skeletal muscle in order to design exercise interventions to appropriately modify these characteristics.

Although the primary aim of LS-HIT is to elicit adaptations in aerobic endurance performance, it may also induce neuromuscular and endocrine adaptions that have a positive effect on running speed and power, both important fitness characteristics for optimal performance in Gaelic football. It was hypothesised that running speed and measures of lower body power would decrease significantly following 6 weeks of HVET and would be maintained or increased in response following 6 weeks of LS-HIT. Time to

complete a 20 m sprint increased significantly and VJ performance decreased significantly in the HVET following the 6 week training program. In contrast, there was no significant change in 5 m speed, 20 m speed, VJ or CMJ performance in the LS-HIT group.

Considering that both running speed and power are essential fitness components for players in many invasion field games, it is surprising that relatively few published studies have simultaneously evaluated the effect of LS-HIT and HVET on indices of running speed and jump performance. There are however, studies which have investigated longer duration interval training on running speed and jump performance in soccer players. Helgerud *et al*., (2001) found no significant change in VJ performance, 10 m and 40 m running speed, in response to an 8 week interval training program in 19 elite junior soccer players [34]. In contrast, McMillan *et al*., (2005) found a significant improvement in CMJ performance in professional youth soccer players following 10 weeks of interval training [84]. Sperlich *et al*., (2011) found a significant improvement in 20, 30 and 40 m sprint performance in adolescent soccer players following 5 weeks of both interval training and HVET [154].

The increase in MPO following LS-HIT is similar to previous studies that have reported average improvements of 6-8% in MPO and PPO during 30-sec Wingate cycling tests in active college age students [61,64,66,67,71]. One previous study compared the effect of LS-HIT vs. HVET on anaerobic power [8]. Similar to the findings in study 2, PPO increased following 6 weeks of LS-HIT and HVET. In contrast to study 2, MPO was significantly increased following LS-HIT only.

The maintenance of running speed, jump height and power in response to LS-HIT may have been due, in part, to the fact that both fast twitch type IIa and type IIX muscle fibres were recruited to supply the high force demands during training. Muscle fibre recruitment is determined by force requirements, with the slow muscle fibres being activated for low force contractions and increasingly fast muscle fibres being additionally activated to supply greater force demands.

It is likely that HVET involved recruitment of primarily slow twitch and fast twitch IIa motor units. Since type IIa fast twitch fibres display considerable plasticity in relation to their biochemical and morphological properties when exposed to different functional demands it is possible that HVET induced remodelling resulting in these fibres taking on many of the characteristics of slow twitch fibres. Although beneficial for improving endurance exercise performance, these adaptations do not provide the desired loading for type IIX fibres to maintain speed and power. Considering that HVET is commonly used in the preparation of players for many invasion field games, it is interesting that relatively few published studies have simultaneously evaluated the effect of this form of training on $\dot{V}O_2max$, running speed and vertical jump performance in players involved in invasion team sports.

Study 3

The ability to perform repeated sprints at high intensity is termed repeated sprint ability (RSA). It is an important fitness component for Gaelic football. [2]. Different exercise protocols have been developed to measure RSA in a number of invasive field-based team sports, particularly soccer [39,42,46,133,141]. These protocols differ in terms of exercise mode, sprint duration, number of sprint repetitions and type of recovery in order to match the work-rest pattern during match play. Study 3 was the first to evaluate the construct validity and determinant of RSA tests among Gaelic football players.

Despite the differences in sprint duration and recovery time, the average sprint time for each RSA test was significantly correlated with each other. These results are not surprising considering that each test was designed to cover a set distance of 240 m and ensure an identical work to rest ratio. The RSA protocol design was based on an understanding of Gaelic football and previous research studies. A sprint distance (10 – 40 m), number of intervals (6 – 24) and recovery duration (10 – 30 sec) was chosen to induce a modest degree of sprint decrement without altering sprint mechanics excessively.

Construct validity refers to the properties of the test in allowing it to discriminate between different groups of people performing the same test. Study 3 compared the performance across 4 different RSA tests in club and county level Gaelic football players to determine construct validity. Only RSA-2 test results were significantly different between club and county level players and therefore met the criteria for construct validity. The test involved 8 maximal 30 m sprints on a 22.5 sec cycle. The average sprint time ranged from 4-

5 sec with a 17-18 sec recovery period. This resulted in work to rest ratio of 1:4. The mean blood lactate levels at the end of the test were similar in club (7.7 $mmol \cdot L^{-1}$) and county (7.5 $mmol \cdot L^{-1}$) players.

Bivariate regression analysis identified CMJ, DJ, Margaria-Kalamen time, 5 m and 20 m running speed and %HRmax at 2.0 and 4.0 $mmol \cdot L^{-1}$ blood lactate concentration as independent predictors of RSA-2 performance. As this is the first study to evaluate the construct validity and determinants of RSA tests among club and county level Gaelic football, the findings need to be replicated in a larger sample before the test can recommended for use among Gaelic football teams.

Since RSA tests are a measure of an individual's ability to perform repeated sprints at high intensity with short recovery periods and uses both the phosphagen system and anaerobic glycolysis [39] it is perhaps not surprising that the predictor variables identified in the bivariate regression analysis were related to muscle speed and power, and anaerobic capacity. Others using a similar protocol also found a significant correlation between 5 m and 20 m speed and RSA performance [168]. It has been suggested that the relation between maximal speed and RSA performance reflects the theory that in a group of homogenous field based invasive team sport athletes, the ability to produce a high sprint speed during a single effort will positively influence RSA [134].

While previous studies have extensively examined the relation between $\dot{V}O_2max$ and RSA performance, only two studies have investigated the relation between jump performance and RSA, reporting an inverse relation between counter-movement and vertical jump height and total sprint time in a RSA test [135,142]. It is reasonable to speculate

that the relation between jump performance and RSA is primarily based upon the association between jump height and short sprint performance. Jump height has been found to be significantly correlated with maximal acceleration during sprint running [169]. A similar contribution of the energy systems is also likely to be responsible for the relation between jump height and RSA performance. Similar to running speed, jump height and RSA performance is directly related to the rate of phosphocreatine metabolism and phosphocreatine depletion [18,112].

There was no relation between Wingate performance and RSA-2. Keir *et al*., (2012) also found no relation between performance in the Wingate test and RSA test performance in soccer players [140]. This finding is surprising considering that both tests measure the same anaerobic capabilities. However, previous studies have reported inverse relation between MPO and total time for various RSA tests in field based team sports [46,137,139,141] The modest relation between %HR at the fixed blood lactate concentrations of 2.0 $mmol \cdot L^{-1}$ (r = 0.48) and 4.0 (r = 0.46) $mmol \cdot L^{-1}$ and average sprint time for RSA-2 is evidence of a link between RSA and anaerobic metabolism.

Research is equivocal, in relation to the role of $\dot{V}O_2max$ in RSA performance. In agreement with others studies we found no relation between $\dot{V}O_2max$ and RSA performance [36,43]. This is surprising considering that PCr restoration occurs in the mitochondria in the presence of molecular O_2 [21,22]. A high $\dot{V}O_2max$ should allow for a greater power maintenance during high intensity exercise and a decrease demand on anaerobic glycolysis. The rate of phosphocreatine metabolism has previously been reported as a determinant

factor in RSA and running speed performance [112]. Likewise, the rate of phosphocreatine depletion has been described as a limiting factor in running speed and RSA performance [18].

Using protocols similar to those used in study 3, a number of studies have found an inverse relation between $\dot{V}O_2$max and RSA mean sprint time, total time and fatigue index in invasive team based field sports [39–42,45]. In addition, junior level soccer players with a higher $\dot{V}O_2$max, have been found to have a greater number of ball touches during a game, made a greater number of sprints and covered a larger distance than players with a lower $\dot{V}O_2$max [34].

Conclusion

LS-HIT is a more time efficient training method than HVET for improving aerobic capacity and maintaining running speed and power in club level Gaelic football players. $\dot{V}O_2$max and endurance performance exhibit a different time course in their response to a short HVET program. Compared to pre-training, endurance exercise performance but not $\dot{V}O_2$max increased significantly after 6 sessions of HVET. However, HVET consisting of 18 sessions over a 6 week period significantly increases both $\dot{V}O_2$max and endurance performance. Despite a much lower training volume, similar increases in $\dot{V}O_2$max and endurance exercise performance can be found following 6 and 18 sessions of LS-HIT over a 2 and 6 week period, respectively. Six weeks of LS-HIT was found to maintain running speed and lower body power. In contrast, running speed and VJ performance, a measure of lower body power decreased significantly following HVET.

The ability to perform repeated sprints has a greater relation to running speed and power and blood lactate levels than indices of endurance performance. A test involving 8 x 30 m sprints on a 22.5 sec cycle can discriminate RSA performance between players of different competitive levels and supports the construct validity of this test in Gaelic football. However, a definitive confirmation of the validity of this test requires further investigation.

Study Limitations

- As only one previous study has investigated a period of LS-HIT vs. HVET on an invasive field based team sport, this study was designed to be a pilot study. However the small sample size in study 1 may have influenced statistical significance
- Since study 1 and 2 were undertaken during the competitive season it was not possible to recruit a control group
- Although heart rate (telemetry) and velocity data (GPS) were measured during each training session in study 1, the data could not be analyzed due to technical issues
- No information is available regarding the cellular or molecular mechanism underpinning the changes in fitness and performance in study 1 and 2

Future Direction

- Examine the most appropriate work to rest ratio to use during LS-HIT in order to simultaneously improve or maintain aerobic capacity and indices of running speed and power in Gaelic football players

- Compare the effects of LS-HIT and HVET on aerobic capacity and indices of running speed and power among county level senior Gaelic football players
- Compare and examine the cellular and molecular mechanisms underpinning the response to LS-HIT and HVET
- Examine in greater detail the effect of LS-HIT and HVET on monocarboxylate transporters in Gaelic football players
- Further investigate the validity and reliability of RSA-2 among Gaelic football players

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Appendices

Appendix A

Dublin City University
RESEARCH ETHICS COMMITTEE

APPLICATION FOR APPROVAL OF A PROJECT INVOLVING **HUMAN PARTICIPANTS**

Application No. *(office use only)* DCUREC/2010/ ☐☐☐

Period of Approval *(office use only)* ……/……/…… to ……/……/….

This application form is to be used by researchers seeking ethics approval for individual projects and studies. The **signed original and an electronic copy** of your completed application must be submitted to the DCU Research Ethics Committee.

NB - The hard copy must be signed by the PI. The electronic copy should consist of one file only, which incorporates all supplementary documentation. The completed application must be proofread and spellchecked before submission to the REC. All sections of the application form should be completed. Applications which do not adhere to these requirements will not be accepted for review and will be returned directly to the applicant.

Applications must be completed on the form; answers in the form of attachments will not be accepted, except where indicated. No handwritten applications will be accepted. **Research must not commence until written approval has been received from the Research Ethics Committee.**

PROJECT TITLE	**Adaptations in response to low volume short duration high-intensity interval training and repeated sprint ability in Gaelic football players**
PRINCIPAL INVESTIGATOR(S)	**Prof. Niall Moyna**

Please confirm that **all** supplementary information is included in your application (in both signed original and electronic copy). If questionnaire or interview questions are submitted in

draft form, a copy of the final documentation must be submitted for final approval when available.

	INCLUDED		NOT APPLICABLE
Bibliography	☒		☐
Recruitment advertisement	☒		☐
Plain language statement/Information Statement	☒		☐
Informed Consent form	☒		☐
Evidence of external approvals related to the research	☐		☒
Questionnaire	☐ draft	☐ final	☒
Interview Schedule	☐ draft	☐ final	☒
Debriefing material	☐		☒
Other	☐		☒

Please note:

1. Any amendments to the original approved proposal must receive prior REC approval.

2. As a condition of approval investigators are required to document and report immediately to the Secretary of the Research Ethics Committee any adverse events, any issues which might negatively impact on the conduct of the research and/or any complaint from a participant relating to their participation in the study

Please submit the **signed original, plus the electronic copy** of your completed application to: Ms. Fiona Brennan, Research Officer, Office of the Vice-President for Research (fiona.brennan@dcu.ie, Ph. 01-7007816)

Guidelines to applicants

1.1 PRINCIPAL INVESTIGATOR(S): *The named Principal Investigator is the person with primary responsibility for the research project. Doctoral researchers and Research Masters or their supervisors may be listed as Principal Investigators, depending on the conventions of the discipline and on the individual case. It should be made clear, in subsequent sections of this application, who is carrying out the research procedures. In the case of Taught Masters and undergraduate student projects the supervisors are Principal Investigators.*

2.0 PROJECT OUTLINE: *Provide a brief outline of the project, aims, methods, duration, funding, profile of participants and proposed interaction with them. This description must be in everyday language that is free from jargon. Please explain any technical terms or discipline-specific phrases.*

2.1 LAY DESCRIPTION: *Provide a brief outline of the project, including what participants will be required to do. This description must be in everyday language which is free from jargon. Please explain any technical terms or discipline-specific phrases. (No more than 300 words).*

2.2 AIMS OF AND JUSTIFICATION FOR THE RESEARCH: *State the aims and significance of the project (approx. 400 words). Where relevant, state the specific hypothesis to be tested. Also please provide a brief description of current research, a justification as to why this research should proceed and an explanation of any expected benefits to the community.* ***NB – all references cited should be listed in an attached bibliography.***

2.3 PROPOSED METHOD: *Provide an outline of the proposed method, including details of data collection techniques, tasks participants will be asked to do, the estimated time commitment involved, and how data will be analysed. If the project includes any procedure which is beyond already established and accepted techniques please include a description of it. (No more than 400 words.)*

2.4 PARTICIPANT PROFILE: *Provide number, age range and source of participants. Please provide a justification of your proposed sample size. Please provide a justification for selecting a specific gender.*

2.5 MEANS BY WHICH PARTICIPANTS ARE TO BE RECRUITED: *Please provide specific details as to how you will be recruiting participants. How will people be told you are doing this research? How will they be approached and asked if they are willing to participate? If you are mailing to or phoning people, please explain how you have obtained their names and contact details. This information will need to be included in the plain language statement. If a recruitment advertisement is to be used, please ensure you attach a copy to this application.*

3.3 POTENTIAL RISKS TO PARTICIPANTS AND RISK MANAGEMENT PROCEDURES*: Identify, as far as possible, all potential risks to participants (physical, psychological, social, legal or economic etc.), associated with the proposed research. Please explain what risk management procedures will be put in place.*

3.6 ADVERSE/UNEXPECTED OUTCOMES: *Please describe what measures you have in place in the event that there are any unexpected outcomes or adverse effects to participants arising from involvement in the project.*

3.7 MONITORING: *Please explain how you propose to monitor the conduct of the project (especially where several people are involved in recruiting or interviewing, administering procedures) to ensure that it conforms with the procedures set out in this application. In the case of student projects please give details of how the supervisor(s) will monitor the conduct of the project.*

3.8 SUPPORT FOR PARTICIPANTS: *Depending on risks to participants you may need to consider having additional support for participants during/after the study. Consider whether your project would require additional support, e.g., external counselling available to participants. Please advise what support will be available.*

4.0 INVESTIGATORS' QUALIFICATIONS, EXPERIENCE AND SKILLS: *List the academic qualifications and outline the experience and skills relevant to this project that the researchers and any supporting staff have in carrying out the research and in dealing with any emergencies, unexpected outcomes, or contingencies that may arise.*

5.2 HOW WILL THE ANONYMITY OF THE PARTICIPANTS BE RESPECTED? *Please bear in mind that where the sample size is very small, it may be impossible to guarantee anonymity/confidentiality of participant identity. Participants involved in such projects need to be advised of this limitation.*

5.3 LEGAL LIMITATIONS TO DATA CONFIDENTIALITY: *Participants need to be aware that confidentiality of information provided can only be protected within the limitations of the law - i.e., it is possible for data to be subject to subpoena, freedom of information claim or mandated reporting by some professions. Depending on the research proposal you may need to specifically state these limitations.*

6.0 DATA/SAMPLE STORAGE, SECURITY AND DISPOSAL: *For the purpose of this section, "Data" includes that in a raw or processed state (e.g. interview audiotape, transcript or analysis). "Samples" include body fluids or tissue samples.*

8.0 PLAIN LANGUAGE STATEMENT: *Written information in plain language that you will be providing to participants, outlining the phases and nature of their involvement in the project and inviting their participation. Please note that the language used must reflect the participant age group and corresponding comprehension level.*

9.0 INFORMED CONSENT FORM: *This is a very important document that should be addressed by participants to researchers, requiring participants to indicate their consent to specific statements, and give their signature.*

FOR FURTHER INFORMATION AND NOTES ON THE DEVELOPMENT OF PLAIN LANGUAGE STATEMENTS AND INFORMED CONSENT FORMS, PLEASE CONSULT THE DCU REC WEBSITE: WWW.DCU.IE/RESEARCH/ETHICS

1. ADMINISTRATIVE DETAILS

THIS PROJECT IS: *(tick as many as apply)*

- ☐ Research Project
- ☐ Practical Class
- ☐ Funded Consultancy
- ☐ Clinical Trial
- ☒ Student Research Project *(please give details)*
  - ☒ Research Masters
  - ☐ Taught Masters
  - ☒ PhD
  - ☒☐ Undergraduate
- ☐ Other - *Please Describe:*

Project Start Date: **September 2010**

Project End date: **December 2011**

1.1 INVESTIGATOR CONTACT DETAILS

PRINCIPAL INVESTIGATOR(S):

TITLE	*SURNAME*	*FIRST NAME*	*PHONE*	*FAX*	*EMAIL*
Prof	Moyna	Niall	7008802	7008888	niall.moyna@dcu.ie

OTHER INVESTIGATORS:

TITLE	*SURNAME*	*FIRST NAME*	*PHONE*	*FAX*	*EMAIL*
Dr.	McCaffrey	Noel	0872797597	7008888	noel.mccaffrey@dcu.ie
Dr.	Susta	Davide		7008888	davide.susta@dcu.ie
Mr.	Kelly	David	0851618207	7008888	david.kelly59@mail.dcu.ie
Ms	Tobin	Crionna	0860705130	7008888	crionna.tobin9@mail.dcu.ie
Mr.	Cregg	Cathal	0877633021	7008888	cathal.cregg2@mail.dcu.ie

FACULTY/DEPARTMENT/SCHOOL/ CENTRE: School of Health and Human Performance

1.2 WILL THE RESEARCH BE UNDERTAKEN ON-SITE AT DUBLIN CITY UNIVERSITY?

☒ YES ☐ NO

1.3 IS THIS PROTOCOL BEING SUBMITTED TO ANOTHER ETHICS COMMITTEE, OR HAS IT BEEN PREVIOUSLY SUBMITTED TO AN ETHICS COMMITTEE?*)*

☐ YES ☒ NO

DECLARATION BY INVESTIGATORS

The information contained herein is, to the best of my knowledge and belief, accurate. I have read the University's current research ethics guidelines, and accept responsibility for the conduct of the procedures set out in the attached application in accordance with the guidelines, the University's policy on Conflict of Interest and any other condition laid down by the Dublin City University Research Ethics Committee or its Sub-Committees. I have

attempted to identify all risks related to the research that may arise in conducting this research and acknowledge my obligations and the rights of the participants.

If there any affiliation or financial interest for researcher(s) in this research or its outcomes or any other circumstances which might represent a perceived, potential or actual conflict of interest this should be declared in accordance with Dublin City University policy on Conflicts of Interest.

I and my co-investigators or supporting staff have the appropriate qualifications, experience and facilities to conduct the research set out in the attached application and to deal with any emergencies and contingencies related to the research that may arise.
Signature(s):

Principal investigator(s): Niall Moyna

Print name(s) in block letters: *Niall Moyna*

Date: *3/9/2010*

2. PROJECT OUTLINE

2.1 LAY DESCRIPTION

Endurance training predominates in intermittent type sports such as Gaelic games in which aerobic fitness is essential (1). Recent studies have shown that brief repeated sessions of 'all-out' high intensity or sprint type interval training (SIT) induce changes in skeletal muscle metabolism that resemble endurance type (ET) training (3;4). Most of the studies which confirm these findings are based on untrained subjects who trained on a stationary bike in a laboratory (4, 5). The purpose of this study is to compare the effect of 6 weeks (3 d/week) of SIT with 6 weeks (3 d/week) of ET on measures of fitness and performance in trained and untrained Gaelic football players. The total training time will be approximately 11 h 33 min and 13.4 min for the ET and SIT respectively. A total of 20 trained (T) and 20 untrained (U) subjects will be randomly assigned to an endurance training group (ET) or a high intensity interval training group (HIIT). Before and after the 6 week training program the subjects will have a muscle biopsy and blood sample taken and will undergo a number of tests to measure body composition, speed, power, agility, lactate threshold, aerobic capacity, anaerobic capacity, and endurance performance. Blood lactate levels will be measured before and immediately after the third weekly training session. The results of the study may have significant implications for training guidelines for Gaelic football.

2.2 AIMS OF AND JUSTIFICATION FOR THE RESEARCH

Aims of the Research:

To compare the effect of 6 weeks of SIT and ET on speed, power, agility, maximal aerobic capacity, anaerobic capacity, intermittent endurance capacity, muscle oxidative capacity and selected measures of whole body and skeletal muscle substrate metabolism in trained and untrained Gaelic football players. The total training will be 11 h 33 min and 13.4 min for the SIT and ET group respectively.

Justification:

Endurance training induces numerous physiological and metabolic adaptations that improve endurance capacity (2). Although this type of training offers significant training adaptations it requires a large time commitment. Recent studies have shown that brief repeated sessions of 'all-out' high intensity or sprint type interval training (SIT) induces changes in skeletal muscle energy metabolism that resemble endurance type training (3;4). Gibala et al (4) found similar molecular and cellular adaptations in skeletal muscle following 6 sessions of SIT or endurance training (ET) performed over 2 weeks despite the fact that the total training time commitment and exercise volume were significantly lower in SIT groups.

In a more recent study (5), active but untrained subjects performed a constant-load cycling challenge (1 h at 65% of $\dot{V}O_2max$) before and after 6 weeks of SIT or ET. The SIT group trained 3 d/week and each session consisted of four to six repeats of a 30 s 'all out' Wingate Test (mean power output~500W) with 4.5 min recovery between repeats, 3 days per week. The ET group trained 5 d/week and each session consisted of 40 -60 min of continuous cycling at a workload that elicited 65% $\dot{V}O2max$ (mean power output 150W). Despite the large time commitment differences, both

protocols induced similar increases ($p<0.05$) in mitochondrial markers for skeletal muscle CHO (pyruvate dehydrogenase E1α protein content) and lipid oxidation (3-hydroxyacyl CoA dehydrogenase activity) and protein content of peroxisome proliferator-activated receptor-γ coactivator-1α. Glycogen and phosphocreatine utilization during exercise were reduced after training, and calculated rates of whole-body CHO and lipid oxidation were decreased and increased, respectively, with no differences between groups (all main effects, $P <0.05$). Given the markedly lower training volume in the SIT group, these data suggest that high-intensity interval training is a time-efficient strategy to increase skeletal muscle oxidative capacity and induce specific metabolic adaptations during exercise that are comparable to traditional ET. The majority of training studies (4-7) have used relatively untrained individuals and involved cycling as the mode of exercise.

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2. Gollnick PD AR (1973) Effect of training on enzyme activity and fiber type composition of human skeletal muscle. J. Appl.Physiol. 107-111
3. Henriksson J, Reitman JS (1976) Qualitative measures of enzyme activities in type I and type II muscle fibers of man after training. Acta Physiologica Scandinavica 97: 392-397
4. Gibala MJ, Little PJ (2006) Short-term sprint interval versus traditional endurance training: similar initial adaptations in human skeletal muscle and exercise performance. Journal of Physiology 901-911
5. Burgomaster KA, Howarth KR, Gibala MJ (2008) Similar metabolic adaptations during exercise after low volume sprint interval and traditional endurance training in humans. Journal of Physiology 586: 151-160
6. Burgomaster KA, Heigenhauser G J F, Gibala MJ (2006) Effect of short-term sprint interval training on human skeletal muscle carbohydrate metabolism during exercise and time-trial performance. J Appl.Physiol. 2041-2047
7. Burgomaster KA, Hughes SC, Heigenhauser G J F, Gibala MJ (2005) Six sessions of sprint interval training increases muscle oxidative potential and cycle endurance capacity in humans. J Appl.Physiol. 1985-1990

2.3 PROPOSED METHOD

Study Overview

The study will take place in the School of Health and Human Performance at DCU and the DCU Sports Grounds. Subjects will undertake 6 weeks (3d/week) of endurance training (ET) or high intensity interval training (HIT). Subjects will visit DCU on 3 separate occasions (1 screening and 2 study visits) before the study and on 2 separate occasions at the end of the study. They will have a muscle biopsy and blood sample taken and will undergo a number of tests to measure body composition, speed, power, agility, lactate threshold, aerobic capacity, anaerobic capacity, and endurance performance. Heart rate will be recorded during each training session and blood lactate levels will be measured before and immediately after the third weekly training session. Each visit will be separated by at least 24 h.

Screening Visit

The screening visit will last approximately 1 h. Subjects will undergo a brief medical examination and perform a Bangsbo Yo Yo Intermittent Recovery test.

Study Visits

Visit 1 - The visit will last approximately 2 h and will be used to measure body composition, muscle power, speed, agility, lactate threshold and maximal aerobic capacity ($\dot{V}O_2max$).

Visit 2 – A blood and a muscle biopsy sample will be taken after which the subject will undertake a 30 sec Wingate test.

Endurance Training Program

Subjects will run on a treadmill at 70-80% $\dot{V}O_2max$. Subjects will run for 30 min during week 1, and the duration will be gradually increased to 40 min by the end of week 2 and remain at 40 min for the remaining training sessions.

Sprint-Interval Training Protocol

Subjects will sprint 100 m followed by a 50 metre recovery run. The sprint and recovery run must be completed in 40 sec. This will be repeated 3 more times followed by a 3 min recovery period (1 set). Subjects will complete 3 sets during the first training session and the number of sets will be increased to 5 during the training study.

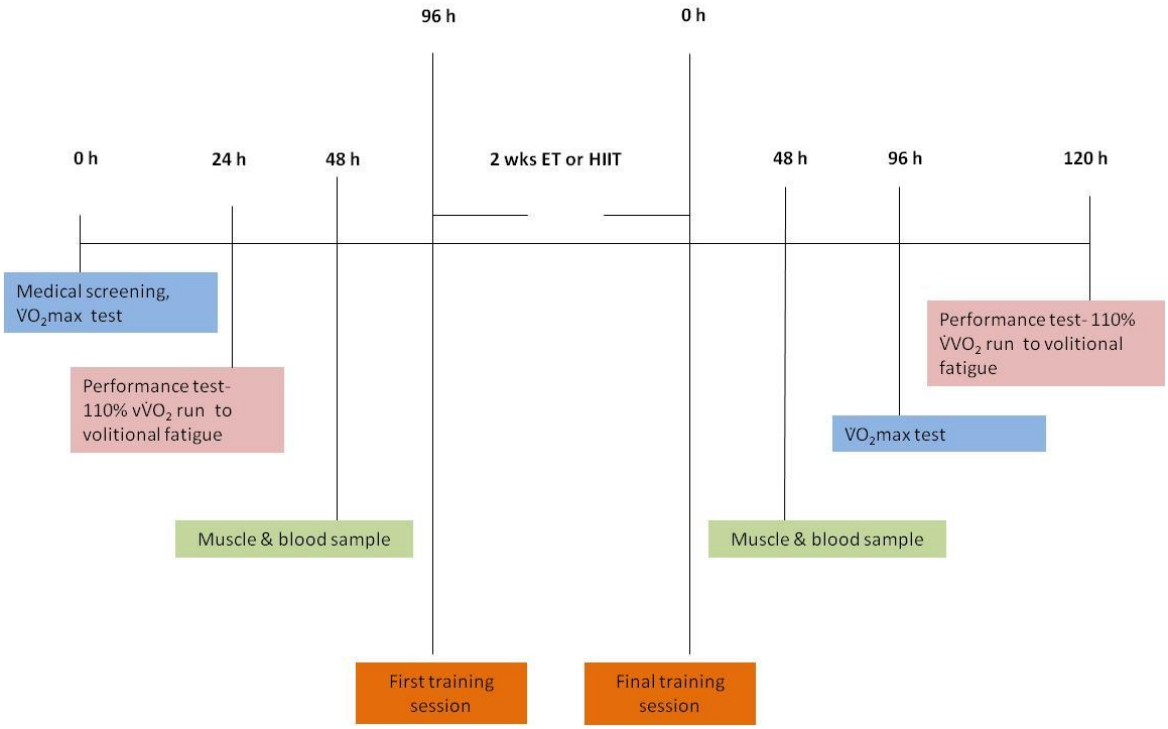

Figure : Study Design

Laboratory Procedures:

Maximal Aerobic Capacity Assessment/ Lactate Threshold: Maximal aerobic capacity will be determined on a treadmill (Woodway ELG 55, Waukesha, WI) using a ramp protocol. Subjects will warm-up at 8 km/h for 3 min at 1% gradient. Following the warm-up, the speed will be increased 1 km/h every 3 min. At baseline and at the end of each 3 min stage a blood sample will be taken to determine blood lactate concentration. When lactate concentrations reach 4 mmol the speed will remain constant and the gradient will be increased by 1% every 30 sec until the subject reaches volitional exhaustion. The test will be deemed to be maximal if it satisfies at least 3 of the following criteria; levelling of oxygen consumption, volitional exhaustion, RER > 1.1 and heart rate within ± 10 beats of the age predicted max. HR will be recorded continuously, will be assessed each minute.

Respiratory Metabolic Measures: Expired oxygen, carbon dioxide, ventilatory volume and respiratory exchange ratios (RER) will be determined using a Sensormedics Vmax 229 metabolic system (SensorMedics Corp., Yorba Linda CA). Prior to testing, the gas analysers will be calibrated with standard gases of known concentration.

Percent Body Fat: Lange skinfold calliper (Cambridge Scientific Industries, MD) will be used to measure double thickness subcutaneous adipose tissue on the right side of the body. The following anatomical sites will be used: suprailiac, triceps and thigh. A minimum of 2 measurements will be taken at each site. If the measurements vary by more than 1 mm a third measurement will be taken.

Blood Sampling at Rest: A standard venous puncture will be used to collect blood samples at rest before and after the training study. A total volume of 30 ml will be taken.

Blood Sampling During Exercise: Blood samples (5-10 µl) will be taken from the earlobe using capillary tubes. The earlobe will be sterilized with a sterile wipe and then pricked with a lancet (AccuCheck Softclix Pro Lancet, Accu Check, Australia) to promote blood flow.

Lactate Analysis: Whole blood lactate concentration will be measured using a YSI 1500 Sport Lactate Analyzer (YSI UK limited).

Standing Jump for Distance: The subject will jump in a horizontal direction for maximal distance.

Counter Movement Jump (CMJ): The CMJ will be performed on a force platform. Subjects will place their hands on their hips, flex their lower limb joints and then jump vertically as high as possible. The best of 3 trials will be recorded.

Speed: Subjects will sprint 20 metres. Electronic timing gates will be positioned at 5 metres intervals. Each subject will perform 3 trials and the best score will be recorded.

Agility: Subjects will complete a predetermined course in the fastest possible time. The total time will be measured using electronic timing gates. Each subject will perform 3 trials and the best score will be recorded.

Bangsbo Yo Yo Intermittent Recovery test: The Yo-Yo IR level 1 consists of repeated pairs of 20-m runs at a progressively increasing speeds controlled by audio bleeps

from a tape recorder. Between each running bout the participants will have a 10-sec rest period consisting of 2x5 m jogs. The test will be terminated if a subject withdraws voluntarily, or is no longer complying to test regulation i.e., when subject does not reach target line on two consecutive occasions.

Wingate Tests: Subjects will undertake a 5 min submaximal warm-up against a light resistance (2.0% body mass) using a self-selected cadence. During the warm-up they will perform 2 separate 5-s sprints against a fixed resistance (4.0% body mass). A 3 min rest period will follow the warm-up. During the first 10 s of the Wingate test the subjects will cycle at approx. 60 rpm against zero resistance. Following a 5-s countdown a resistance equal to 8.5% of the subjects body mass will be applied and the subject will then exercise maximally for 30-sec. Each subject will perform 3 Wingate tests each separated by a 1-min recovery period. Peak power, mean power and total work will be measured. After completion of the third trial, subjects continued to cycle against a light load for 2-3 mins to assist recovery. Peak power, mean power and the total work were measured.

Muscle Biopsy: Rationale for muscle biopsy samples

Skeletal muscle biopsies are necessary before and after the training intervention to determine the molecular and cellular adaptations induced by the training intervention in skeletal muscle.

1. *Little JP. A practical model of low-volume high-intensity interval training induces mitochondrial biogenesis in human skeletal muscle: potential mechanism. J Physiol 588.6: 1011-1022, 2010*
2. *Burgomaster KA. Similar metabolic adaptations during exercise after low volume sprint interval and traditional endurance training in humans. J Physiol 586: 151-160, 2008*
3. *Burgomaster KA. Effect of short-term sprint interval training on human skeletal muscle carbohydrate metabolism during exercise and time-trial performance. J Appl Physiol 100: 2041-2047, 2006*

Statistical Analysis:

A group (Trained or Untrained) x condition (ET or SIT) x time repeated measures ANOVA will be used to compare the mean differences within and between group. SPSS for Windows statistical software will be used to perform the statistical analysis. Statistical significance will be accepted at the $P < 0.05$ level of confidence

2.4 PARTICIPANT PROFILE

Inclusion criteria: Apparently healthy men, currently playing at junior club level or higher level, and between the ages of 18 – 35 years.

Fitness classification will be based on performance in the Bangsbo Yo-Yo Intermittent Recovery test. Subjects who achieve a level ≤ 16.8 will be classified as untrained. Subjects who achieve a level **≥ 16.8** will be classified as trained

Exclusion criteria: Volunteers will be excluded if they smoke or have any other medical conditions that contraindicate exercise participation.

2.5 MEANS BY WHICH PARTICIPANTS ARE TO BE RECRUITED

A recruitment advertisement will be emailed to members of the Dublin City University Gaelic games club and all Dublin city Gaelic games clubs. Permission will be sought from each club prior to posting the advertisement. The aim of the study, the rationale for the study, the tests involved, the time commitment and the potential benefits will be explained to the players. Players will be provided with an opportunity to ask questions. If they wish to participate in the study they will have to provide a written informed consent, which will be witnessed on their visit to the School of Health and Human Performance.

2.6 PLEASE EXPLAIN WHEN, HOW, WHERE, AND TO WHOM RESULTS WILL BE DISSEMINATED, INCLUDING WHETHER PARTICIPANTS WILL BE PROVIDED WITH ANY INFORMATION AS TO THE FINDINGS OR OUTCOMES OF THE PROJECT*?*

The study findings will be presented at scientific meetings and published in scientific journals. Subjects will be provided with a report, which will summarise the relevant results from their participation in the research project.

2.7 OTHER APPROVALS REQUIRED *Has permission to gain access to another location, organisation etc. been obtained? Copies of letters of approval to be provided when available.*

☐ YES ☐ NO ☒ NOT APPLICABLE

2.8 HAS A SIMILAR PROPOSAL BEEN PREVIOUSLY APPROVED BY THE REC?

☐ YES ☒ NO

(If YES, please state both the REC Application Number and Project Title)

3. RISK AND RISK MANAGEMENT

3.1 ARE THE RISKS TO SUBJECTS AND/OR RESEARCHERS ASSOCIATED WITH YOUR PROJECT GREATER THAN THOSE ENCOUNTERED IN EVERYDAY LIFE?

☒ YES ☐ NO *If YES, this proposal will be subject to full REC review*
If NO, this proposal may be processed by expedited administrative review

3.2 WHAT DOES THE RESEARCH INVOLVE:

	YES	N
• Use of a questionnaire? (attach copy)?	☐	☒
• Interviews (attach interview questions)?	☐	☒
• Observation of participants without their knowledge?	☐	☒
• Participant observation (provide details in section 2)?	☐	☒
• Audio- or video-taping interviewees or events?	☐	☒
• Access to personal and/or confidential data (including student,	☐	☒

patient or client data) without the participant's specific consent?

• administration of any stimuli, tasks, investigations or procedures which may be experienced by participants as physically or mentally painful, stressful or unpleasant during or after the research process?	☒	☐
• Performance of any acts which might diminish the self-esteem of participants or cause them to experience embarrassment, regret or depression?	☐	☒
• Investigation of participants involved in illegal activities?	☐	☒
• Procedures that involve deception of participants?	☐	☒
• Administration of any substance or agent?	☐	☒
• Use of non-treatment of placebo control conditions?	☐	☒
• Collection of body tissues or fluid samples?	☒	☐
• Collection and/or testing of DNA samples?	☐	☒
• Participation in a clinical trial?	☐	☒
• Administration of ionising radiation to participants?	☐	☒

3.3 POTENTIAL RISKS TO PARTICIPANTS AND RISK MANAGEMENT PROCEDURES *(see Guidelines)*

The nature and risks involved in the study will be explained prior to starting the study, and a contact number will be provided.

Subjects may experience some muscle soreness in their legs or nausea following the maximal exercise test. Exercise testing carries with it a very small risk of abnormal heart rhythms, heart attack, or death in less than one in 30,000 patients. The pre-test likelihood of these risks in asymptomatic men < 55 years of age is very low. There may be discomfort during the muscle biopsy with some pain and delayed soreness afterward. There is a risk of bleeding, bruising, infection and scaring of the skin. Temporary numbness of the skin near the biopsy site may occur. There may be discomfort when taking blood and the development of a small bruise at the site of puncture.

High intensity may increase the risk for muscle strains and tears. A 5 min warm-up will precede each training session to help reduce the risk of injury.

3.4 ARE THERE LIKELY TO BE ANY BENEFITS (DIRECT OR INDIRECT) TO PARTICIPANTS FROM THIS RESEARCH?

☒ YES ☐ NO The study will provide information than can be used to develop training programs for Gaelic football.

3.5 ARE THERE ANY SPECIFIC RISKS TO RESEARCHERS? *(E.g. risk of infection or where research is undertaken at an off-campus location)*

☒ YES ☐ NO There is a small risk of infection from needle and blood samples. Standard safety procedures will be strictly adhered to.

3.6 ADVERSE/UNEXPECTED OUTCOMES

The School of Health and Human Performance has the facilities to deal with all aspects of this study and an emergency plan is in place for adverse events. All minor injuries will be addressed by an individual trained in first aid (either a member of the research team or the staff). The laboratory is equipped with an emergency crash cart and defibrillator. An individual trained in first aid (or Advanced Cardiac Life Support) will be present during each test. In the unlikely event of a serious adverse outcome, the subject will be brought to the VHI clinic on campus.

3.7 MONITORING

Weekly meetings will take place between Prof. N. Moyna (principal investigator) and the other researchers. These meetings will provide opportunities to access progress, give feedback, and monitor development of the research. The School of Health and Human Performance has a detailed list of Standard Operating Procedures for each of the protocols in this study. All researchers will be familiar with the procedures and the Safety Statement before beginning data collection.

3.8 SUPPORT FOR PARTICIPANTS

It is anticipated that no additional support will be required.

3.9 DO YOU PROPOSE TO OFFER PAYMENTS OR INCENTIVES TO PARTICIPANTS?

☐ YES ☒ NO *(If YES, please provide further details.)*

4. INVESTIGATORS' QUALIFICATIONS, EXPERIENCE AND SKILLS *(Approx. 200 words – see Guidelines)*

Prof. Moyna is an exercise physiologist and has extensive experience with exercise testing

Dr. Noel McCaffrey and Dr. Davide Susta are physicians with extensive experience in the muscle biopsy technique

Crionna Tobin is a PhD student at the School of Health and Human Performance. She has a Bsc, a Higher Diploma in Human Nutrition and a Higher Diploma in Sports Nutrition.

Mr. David Kelly is a PhD student and Cathal Cregg is a postgraduate student at the school of Health and Human Performance, and have extensive experience in laboratory and field based exercise testing.

5. CONFIDENTIALITY/ANONYMITY

5.1 WILL THE IDENTITY OF THE PARTICIPANTS BE PROTECTED?

☒ YES ☐ NO *(If NO, please explain)*

IF YOU ANSWERED YES TO 5.1, PLEASE ANSWER THE FOLLOWING QUESTIONS:

5.2 HOW WILL THE ANONYMITY OF THE PARTICIPANTS BE RESPECTED?

Confidentiality is an important issue during data collection. Participant's identity, or other personal information, will not be revealed or published. Subjects will be assigned an ID number under which all personal information will be stored in a secure file and saved in password protected file in a computer at DCU. The investigators alone will have access to the data.

5.3 LEGAL LIMITATIONS TO DATA CONFIDENTIALITY: *(Have you included appropriate information in the plain language statement and consent form? See Guidelines)*

☒ YES ☐ NO *(If NO, please advise how participants will be advised.)*

The following statement should be included in the plain language statement.
'Confidentiality of information provided can only be protected within the limitations of the law. It is possible for data to be subject to subpoena, freedom of information claim or mandated reporting by some professions.

6 DATA/SAMPLE STORAGE, SECURITY AND DISPOSAL *(see Guidelines)*

6.1 HOW WILL THE DATA/SAMPLES BE STORED? *(The REC recommends that all data be stored on campus)*

Stored at DCU ☒
Stored at another site ☐ **(***Please explain where and for what purpose)*

6.2 WHO WILL HAVE ACCESS TO DATA/SAMPLES?

Access by named researchers only ☒
Access by people other than named researcher(s) ☐ **(***Please explain who and for what purpose)*
Other *:* ☐ **(***Please explain)*

6.3 IF DATA/SAMPLES ARE TO BE DISPOSED OF, PLEASE EXPLAIN HOW, WHEN AND BY WHOM THIS WILL BE DONE?

The principal investigator will be responsible for security of the collected data. The data will be kept in locked facilities in the department through which the project is being conducted. Access to the data will only be attainable by the main researchers. Data will be kept for a minimum of five years from the date of publication of the research. Aside from the main researchers, no others will have access to the raw data. Data will be shredded after five years and Prof. Moyna will carry this out.

7. FUNDING

7.1 HOW IS THIS WORK BEING FUNDED?

The Gaelic Athletic Association

7.2 PROJECT GRANT NUMBER (If relevant and/or known)

7.3 DOES THE PROJECT REQUIRE APPROVAL BEFORE CONSIDERATION FOR FUNDING BY A GRANTING BODY?

☐ YES ☒ NO

7.4 HOW WILL PARTICIPANTS BE INFORMED OF THE SOURCE OF THE FUNDING?

In the plain language statement

7.5 **DO ANY OF THE RESEARCHERS, SUPERVISORS OR FUNDERS OF THIS PROJECT HAVE A PERSONAL, FINANCIAL OR COMMERCIAL INTEREST IN ITS OUTCOME THAT MIGHT COMPROMISE THE INDEPENDENCE AND INTEGRITY OF THE RESEARCH, OR BIAS THE CONDUCT OR RESULTS OF THE RESEARCH, OR UNDULY DELAY OR OTHERWISE AFFECT THEIR PUBLICATION?**

NO

8. PLAIN LANGUAGE STATEMENT

Plain Language Statement

Dublin City University

Project Title: Muscle adaptations in response to low volume high intensity interval training and endurance training in Gaelic games

The Research Study will take place in the School for Human Health and Human Performance DCU and the DCU Sports Grounds

The research study is being funded by the Gaelic Athletic Association.

The principal investigator is: Prof. Niall M. Moyna, (Tel: 7008802 Fax 7008888) EMAIL niall.moyna@dcu.ie

1. A good level of endurance is important for Gaelic football players. Many players spend considerable time running long distances to improve their endurance. Research studies have shown that training involving short sprints with short recovery periods (sprint interval training) can also improve endurance. The amount of time required to improve endurance is considerable less when sprint interval training is undertaken compared to distance running. No studies have compared the effect of endurance training and sprint interval training on endurance performance in Gaelic football players. The purpose of this study is to compare the effect of a 6 week endurance training and sprint interval training program on endurance performance in Gaelic football players.

2. You will make 3 visits to the Human Performance Laboratory in DCU before and 2 visits after taking part in the training program. The first visit before the study will last approximately 1 hour and will involve you undergoing a brief medical examination and performing an endurance exercise test. The second visit will be 2 hours in duration and will be used to measure body fat, muscle power, speed, agility, lactate threshold, and your aerobic fitness. During the third visit you will have a blood and a muscle biopsy sample taken and you will undertake a test on stationary bike (Wingate test) to measuring your power output during exercise. During the final training session you will repeat the same endurance test that you undertook before the study. You will repeat the elements of the previous second and third visits in the human performance lab in DCU 24-48 hrs after the last training session. During the first of the post-training visits to the human performance lab in DCU you will have a blood and a muscle biopsy sample taken. You will not be allowed to play in any team sport or participate in any other type of exercise program during this 6 week period.

3. You will be assigned, by chance, to one of two groups. One group will take part in sprint-interval training and the other group will take part in endurance training. Each group will train 3 times per week for 6 weeks. Subjects randomised to the endurance training group will run on a treadmill at 70-80% of their maximal fitness level. Subjects will run for 30 min during week 1, and the duration will be gradually

increased to 40 min by the end of week 2 and remain at 40 min for the remaining training sessions. Each training session will be preceded by a 5 minute warm-up. Subjects randomised to the sprint-interval training will sprint 100 m followed by a 50 metre recovery run. The sprint and recovery run must be completed in 40 sec. This will be repeated 3 more times followed by a 3 min recovery period (1 set). Subjects will complete 3 sets during the first training session and the number of sets will be increased to 5 during the training study. Training sessions will be carried out on the sprint track in DCU or in the DCU gym depending on which training program you are undertaking. Each training session will be monitored to ensure compliance.

4. You will receive a report summarizing the results from your tests undertaken during the study. No other benefits have been promised.

5. Your identity and other personal information will not be revealed, published or used in further studies. You will be assigned an ID number under which all personal information will be stored in a secure file and saved in a password protected file in a computer at DCU. The principal investigator, and collaborators listed on this ethics application will have access to the data. You need to be aware that confidentiality of information provided can only be protected within the limitations of the law. It is possible for data to be subject to subpoena, freedom of information claim or mandated reporting by some professions.

6. The original documentation will be stored for a maximum of 5 years. Thereafter the documentation will be shredded.

7. Your participation in this research project is voluntary and you may withdraw your consent at any time.

If participants have concerns about this study and wish to contact an independent person, please contact:

The Secretary, Dublin City University Research Ethics Committee, c/o Office of the Vice-President for Research, Dublin City University, Dublin 9. Tel 01-7008000

9. INFORMED CONSENT FORM

INFORMED CONSENT

Title: Muscle adaptations in response to low volume high intensity interval training and endurance training in Gaelic games

Principal investigator: Prof Niall M. Moyna

Other investigators: Ms Crionna Tobin, Mr Cathal Cregg, Mr David Kelly, Dr. Noel McCaffrey, Dr. Davide Susta

Purpose: The purpose of this study is to compare the effect of a 6 week endurance training and sprint interval training program on endurance performance in Gaelic football players.

Participant Requirements

1. I will have the purpose of the study, each of the steps involved and the risks of participating in the study explained to me. I will have the opportunity to ask any questions and if I am happy with the answers I will provide written informed consent for participation in the research project. I will then complete a medical history form, which will ask questions about my general health, personal and family health history, smoking, exercise, and dietary habits. I will talk with a medical doctor about the information I have provided and I understand, based on the information provided, the medical doctor may exclude me from participating in the research project. If I agree to participate in the study I will make 3 visits to the Human Performance Laboratory in DCU before and 2 visits after taking part in the training program.
2. For the first visit, I will arrive in the morning to the Human Performance Laboratory in DCU following my normal breakfast. I will undergo a brief medical screening to evaluate my current physical condition. I will take part in an endurance fitness test to measure my endurance capacity. This will involve taking part in a repeated pair of 20 m runs at progressively increasing speeds until I fatigue.
3. On my second visit to the Human Performance Laboratory my height and weight will be taken and my percentage body fat will be measured using skin calipers. I will then undergo a series of tests to measure my speed, agility and muscle power. Finally, I will undergo an exercise test on a treadmill to measure my aerobic fitness and lactate threshold. To assess my fitness I will have a mouthpiece similar to a snorkel in my mouth to measure the amount of air I breathe in and out. To assess my lactate threshold I will have my ear pricked to collect a small blood sample
4. During the third visit I will have a blood and a muscle biopsy sample taken and I will undertake a test on a stationary bike (Wingate test) to measure how good I am at performing high intensity exercise. The muscle biopsy sample will involve taking a small piece of muscle, about the size of a pea taken from my thigh with a special biopsy needle. A small area of the leg will be injected with a local anesthetic, then a small incision will be made in the skin and a needle inserted briefly into the muscle. The incision will be closed with sterile strip bandaids, and my leg will be wrapped snugly with an elastic bandage to maintain pressure. Before I leave I will be given supplies to change the dressing around the biopsy sites.

5. After the third visit to the laboratory I will be assigned, by chance, to one of two groups. I will take part in sprint-interval training or endurance training 3 times per week for 6 weeks. At the end of the third weekly training session I will have my ear pricked to collect a small blood sample to measure my blood lactate levels. This test will assess how well I am responding to each training session.
6. During the last training session I will repeat the same endurance test that I undertook before the study. I will repeat the elements of the previous second and third visits in the Human Performance Laboratory in DCU 24-48 hrs after the last training session.
7. I will not participate in any other type of exercise during this 6 week period.

Sometimes there are side effects from performing exercise tests. These side effects are often called risks, and for this project, the risks are:

1. Exercise testing carries with it a very small risk of exercise induced asthma, abnormal heart rhythms, heart attack, or death in less than one in 30,000 patients. The risk of sudden death during exercise for healthy men is 1:15000-18000. Because I will be asked to give a maximum effort, I may experience some muscle soreness in my arms and legs or nausea following the maximal exercise test. It should be noted that if the experimental protocol is adhered to, the likelihood of these risks occurring is minimal.
2. I understand that the insertion and placement of a cannula (to take blood samples) should be minimally painful but a slight ache may be felt and a small bruise may appear on my arm. There is also a small risk of infection, but by using the appropriate techniques this risk is minimal.
3. I understand that there may be discomfort during the muscle biopsy with some pain and delayed soreness afterward. There is a risk of bleeding, bruising, infection and scaring of the skin. After the biopsy, my leg may feel stiff and sore. Temporary numbness of the skin near the biopsy may also occur.
4. High intensity may increase the risk for muscle strains and tears. A 5 min warm-up will precede each training session to help reduce the risk of injury.

There may be benefits from my participation in this study. These are:

1. I will receive a copy of my personal results, body fat and fitness measurements
2. I understand that no other benefits have been promised me.

Participant – please complete the following (Circle Yes or No for each question)

I have read the Plain Language Statement Yes/No
I understand the information provided Yes/No
I have had an opportunity to ask questions and discuss this study Yes/No
I have received satisfactory answers to all my questions Yes/No

<u>My confidentiality will be guarded:</u>

Dublin City University will protect all the information about me, and my part in this study, within the limitations of the law. My identity or personal information will not be revealed or published. All records associated with my participation in the study will be subject to the usual confidentiality standards applicable to medical records. In addition, the study findings may be presented at scientific meetings and published in a scientific journal and/or as part of a postgraduate thesis, but my identity will not be divulged and only presented as part of a group.

If I have questions about the research project, I am free to call Prof Niall Moyna at 01-7008802.

Taking part in this study is my decision.

I understand that my participation in this study is voluntary and that I may withdraw my consent at any time by notifying any of the investigators. I may also request that my data and samples be removed from the database or storage and destroyed. My withdrawal from this study, or my refusal to participate, will in no way affect my relationship with Dublin City University or my entitlements as a student or staff member. I understand that my participation in this research may be terminated by the investigator without regard to my consent if I am unable or unwilling to comply with the guidelines and procedures explained to me.

Signature:

I have read and understood the information in this form. My questions and concerns have been answered by the researchers, and I have a copy of this consent form. Therefore, I consent to take part in this research project

Participants Signature: _____

Name in Block Capitals: _____

Witness: _____

Date: _____

Email to participants:

The school of Health and Human Performance is conducting a study to compare the effect of a 6 week endurance training and sprint interval training program on speed, agility, power and endurance performance in Gaelic football players. You will make 3 visits to the Human Performance Laboratory in DCU before and 2 visits after taking part in the training program. The first visit before the study will last approximately 1 hour and will involve you undergoing a brief medical examination and performing an endurance exercise test. The second visit will be 2 h in duration and will be used to measure body fat, muscle power, speed, agility, lactate threshold and your aerobic fitness. During the third visit you will have a blood and a muscle biopsy sample taken and you will undertake a test on a stationary bike (Wingate test) to measure your power output during exercise. You will then be assigned, by chance, to one of two groups. One group will take part in sprint-interval training and the other group will take part in endurance training 3 times per week for 6 weeks. During the last training session you will take part in an endurance test. You will repeat the elements of the previous second and third visits in the Human Performance Laboratory in DCU 24-48 hrs after the last training session. We are looking for 40 healthy men, currently playing Gaelic football at any level, and between the ages of 18 – 35 years.

If you would like to hear more about this study or would consider participating, please contact one of the following;

Crionna Tobin
Email: Crionna.tobin9@mail.dcu.ie
Mobile number: 086-0705130

David Kelly
Email: david.kelly59@mail.dcu.ie
Mobile number: 085-1618207

Cathal Cregg
Email: cathal.cregg2@mail.dcu.ie
Mobile number: 087- 7633021

Thank you,

Niall M. Moyna, PhD

Standard template for ethical justification for blood sampling associated with human studies conducted within DCU.

Completion instructions:

This document is intended to prompt responses to a number of standard questions which generally need to be answered to justify the sampling of blood associated with human studies.

The document is not meant to be an exhaustive exploration of the justification for such sampling and in specific situations. Additional information may be required/ requested.

Answers are expected to be brief but should also be informative. See a sample completed form at the end.

Queries should be directed to the Secretary of the Research Ethics Committee in the OVPR office.

1) **Briefly explain why blood sampling is required**

To monitor circulating levels of glucose, lactate, free fatty acids and insulin, this will be used to determine adaptations in the subjects following the research intervention

2) **Outline the analyses, components or general applications to be investigated in subject blood (now and any future studies)**

Blood lactate will be determined using a YSI 1500 Sport Lactate Analyzer (YSI UK limited). Glucose will be analysed using a YSI 2300 Analyzer (YSI UK limited). Free fatty acids and insulin will be investigated using an automated clinical chemistry analyzer, Randox Daytona (Randox UK limited)

3) **Are any alternatives available to substitute the venous sampling of blood? yes/no.**

No

4) **Will sampling require cannulation or direct vein puncture?**

Direct vein puncture and ear prick with lancet

5) **Outline the minimum volume of original subject blood (i.e. not serum or plasma) required to measure the required components.**

4.0 ml for circulating levels of glucose, free fatty acids and insulin.

6) **Are steps being taken in the protocol to minimise the volume of blood samples being taken? Yes**

7) **taken?**

Yes. We have taken the minimum volume of blood that will allow us to examine circulating levels of glucose, lactate, free fatty acids and insulin.

Yes. We have taken the minimum number of blood samples that will allow us to examine circulating levels of glucose, lactate, free fatty acids and insulin.

8) **Anticipated sampling methodology**

Volume of blood to be taken per sample	4.0 ml for glucose, insulin and free fatty acids 100µl for lactate
Maximum number of samples to be taken per "sitting"	6 for lactate 6 for glucose, insulin and free fatty acids
Maximum number of samples taken per day	Screening Visit- 0 samples Visit 1 – 6 samples Visit 2 – 6 samples During training – 2 samples Visit 3 (post training program) – 6 samples Visit 4 (post training program) – 6 samples
Maximum number of samples to be taken over the course of the full study (if long duration study indicate the amount taken in an active 1 month period)	12 blood samples and 14 lactate samples
Maximum anticipate number of vein puncture episodes	2
Total volume of blood that will be taken from subject.	50 ml

9) I certify that:-

- all persons sampling blood in this study are certified to do so through the school/unit where this work is being conducted

- that all those manipulating the resultant samples are fully trained in the safe practice of handling blood
- All persons handling this blood have received appropriate information according to current vaccination policy.

Signature of Study PI Niall Mayna Date:

An original signed copy must accompany electronic submissions. Alternatively, a PDF or other scanned version with a signature may be submitted

PAR-Q Questionnaire

PAR – Q & YOU QUESTIONAIRE

Common sense is your best guide when you answer these questions. Please read the questions carefully and answer each one honestly: check YES or NO

YES	NO	No.	Question
		1	Has your doctor every said that you have a heart condition and that you should only do physical activity recommended by a doctor?
		2	Do you feel pain in your chest when you do physical activity?
		3	In the past month, have you had chest pain when you were not doing physical activity?
		4	Do you loose your balance because of dizziness or do you ever lose consciousness?
		5	Do you have a bone or joint problem that could be made worse by a change in your physical activity?
		6	Is your doctor currently prescribing drugs (for example, water pills) for your blood pressure or heart condition/.
		7	Do you no of any other reason why you should not do physical activity?

If you answered YES to one or more questions

Talk with your doctor by phone or in person BEFORE you start becoming much more physically active or BEFORE you have a fitness appraisal. Tell your doctor about the PAR-Q and which questions you answered YES

- You may be able to do any activity you want – as long as you start slowly and build up gradually. Or, you may need to restrict your activities to those which are safe for you. Talk with your doctor about the kind of activities you wish to participate in and follow his/her advice
- Find out which community programs are safe and helpful for you.

If you answered NO to all questions.

If you answered NO honestly to all PAR-Q questions, you can be reasonably sure that you can:

- Start becoming much more physically active – begin slowly and build up gradually. This is the safest and easiest way to go.
- Take part in a fitness appraisal- this is an excellent way to determine your basic fitness so that you can plan the best way for you to live actively.

Delay becoming much more active:

- If you are not feeling well because of a temporary illness such as a cold or a fever – wait until you feel better; or
- If you are or many be pregnant – talk to your doctor before you start becoming more active

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

NAME .

SIGNATURE DATE .

SIGNATURE OF PARENT . WITNESS .

Or Guardian (for participants under the age of majority)

Appendix B

Dublin City University

RESEARCH ETHICS COMMITTEE

APPLICATION FOR APPROVAL OF A PROJECT INVOLVING HUMAN PARTICIPANTS

Application No. *(office use only)* DCUREC/2012/ ☐☐☐

This application form is to be used by researchers seeking ethics approval for individual projects and studies. **An electronic copy** of your completed application must be submitted to the DCU Research Ethics Committee**. Student applicants must cc their supervisor on that e-mail** – this applies to undergraduate, masters and postgraduate students.

NB - The application should consist of <u>one file only</u>, with an electronic signature from the PI. The completed application must incorporate all supplementary documentation, especially that being given to the proposed participants. It must be proofread and spellchecked before submission to the REC. All sections of the application form should be completed. Applications which do not adhere to these requirements will not be accepted for review and will be returned directly to the applicant.

Applications must be completed on the form; answers in the form of attachments will not be accepted, except where indicated. No hardcopy applications will be accepted. **Research must <u>not</u> commence until written approval has been received from the Research Ethics Committee.**

Note: If your research requires approval from the Biosafety Committee, this approval should be in place prior to REC submission. Please attach the approval from the BSC to this submission.

PROJECT TITLE **Repeated Sprint Ability in Collegiate Level Gaelic Football Players**

PRINCIPAL INVESTIGATOR(S) **Prof. Niall Moyna**

Please confirm that **all** supplementary information is included in your application (in electronic copy). If questionnaire or interview questions are submitted in draft form, a copy of the final documentation must be submitted for final approval when available.

	INCLUDED		**NOT APPLICABLE**
Bibliography	☐		☐
Recruitment advertisement	☒		☐
Plain language statement/Information Statement	☒		☐
Informed Consent form	☒		☐
Evidence of external approvals related to the research	☐		☐
Questionnaire	☐ draft	☒ final	☐
Interview Schedule	☐ draft	☐ final	☐
Debriefing material	☐		☐
Other	☐		☐

Please note:

3. Any amendments to the original approved proposal must receive prior REC approval.

4. As a condition of approval investigators are required to document and report immediately to the Secretary of the Research Ethics Committee any adverse events, any issues which might negatively impact on the conduct of the research and/or any complaint from a participant relating to their participation in the study

Please submit the electronic copy of your completed application to fiona.brennan@dcu.ie
Fiona Brennan, Research Officer, Office of the Vice-President for Research and Innovation (Ph. 01-7007816)

Guidelines to Applicants

1.1 PRINCIPAL INVESTIGATOR(S): *The named Principal Investigator is the person with primary responsibility for the research project. Doctoral researchers and Research Masters or their supervisors may be listed as Principal Investigators, depending on the conventions of the discipline and on the individual case. It should be made clear, in subsequent sections of this application, which is carrying out the research procedures. In the case of Taught Masters and undergraduate student projects the supervisors are Principal Investigators.*

2.0 PROJECT OUTLINE: *Provide a brief outline of the project, aims, methods, duration, funding, profile of participants and proposed interaction with them. This description must be in everyday language that is free from jargon. Please explain any technical terms or discipline-specific phrases.*

2.1 LAY DESCRIPTION: *Provide a brief outline of the project, including what participants will be required to do. This description must be in everyday language which is free from jargon. Please explain any technical terms or discipline-specific phrases. (No more than 300 words).*

2.2 AIMS OF AND JUSTIFICATION FOR THE RESEARCH: *State the aims and significance of the project (approx. 400 words). Where relevant, state the specific hypothesis to be tested. Also please provide a brief description of current research, a justification as to why this research should proceed and an explanation of any expected benefits to the community.* ***NB – all references cited should be listed in an attached bibliography.***

2.3 PROPOSED METHOD: *Provide an outline of the proposed method, including details of data collection techniques, tasks participants will be asked to do, the estimated time commitment involved, and how data will be analysed. If the project includes any procedure which is beyond already established and accepted techniques please include a description of it. (No more than 400 words.)*

2.4 PARTICIPANT PROFILE: *Provide number, age range and source of participants. Please provide a justification of your proposed sample size. Please provide a justification for selecting a specific gender.*

2.5 MEANS BY WHICH PARTICIPANTS ARE TO BE RECRUITED: *Please provide specific details as to how you will be recruiting participants. How will people be told you are doing this research? How will they be approached and asked if they are willing to participate? If you are mailing to or phoning people, please explain how you have obtained their names and contact details. This information will need to be included in the plain language statement. If a recruitment advertisement is to be used, please ensure you attach a copy to this application.*

3.3 POTENTIAL RISKS TO PARTICIPANTS AND RISK MANAGEMENT PROCEDURES*: Identify, as far as possible, all potential risks to participants (physical, psychological, social, legal or economic etc.), associated with the proposed research. Please explain what risk management procedures will be put in place.*

3.6 ADVERSE/UNEXPECTED OUTCOMES: *Please describe what measures you have in place in the event that there are any unexpected outcomes or adverse effects to participants arising from involvement in the project.*

3.7 MONITORING: *Please explain how you propose to monitor the conduct of the project (especially where several people are involved in recruiting or interviewing, administering procedures) to ensure that it conforms with the procedures set out in this application. In the case of student projects please give details of how the supervisor(s) will monitor the conduct of the project.*

3.8 SUPPORT FOR PARTICIPANTS: *Depending on risks to participants you may need to consider having additional support for participants during/after the study. Consider whether your project would require additional support, e.g., external counselling available to participants. Please advise what support will be available.*

4.0 INVESTIGATORS' QUALIFICATIONS, EXPERIENCE AND SKILLS: *List the academic qualifications and outline the experience and skills relevant to this project that the researchers and any supporting staff have in carrying out the research and in dealing with any emergencies, unexpected outcomes, or contingencies that may arise.*

5.2 HOW WILL THE ANONYMITY OF THE PARTICIPANTS BE RESPECTED? *Please bear in mind that where the sample size is very small, it may be impossible to guarantee anonymity/confidentiality of participant identity. Participants involved in such projects need to be advised of this limitation.*

5.3 LEGAL LIMITATIONS TO DATA CONFIDENTIALITY: *Participants need to be aware that confidentiality of information provided can only be protected within the limitations of the law - i.e., it is possible for data to be subject to subpoena, freedom of information claim or mandated reporting by some professions. Depending on the research proposal you may need to specifically state these limitations.*

6.0 DATA/SAMPLE STORAGE, SECURITY AND DISPOSAL: *For the purpose of this section, "Data" includes that in a raw or processed state (e.g. interview audiotape, transcript or analysis). "Samples" include body fluids or tissue samples.*

8.0 PLAIN LANGUAGE STATEMENT: *Written information in plain language that you will be providing to participants, outlining the phases and nature of their involvement in the project and inviting their participation. Please note that the language used must reflect the participant age group and corresponding comprehension level.*

9.0 INFORMED CONSENT FORM: *This is a very important document that should be addressed by participants to researchers, requiring participants to indicate their consent to specific statements, and give their signature.*

FOR FURTHER INFORMATION AND NOTES ON THE DEVELOPMENT OF PLAIN LANGUAGE STATEMENTS AND INFORMED CONSENT FORMS, PLEASE CONSULT THE DCU REC WEBSITE:
HTTP://WWW.DCU.IE/INTERNAL/RESEARCH/REC_FORMS.SHTML

1. ADMINISTRATIVE DETAILS

THIS PROJECT IS: *(tick as many as apply)*

- ☐ Research Project
- ☐ Practical Class
- ☒ Student Research Project
  - ☐ Research Masters
  - ☐ Taught Masters
  - ☒ PhD
  - ☒ Undergraduate
- ☐ Funded Consultancy
- ☐ Clinical Trial
- ☐ Other - *Please Describe:*

(please give details)

Project Start Date: **Jan 2013**

Project End date: **June 2014**

1.1 INVESTIGATOR CONTACT DETAILS

PRINCIPAL INVESTIGATOR(S):

TITLE	*SURNAME*	*FIRST NAME*	*PHONE*	*FAX*	*EMAIL*
Prof	Moyna	Niall	017008888	017008888	niall.moyna@dcu.ie

OTHER INVESTIGATORS:

TITLE	*SURNAME*	*FIRST NAME*	*PHONE*	*FAX*	*EMAIL*
Mr	David	Kelly	0851618207	017008888	David.kelly59@mail.dcu.ie
Mr	Boyle	Michael	0861630332	017008888	Michael.boyle24@mail.dcu.ie

Mr	Sheridan	Kieran	0851492620	017008888	Kieran.sheridan23@mail.dcu.ie

FACULTY/DEPARTMENT/SCHOOL/ CENTRE:

(NB – if Nursing and Human Sciences, please note all students including PhD's must attach the letter from their Ethics Advisory Committee to this application)

School of Health & Human Performance

1.2 WILL THE RESEARCH BE UNDERTAKEN ON-SITE AT DUBLIN CITY UNIVERSITY?

☒ YES ☐ NO *(If NO, give details of off-campus location.)*

1.3 IS THIS PROTOCOL BEING SUBMITTED TO ANOTHER ETHICS COMMITTEE, OR HAS IT BEEN PREVIOUSLY SUBMITTED TO AN ETHICS COMMITTEE?*)*

☐ YES ☒ NO *(If YES, please provide details and copies of approval(s) received etc.)*

DECLARATION BY INVESTIGATORS

The information contained herein is, to the best of my knowledge and belief, accurate. I have read the University's current research ethics guidelines, and accept responsibility for the conduct of the procedures set out in the attached application in accordance with the guidelines, the University's policy on Conflict of Interest, Code of Good Research Practice and any other condition laid down by the Dublin City University Research Ethics Committee or its Sub-Committees. I have attempted to identify all risks related to the research that may arise in conducting this research and acknowledge my obligations and the rights of the participants.

If there any affiliation or financial interest for researcher(s) in this research or its outcomes or any other circumstances which might represent a perceived, potential or actual conflict of interest this should be declared in accordance with Dublin City University policy on Conflicts of Interest.

I and my co-investigators or supporting staff have the appropriate qualifications, experience and facilities to conduct the research set out in the attached application and to deal with any emergencies and contingencies related to the research that may arise.

Electronic Signature(s):

Principal investigator(s): Niall Moyna

Print Name: *Niall Moyna*

Date: 2/11/2012

2. PROJECT OUTLINE

5. LAY DESCRIPTION

Gaelic football is one of the most popular sports in Ireland. It is characterised by irregular bouts of maximal or near maximal sprints of short duration (1–7 s) with brief recovery periods of light-to-moderate aerobic activity. The ability to recover and reproduce maximal performance in subsequent sprints is an important component of fitness and has been termed repeated sprint ability (RSA). Consequently, repeated-sprint ability exercises are now commonly used for training and testing in team sports such as soccer and Australian Rules football. There is presently no information available to coaches regarding repeated sprint ability performance among Gaelic football players. Understanding the determinants of RSA is important in order to design appropriate training programs. Differences in exercise mode, sprint duration, number of sprint repetitions, type of recovery, and training status of subjects make it difficult to evaluate and compare between studies. This study will compare performance in a number of RSA tests and examine the relation between selected physical and performance factors and RSA performance among collegiate level male Gaelic football players.

2.2 AIMS OF AND JUSTIFICATION FOR THE RESEARCH

Team-sport games such as Gaelic football require participants to perform a number of short sprints, interspersed with periods of rest or low- to moderate-intensity activity. Many of these sprints are separated by rest periods long enough (<1 min) to allow complete or near complete recovery and therefore subsequent sprint performance is not significantly impaired. However, in some instances these sprints are separated by short rest periods (<30 s), which may negatively affect subsequent sprint performance. The ability to perform short-duration sprints (<10 s) with a short recovery time (<30 s) is called repeat sprint ability and is an important fitness component for Gaelic football. Many different exercise protocols have been used to investigate RSA. Differences in exercise mode, sprint duration, number of sprint repetitions, type of recovery, and training status of subjects make it difficult to evaluate and compare between studies. In addition, the large differences between some exercise protocols and the repeated-sprint activity patterns of team sports may question the validity and sport specific relevance of many of these protocols. There is presently no information available to coaches regarding RSA performance among Gaelic football players, or the factors that determine RSA. The purpose of this study is to i) compare performance in a number of RSA tests among collegiate level Gaelic football players and ii) examine the relation between selected physical and performance factors and RSA performance among collegiate level male Gaelic football players.

2.3 PROPOSED METHOD

Overview

The study will take place in the School of Health and Human Performance Laboratories and DCU Sport. Participants will visit DCU on 5 separate occasions. During the first visit, participants will have their height, weight and body composition assessed and they will then undergo a series of tests to measure muscle power (standing long jump, vertical jump, counter movement jump, Margaria test), speed (5m, 15 and 20,) and running economy/lactate threshold/VO_2max. The second visit will be used to assess leg strength and pulmonary function after which they will perform a Wingate test. During the third visit participants will undergo a treadmill test to measure maximal accumulated oxygen deficit (MAOD). During the final two visits, participants will perform two different RSA tests separated by 30 min.

Height: Height will be measured to the nearest centimetre using a stadiometer (Seca Model 220, GMBH Hamburg. Germany)

Weight: Weight will be measured to nearest kg using a medical scale (Seca Ltd, Hamburg, Germany)

Skinfolds: Lange skinfold calliper (Cambridge Scientific Industries, MD) will be used to measure double thickness subcutaneous adipose tissue on the right side of the body. The following anatomical sites will be used: triceps, chest, subscapular, suprailiac, mid-axillary, abdomen and thigh. A minimum of 2 measurements will be taken at each site. If the measurements vary by more than 1 mm a third measurement will be taken.

Vertical Jump: Participants will stand on a FSL JumpMat (FSL, Cookstown, UK) with their feet shoulder width apart and arms hanging loosely. When instructed, participants will move into a semi-squat position and then jump as high as possible, landing on the mat. They will be encouraged to use their arms to help propel their body upwards.

Counter Movement Jump (CMJ): The test will involve the same procedure as the vertical jump with the exception that participants will be instructed to keep their hands on their hips throughout the jump.

Standing Jump for Distance: Participants will jump in a horizontal direction for maximal distance

Pulmonary Function: Basic spirometry will be used to assess pulmonary function

Wingate Tests: Participants will perform 6 maximal 10 sec sprints interspersed with recovery period of between 20 -50 sec recovery on a Monark cycle ergometer against a resistance equal to 8.5% body weight. Peak power, mean power, total work and fatigue index will be measured.

Margaria Test: This test will calculate power output during stair climbing at maximal speed. Participants will run up stairs at maximum speed taking three steps at a time. The starting line is placed 6 m from the base of the first step. Timing gates will be placed on the third and ninth steps. The time starts when the study participants foot strikes the third step and ends when the foot lands on the ninth step. Participants will be encouraged to run as fast as possible.

Leg Strength: Maximum voluntary isometric contraction (MVIC) peak torque of the quadriceps femoris muscle of both limbs will be assessed using a Biodex dynamometer (Biodex Medical Instruments, Shirley, NY). The testing position will be standardised with a hip angle of 110° and the knee flexed at 60°. The fulcrum of the dynamometer lever arm will aligned with the inferior aspect of the lateral femoral condyle. Waist, thigh, and shoulder straps will be used to established subjects during testing to minimise additional muscle group substitution. Following three submaximal contractions, subjects will perform three consecutive maximal contractions. Each contraction will 5 sec in duration interspaced with a 50 sec rest period. The highest peak torque generated will be recorded as the MVIC.

Running Economy/Lactate Threshold/VO2max: Maximal aerobic capacity will be determined on a treadmill (Woodway ELG 55, Waukesha, WI). Participants will warm-up at 8 km/h for 3 min at 1% grade. Following the warm-up, the velocity will be increased 1 km/h every 3 min until the blood lactate concentration reaches 4 $mmol.L^{-1}$. The treadmill will then be set at a velocity corresponding to RPE 13 and the grade will be set at 4%. The speed will remained constant and the gradient will be increased by 1% every min until the participant reaches volitional fatigue. Ventilation and respiratory gases will be continuously measured using open circuit spirometry and heart rate will be measured using telemetry.

Speed: Participants will sprint 20 metres. Electronic timing gates (Fusion Sport International) will be positioned on the start line and at 5 metres intervals.

Maximal Accumulated Oxygen Deficit: Participants will run to volitional fatigue at 120% VO_2max. Ventilation, respiratory gases and heart rate will be continuously monitored. It is expected that the test will last between 2 and 6 min.

Lactate Measurements: A 5 μL sample of whole blood will be aspirated into a single use, enzyme-coated electrode test strip (Lactate Pro Akray, Japan) that fills by

capillary action directly from the earlobe. Blood samples will be analysed using and a hand-held portable analyser (Lactate Pro Akray, Japan).

Repeated Sprint Ability:

Test 1: 6 x 40 m Sprint commences every 30 sec

Test 2: 8 x 30 m Sprint commences every 22.5 sec

Test 3: 12 x 20 m Sprint commences every 15 sec

Test 4: 24 x 10 m Sprint commences every 7.5 sec

Each sprint will be timedusing electronic timing gates (Fusion Sport International) and performance time decrement will be assessed. Heart rate and blood lactate will be measured and RPE will be assessed at the beginning and end of each test.

2.4 PARTICIPANT PROFILE

Club level (U-18) and collegiate level Gaelic football players will be recruited to take part in the study.

Inclusion criteria:

- Current member of a division 1 collegiate senior Gaelic football panel
- Male
- Clinically stable and in good health

Exclusion criteria:

Potential participants will be excluded if:

- Current smoker
- Clinical conditions that may preclude them from exercise. This information will be obtained from a questionnaire that will be completed by the participants

2.5 MEANS BY WHICH PARTICIPANTS ARE TO BE RECRUITED *(see Guidelines)*

A letter (Appendix A) providing a brief summary of the research project will be sent to the managers of third level senior football teams in the greater Dublin region. David Kelly (PhD student) will make a follow up phone call to each manager and will arrange to give a presentation to each of the teams that agree to participate. The purpose of the study will be outlined and a brief summary of what is involved will be explained to all potential participants. They will be provided with an informed consent to be signed. In addition, they will complete a Physical Activity Readiness Questionnaire (Appendix B)

2.6 PLEASE EXPLAIN WHEN, HOW, WHERE, AND TO WHOM RESULTS WILL BE DISSEMINATED, INCLUDING WHETHER PARTICIPANTS WILL BE PROVIDED WITH ANY INFORMATION AS STO THE FINDINGS OR OUTCOMES OF THE PROJECT?

The results obtained will form the basis for a postgraduate thesis and will be presented at scientific meeting and published in scientific journals. The identity of the individual participants will remain anonymous. Information, as a group, will only be presented. Participants will be provided with a report which will detail their results from participating in the study.

2.7 OTHER APPROVALS REQUIRED *Has permission to gain access to another location, organisation etc. been obtained? Copies of letters of approval to be provided when available.*

☐ YES ☐ NO ☒ NOT APPLICABLE

(If YES, please specify from whom and attach a copy. If NO, please explain when this will be obtained.)

2.8 HAS A SIMILAR PROPOSAL BEEN PREVIOUSLY APPROVED BY THE REC?

☐ YES ☒ NO

(If YES, please state both the REC Application Number and Project Title)

3. RISK AND RISK MANAGEMENT

3.1 ARE THE RISKS TO SUBJECTS AND/OR RESEARCHERS ASSOCIATED WITH YOUR PROJECT GREATER THAN THOSE ENCOUNTERED IN EVERYDAY LIFE?

☒ YES ☐ NO *If YES, this proposal will be subject to full REC review*

If NO, this proposal may be processed by expedited administrative review

3.2 DOES THE RESEARCH INVOLVE:

	YES	N
• use of a questionnaire? (attach copy)?	☒	☐
• interviews (attach interview questions)?	☐	☒
• observation of participants without their knowledge?	☐	☒
• participant observation (provide details in section 2)?	☐	☒
• audio- or video-taping interviewees or events?	☐	☒
• access to personal and/or confidential data (including student, patient or client data) without the participant's specific consent?	☐	☒
• administration of any stimuli, tasks, investigations or procedures which may be experienced by participants as physically or mentally painful, stressful or unpleasant during or after the research process?	☒	☐
• performance of any acts which might diminish the self-esteem of participants or cause them to experience embarrassment, regret or depression?	☐	☒
• investigation of participants involved in illegal activities?	☐	☒
• procedures that involve deception of participants?	☐	☒
• administration of any substance or agent?	☐	☒
• use of non-treatment of placebo control conditions?	☐	☒
• collection of body tissues or fluid samples?	☒	☐
• collection and/or testing of DNA samples?	☐	☒

- participation in a clinical trial? ☐ ☒
- administration of ionising radiation to participants? ☐ ☒

3.3 POTENTIAL RISKS TO PARTICIPANTS AND RISK MANAGEMENT PROCEDURES

1. Exercise is associated with a very small risk of abnormal heart rhythms, heart attack or death. However, the likelihood of a cardiac event in a healthy asymptomatic healthy college age men is extremely rare.
2. The base of ear lobe will be jabbed with a lancet (Accu-Chek Softclix, UK) in order to obtain blood samples for measuring lactate. This procedure may cause slight pain and discomfort. Blood samples will be taken by an experienced researcher. A safe volume of 70-100 1.0 μL l of blood will be drawn.

3.4 ARE THERE LIKELY TO BE ANY BENEFITS (DIRECT OR INDIRECT) TO PARTICIPANTS FROM THIS RESEARCH?

☒ YES ☐ NO Subjects will receive feedback on each of the fitness parameters assessed.

3.5 ARE THERE ANY SPECIFIC RISKS TO RESEARCHERS? *(e.g. risk of infection or where research is undertaken at an off-campus location)*

☒ YES ☐ NO Risk is associated with working with blood and handling lancets. The research team has been immunized for hepatitis B. Standard operating procedures for the handling of biological products exist within the School of Health and Human Performance.

3.6 ADVERSE/UNEXPECTED OUTCOMES

The School of Health and Human Performance has established an emergency protocol for adverse events. In the unlikely event of a major adverse outcome, an ambulance will be called and the participant will be sent immediately to Beaumont Hospital. Any minor adverse outcomes will be dealt with by the study physician who will then refer the participant, if required, to the VHI- Swift Care clinic in Swords for further attention.

3.7 MONITORING

The research team will have meetings on a weekly basis to update on all aspects of the study. All researchers involved in the study will be familiar with testing procedures and the safety statement prior to commencing data collection. A number of practice sessions will be undertaken by all the research team to ensure proficiency and reliability in performing the data collection procedures.

3.8 SUPPORT FOR PARTICIPANTS

This study does not require additional support for participants

3.9 DO YOU PROPOSE TO OFFER PAYMENTS OR INCENTIVES TO PARTICIPANTS?

☐ YES ☒ NO *(If YES, please provide further details.)*

3.10 DO ANY OF THE RESEARCHERS ON THIS PROJECT HAVE A PERSONAL, FINANCIAL OR COMMERCIAL INTEREST IN ITS OUTCOME THAT MIGHT INFLUENCE THE INTEGRITY OF THE RESEARCH, OR BIAS THE CONDUCT OR RESULTS OF THE RESEARCH, OR UNDULY DELAY OR OTHERWISE AFFECT THEIR PUBLICATION?

☐ YES ☒ NO *(If Yes, please specify how this conflict of interest will be addressed.)*

4. INVESTIGATORS' QUALIFICATIONS, EXPERIENCE AND SKILLS *(Approx. 200 words – see Guidelines)*

Prof. Niall M. Moyna is an exercise physiologist and has extensive experience in exercise related research.

David Kelly is a PhD student in exercise physiology. He has a BSc Sport Science and Health, DCU and has extensive experience of the laboratory and field based assessments to be used in the proposed study.

Michael Boyle and Kieran Sheridan are final year students on the BSc Sport Science and Health degree programme in DCU.

5. CONFIDENTIALITY/ANONYMITY

5.1 WILL THE IDENTITY OF THE PARTICIPANTS BE PROTECTED?

☒ YES ☐ NO *(If NO, please explain)*

IF YOU ANSWERED YES TO 5.1, PLEASE ANSWER THE FOLLOWING QUESTIONS:

5.2 HOW WILL THE ANONYMITY OF THE PARTICIPANTS BE RESPECTED? *(see Guidelines)*

Participant confidentiality is an important issue during data collection. Participant's identity and other personal information will not be revealed, published or used in other studies. Participants will be assigned an ID number under which all personal information will be stored in a secure locked cabinet in the School of Health and Human Performance at DCU. Electronic date will be stored on a password-protected computer in DCU. The principal investigator and named collaborators listed on this ethics application will be able to access the data.

5.3 LEGAL LIMITATIONS TO DATA CONFIDENTIALITY: *(Have you included appropriate information in the plain language statement and consent form? See Guidelines)*

☒ YES ☐ NO *(If NO, please advise how participants will be advised.)*

6 DATA/SAMPLE STORAGE, SECURITY AND DISPOSAL

6.1 HOW WILL THE DATA/SAMPLES BE STORED? *(The REC recommends that all data be stored on campus)*

Stored at DCU ☒
Stored at another site ☐ **(***Please explain where and for what purpose)*

6.2 WHO WILL HAVE ACCESS TO DATA/SAMPLES?

Access by named researchers only ☒

Access by people other than named researcher(s) ☐ **(***Please explain who and for what purpose)*
Other *:* ☐ **(***Please explain)*

6.3 IF DATA/SAMPLES ARE TO BE DISPOSED OF, PLEASE EXPLAIN HOW, WHEN AND BY WHOM THIS WILL BE DONE?

The raw data will be stored in a secure locked cabinet in the School of Health and Human Performance at DCU. Electronic date will saved in a password- protected in a computer at DCU. Data will be kept for a minimum of 5 years following from the date of the publication of the research. The principal investigator will be responsible for the security of the data. Only the other investigators listed on this ethics application form will have access to the data. The data will be shredded by the principal investigator after 5 years.

7. FUNDING

7.1 HOW IS THIS WORK BEING FUNDED?

School of Health and Human Performance

7.2 PROJECT GRANT NUMBER (If relevant and/or known)

N/A

7.3 DOES THE PROJECT REQUIRE APPROVAL BEFORE CONSIDERATION FOR FUNDING BY A GRANTING BODY?

☐ YES ☒ NO

7.5 HOW WILL PARTICIPANTS BE INFORMED OF THE SOURCE OF THE FUNDING?

NA

7.5 DO THE FUNDERS OF THIS PROJECT HAVE A PERSONAL, FINANCIAL OR COMMERCIAL INTEREST IN ITS OUTCOME THAT MIGHT COMPROMISE THE INDEPENDENCE AND INTEGRITY OF THE RESEARCH, OR BIAS THE CONDUCT OR RESULTS OF THE RESEARCH, OR UNDULY DELAY OR OTHERWISE AFFECT THEIR PUBLICATION?

☐ YES ☒ NO *(If Yes, please specify how this conflict of interest will be addressed.)*

8. PLAIN LANGUAGE STATEMENT

Plain Language Statement

Project Title: Repeated Sprint Ability in Collegiate Level Gaelic Football Players

Principal investigator Professor Niall M. Moyna (Tel: 01-7008802; Fax 01-7008888)

Centre for Preventive Medicine

School of Health and Human Performance

Email: niall.moyna@dcu.ie

Introduction to the Research Study

I. Gaelic football is one of the most popular sports in Ireland. It is characterised by irregular bouts of maximal or near maximal sprints of short 1 to 7 seconds in duration with brief recovery periods of light-to-moderate aerobic activity. The ability to recover and reproduce maximal performance in subsequent sprints is an important component of fitness and has been termed repeated sprint ability (RSA). There is presently no information available to coaches regarding repeated sprint ability performance among Gaelic football players. Understanding the factors that determine RSA performance is important in order to design appropriate training programs. This study will compare performance in a number of RSA tests and examine the relation between selected physical and performance factors and RSA performance among collegiate level male Gaelic football players.

II. The study will take place in the School of Health and Human Performance Laboratories and DCU Sport. You will make 5 separate visits to DCU. During the first visit, you will have your height and weight measured and a series of skinfolds taken to measure the amount of muscle and fat in your body. You will then undergo a series of tests to measure your running speed muscle power and finally you will undertake a treadmill test to assess your cardiovascular fitness. You will wear a special mouthpiece and nose clip during this test in order to allow the researchers measure your breathing and how much oxygen you are taking into your body. Very small blood samples (about the size of a grain of rice) will be taken from your ear at regular intervals. The visit will last approx. 2 hours. The second visit will be used to assess your leg strength and lung function after which you will perform a test that will involve 6 separate 10 second bouts of “all-out” cycling on a special indoor bike. You will have a 30 second rest between each 10 second bout of cycling. This visit will last approximately 1.5 h. During the third visit you will run at a fast speed on a treadmill for 2 to 6 minutes. You will again wear a special mouthpiece and nose clip and have a small blood sample taken from your ear before and after the test. The third visit will last approx. 30 min. During the final two visits, you will perform two

different RSA tests separated by 30 min. You will wear a heart rate monitor and have a small blood sample taken from your ear before and after you have completed the sprints. The final two visits will be approximately 30 min in duration.

III. You may experience some muscle soreness in your legs or nausea following some of the exercise tests. Exercise carries with it a very small risk of abnormal heart rhythms, heart attack, or death. The likelihood of these risks in healthy young college age men who have no known heart disease is very low.

IV. You will receive a report summarizing the results from your tests undertaken during the study. No other benefits have been promised.

V. Your identity and other personal information will not be revealed, published or used in further studies. You will be assigned an ID number under which all personal information will be stored in a secure file and saved in a password protected file in a computer at DCU. The principal investigator, and collaborators listed on this ethics application will have access to the data. You need to be aware that confidentiality of information provided can only be protected within the limitations of the law. It is possible for data to be subject to subpoena, freedom of information claim or mandated reporting by some professions.

VI. The original documentation will be stored for a maximum of 5 years. Thereafter the documentation will be shredded.

VII. Involvement in this study is completely voluntary. You may withdraw from the Research Study at any point.

VIII. If you have concerns about this study and wish to contact an independent person, please contact: The Secretary, Dublin City University Research Ethics Committee, c/o Office of the Vice-President for Research, Dublin City University, and Dublin 9. Tel 01-7008000

9. INFORMED CONSENT FORM

DUBLIN CITY UNIVERSITY

Informed Assent Form

I. Research Study Title

Repeated Sprint Ability in Collegiate Level Gaelic Football Players

Principle Investigator

Prof. Niall M. Moyna, School of Health and Human Performance, DCU

II. Purpose of the research

- Compare performance in a number of RSA tests among collegiate level male Gaelic football players.

- Examine the relation between selected physical and performance factors and RSA performance among collegiate level male Gaelic football players

III. Confirmation of particular requirements as highlighted in the Plain Language Statement

Participant – please complete the following (Circle Yes or No for each question)

I have read the Plain Language Statement (or had it read to me) Yes ☐ No ☐

I understand the information provided Yes ☐ No ☐

I have had an opportunity to ask questions and discuss this study Yes ☐ No ☐

I have received satisfactory answers to all my questions Yes ☐ No ☐

IV. Confirmation that involvement in the Research Study is voluntary

You may withdraw from the Research Study at any point.

V. Advice as to arrangements to be made to protect confidentiality of data, including that confidentiality of information provided is subject to legal limitations

Your personal information will not be revealed, published or used in further studies. You will be assigned an ID number under which all personal information will be stored in a secure locked cabinet and saved in a password protected file in a computer at DCU. The named investigators will have access to the data. Data will be shredded after 5 years by Prof. Moyna.

Confidentiality is insured, but you must be aware that confidentiality of information provided can only be protected within the limitations of the law. It is possible for data to be subject to subpoena, freedom of information claim or mandated reporting by some professions.

VI. Any other relevant information

If you are in a dependent relationship with any of the researchers their involvement in the project will not affect ongoing assessment/grades/management or treatment of health at DCU.

VII. Signature:

I have read and understood the information in this form. My questions and concerns have been answered by the researchers, and I have a copy of this consent form. Therefore, I consent to take part in this research project

Participants Signature: _____

Name in Block Capitals: _____

Witness: _____

Date: _____

Letter to Team Managers

Dear Manager

The School of Health and Human Performance in Dublin City University is undertaking a study involving repeated sprint ability in collegiate level Gaelic football players. The ability to recover and reproduce maximal performance in subsequent sprints is an important component of fitness for Gaelic football and has been termed repeated sprint ability (RSA). There is presently no information available to coaches regarding repeated sprint ability performance among Gaelic football players. Understanding the factors that determine RSA performance is important in order to design appropriate training programs. This study will compare performance in a number of RSA tests and examine the relation between selected physical and performance factors and RSA performance among Collegiate level Gaelic football players.

The study will take place in the School of Health and Human Performance Laboratories and DCU Sport. Each study participants will be required to make 5 separate visits to DCU. They will undergo a series of tests to measure running speed, leg strength muscle power, cardiovascular fitness and repeated sprint ability.

I would welcome the opportunity to meet up with you to discuss the possible involvement of your team in the research project.

If you would like more information please feel free to contact me at 085-1618207

I will contact you in the near future

Kindest regards,

_____

David Kelly, PhD Student

Physical Activity Readiness
Questionnaire - PAR-Q
(revised 2002)

PAR-Q & YOU

(A Questionnaire for People Aged 15 to 69)

Regular physical activity is fun and healthy, and increasingly more people are starting to become more active every day. Being more active is very safe for most people. However, some people should check with their doctor before they start becoming much more physically active.

If you are planning to become much more physically active than you are now, start by answering the seven questions in the box below. If you are between the ages of 15 and 69, the PAR-Q will tell you if you should check with your doctor before you start. If you are over 69 years of age, and you are not used to being very active, check with your doctor.

Common sense is your best guide when you answer these questions. Please read the questions carefully and answer each one honestly: check YES or NO.

YES	NO		
☐	☐	1.	**Has your doctor ever said that you have a heart condition <u>and</u> that you should only do physical activity recommended by a doctor?**
☐	☐	2.	**Do you feel pain in your chest when you do physical activity?**
☐	☐	3.	**In the past month, have you had chest pain when you were not doing physical activity?**
☐	☐	4.	**Do you lose your balance because of dizziness or do you ever lose consciousness?**
☐	☐	5.	**Do you have a bone or joint problem (for example, back, knee or hip) that could be made worse by a change in your physical activity?**
☐	☐	6.	**Is your doctor currently prescribing drugs (for example, water pills) for your blood pressure or heart condition?**
☐	☐	7.	**Do you know of <u>any other reason</u> why you should not do physical activity?**

If you answered YES to one or more questions

Talk with your doctor by phone or in person BEFORE you start becoming much more physically active or BEFORE you have a fitness appraisal. Tell your doctor about the PAR-Q and which questions you answered YES.

- You may be able to do any activity you want — as long as you start slowly and build up gradually. Or, you may need to restrict your activities to those which are safe for you. Talk with your doctor about the kinds of activities you wish to participate in and follow his/her advice.
- Find out which community programs are safe and helpful for you.

NO to all questions

If you answered NO honestly to <u>all</u> PAR-Q questions, you can be reasonably sure that you can:

- start becoming much more physically active – begin slowly and build up gradually. This is the safest and easiest way to go.
- take part in a fitness appraisal – this is an excellent way to determine your basic fitness so that you can plan the best way for you to live actively. It is also highly recommended that you have your blood pressure evaluated. If your reading is over 144/94, talk with your doctor before you start becoming much more physically active.

DELAY BECOMING MUCH MORE ACTIVE:

- if you are not feeling well because of a temporary illness such as a cold or a fever – wait until you feel better; or
- if you are or may be pregnant – talk to your doctor before you start becoming more active.

PLEASE NOTE: If your health changes so that you then answer YES to any of the above questions, tell your fitness or health professional. Ask whether you should change your physical activity plan.

<u>Informed Use of the PAR-Q</u>: The Canadian Society for Exercise Physiology, Health Canada, and their agents assume no liability for persons who undertake physical activity, and if in doubt after completing this questionnaire, consult your doctor prior to physical activity.

No changes permitted. You are encouraged to photocopy the PAR-Q but only if you use the entire form.

NOTE: If the PAR-Q is being given to a person before he or she participates in a physical activity program or a fitness appraisal, this section may be used for legal or administrative purposes.

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

NAME _____

SIGNATURE _____ DATE _____

SIGNATURE OF PARENT or GUARDIAN (for participants under the age of majority) _____ WITNESS _____

Note: This physical activity clearance is valid for a maximum of 12 months from the date it is completed and becomes invalid if your condition changes so that you would answer YES to any of the seven questions.

Supported by: Health Canada Santé Canada

continued on other side...

Ethical justification for blood sampling associated with human studies conducted within DCU.

Completion instructions:

This document is intended to prompt responses to a number of standard questions which generally need to be answered to justify the sampling of blood associated with human studies.

The document is not meant to be an exhaustive exploration of the justification for such sampling and in specific situations. Additional information may be required/ requested.

Answers are expected to be brief but should also be informative. See a sample completed form at the end.

Queries should be directed to the Secretary of the Research Ethics Committee in the OVPR office.

1) **Briefly explain why blood sampling is required**

To measure blood lactate levels

2) **Outline the analyses, components or general applications to be investigated in subject blood (now and any future studies)**

Blood samples will analysed using and a hand-held portable analyser (Lactate Pro Akray, Japan). The measuring range is 0.8–23 mM/L. Lactate in the sample reacts with potassium ferricyanide and lactate oxidase to form potassium ferrocyanide and pyruvate. Upon the application of a given voltage, ferrocyanide is oxidised, releasing electrons and creating a current. This current is measured amperometrically and is directly proportional to the lactate concentration of the blood sample. The result is displayed after 60 s. The Lactate Pro is

3) **Are any alternatives available to substitute the venous sampling of blood? yes/no.**

Yes.

4) **Will sampling require cannulation or direct vein puncture?**

No. Blood samples were drawn from the earlobe. Prior to each sample, the ear lobe will be wiped with alcohol and allowed to dry thoroughly. The base of ear lobe was jabbed with a lancet (Accu-Chek Softclix, UK). Pressure will be placed on the ear lobe with the thumb and forefinger in order to provide an appropriate sample.

5) **Outline the minimum volume of original subject blood (i.e. not serumr plasma) required to measure the required components.**

5 μL

6) **Are steps being taken in the protocol to minimise the volume of blood samples being taken?** Yes

Yes. A 5 μL sample of whole blood will be aspirated directly by capillary action from the earlobe into a single use, enzyme-coated electrode test strip (Lactate Pro Akray, Japan).

7) **Are steps included to minimise the number of blood samples/vein puncture being taken?**

Yes.

8) **Anticipated sampling methodology**

Volume of blood to be taken per sample	5 μL
Maximum number of samples to be taken per "sitting"	5
Maximum number of samples taken per day	5
Maximum number of samples to be taken over the course of the full study (if long duration study indicate the amount taken in an active 1 month period)	15
Maximum anticipate number of vein puncture episodes	0
Total volume of blood that will be taken from subject.	75-100 μL

9) I certify that:-

- all persons sampling blood in this study are certified to do so through the school/unit where this work is being conducted
- that all those manipulating the resultant samples are fully trained in the safe practice of handling blood
- all persons handling this blood have received appropriate information according to current vaccination policy.

Signature of Study PI  Date: Nov 2, 2012

An original signed copy must accompany electronic submissions. Alternatively, a PDF or other scanned version with a signature may be submitted

Appendix C

Table 7.1: Physiological responses at maximal exercise in the LS-HIT group before and after training

	Experimental Condition				
	LS-HIT				
	Pre Exercise	**Post Exercise**	**Z**	**p-Value**	**Partial Eta Squared**
Age (yr)	21.63 ± 2.13	-	-	-	
Height (cm)	177.11 ± 2.97	-	-	-	
Weight (kg)	74.80 ± 7.30	75.05 ± 6.87	-0.704	0.482	-0.25
$\dot{V}O_2max$ ($ml \cdot kg^{-1} \cdot min^{-1}$)	51.83 ± 4.33	55.56 ± 4.05*	-1.960	0.050	-0.69
$\dot{V}O_2max$ ($L \cdot min^{-1}$)	3.97 ± 0.50	4.26 ± 0.50*	-1.960	0.050	-0.69
Ventilation ($L \cdot min^{-1}$)	98.95 ± 17.42	113.52 ± 14.92*	-2.521	0.012	-0.89
RER	1.08 ± 0.64	1.10 ± 0.07	-1.622	0.105	-0.57
Heart rate ($b \cdot m^{-1}$)	184.50 ± 11.98[x]	188.50 ± 9.13	-1.103	0.270	-0.39
RPE	19.00 ± 1.31	19.75 ± 0.46	-1.342	0.180	-0.47
$v\dot{V}O_2max$ ($km \cdot hr^{-1}$)	14.68 ± 1.68	16.31 ± 2.82	-1.472	0.116	-0.52
Endurance Performance	3.91 ± 2.08	5.17 ± 2.52*	-2.521	0.012	-0.89

Values are mean ± SD; differences in all variables examined using Wilcoxon signed rank test;
*p<0.05 vs. pre exercise

Table 7.2: Physiological responses at maximal exercise in the HVET group before and after training

	Experimental Condition				
	HVET				
	Pre Exercise	**Post Exercise**	**Z**	**p-Value**	**Partial Eta Squared**
Age (yr)	21.86 ± 3.53	-	-	-	
Height (cm)	174.84 ± 7.20	-	-	-	
Weight (kg)	75.14 ± 6.82	75.30 ± 6.64	-0.254	0.799	-0.10
$\dot{V}O_2max$ ($ml \cdot kg^{-1} \cdot min^{-1}$)	51.27 ± 1.88	54.05 ± 4.50	-1.352	0.176	-0.51
$\dot{V}O_2max$ ($L \cdot min^{-1}$)	3.85 ± 0.39	4.06 ± 0.48	-1.352	0.176	-0.51
Ventilation ($L \cdot min^{-1}$)	99.57 ± 17.38	105.50 ± 20.64	-1.183	0.237	-0.45
RER	1.10 ± 0.06	1.04 ± 0.08	-1.572	0.116	-0.59
Heart rate ($b \cdot m^{-1}$)	200.43 ± 12.53	188.86 ± 10.51*	-2.207	0.027	-0.83
RPE	19.29 ± 0.76	20.00 ± 0.00	-1.890	0.059	-0.71
$v\dot{V}O_2max$ ($km \cdot hr^{-1}$)	14.66 ± 1.73	15.00 ± 1.62	-1.572	0.116	-0.59
Endurance Performance	3.87 ± 3.19	4.69 ± 3.00*	-2.366	0.018	-0.89

Values are mean ± SD; differences in all variables examined using Wilcoxon signed rank test;
*p<0.05 vs. pre exercise

Table 7.3: Physiological responses at maximal exercise in the LS-HIT and HVET group before training

	Experimental Condition				
	LS-HIT	**HVET**			
	Pre Exercise	**Pre Exercise**	**Z**	**p-Value**	**Partial Eta Squared**
Age (yr)	21.63 ± 2.13	21.86 ± 3.53	-0.175	0.861	-0.06
Height (cm)	177.11 ± 2.97	174.84 ± 7.20	-0.695	0.487	-0.25
Weight (kg)	74.80 ± 7.30	75.14 ± 6.82	-0.232	0.817	-0.08
$\dot{V}O_2max$ ($ml \cdot kg^{-1} \cdot min^{-1}$)	51.83 ± 4.33	51.27 ± 1.88	-0.347	0.728	-0.12
$\dot{V}O_2max$ ($L \cdot min^{-1}$)	3.97 ± 0.50	3.85 ± 0.39	-0.463	0.643	-0.16
Ventilation ($L \cdot min^{-1}$)	98.95 ± 17.42	99.57 ± 17.38	-0.347	0.728	-0.12
RER	1.08 ± 0.64	1.10 ± 0.06	-0.464	0.643	-0.16
Heart rate ($b \cdot m^{-1}$)	184.50 ± 11.98	200.43 ± 12.53[a]	-2.034	0.042	-0.72
RPE	19.00 ± 1.31	19.29 ± 0.76	-0.130	0.896	-0.05
$v\dot{V}O_2max$ ($km \cdot hr^{-1}$)	14.68 ± 1.68	14.66 ± 1.73	-0.232	0.807	-0.08
Endurance Performance	3.91 ± 2.08	3.87 ± 3.19	-.116	0.908	-0.04

Values are mean ± SD; differences in all variables examined using Mann Whitney U test;
[a]$p<0.05$ vs. pre LS-HIT

Table 7.4: Physiological responses at maximal exercise in the LS-HIT and HVET group after training

	Experimental Condition				
	LS-HIT	HVET			
	Post Exercise	Post Exercise	Z	p-Value	Partial Eta Squared
Age (yr)	21.63 ± 2.13	21.86 ± 3.53	-0.175	0.861	-0.06
Height (cm)	177.11 ± 2.97	174.84 ± 7.20	-0.695	0.487	-0.25
Weight (kg)	75.05 ± 6.87	75.30 ± 6.64	-0.116	0.908	-0.04
$\dot{V}O_2max$ ($ml \cdot kg^{-1} \cdot min^{-1}$)	55.56 ± 4.05	54.05 ± 4.50	-0.695	0.487	-0.25
$\dot{V}O_2max$ ($L \cdot min^{-1}$)	4.26 ± 0.50	4.06 ± 0.48	-0.521	0.602	-0.18
Ventilation ($L \cdot min^{-1}$)	113.52 ± 14.92	105.50 ± 20.64	-0.579	0.563	-0.20
RER	1.10 ± 0.07	1.04 ± 0.08	-1.681	0.093	-0.59
Heart rate ($b \cdot m^{-1}$)	188.50 ± 9.13	188.86 ± 10.51	-0.174	0.862	-0.06
RPE	19.75 ± 0.46	20.00 ± 0.00	-1.373	0.170	-0.49
$v\dot{V}O_2max$ ($km \cdot hr^{-1}$)	16.31 ± 2.82	15.00 ± 1.62	-1.001	0.102	-0.35
Endurance Performance	5.17 ± 2.52	4.69 ± 3.00	-.463	0.643	-0.16

Values are mean ± SD; differences in all variables examined using Mann Whitney U test

Table 7.5: Blood lactate concentration before and after each LS-HIT training session

	Experimental Condition				
	LS-HIT				
	Pre Exercise	**Post Exercise**	**Z**	**p-Value**	**Partial Eta Squared**
Training 1	1.20 ± 0.36	11.41 ± 0.50*	-2.524	0.012	-0.89
Training 2	1.03 ± 0.21	12.19 ± 1.32*	-2.521	0.012	-0.89
Training 3	1.23 ± 0.41	12.45 ± 1.59*	-2.521	0.012	-0.89
Training 4	1.29 ± 0.36	11.88 ± 1.69*	-2.521	0.012	-0.89
Training 5	1.29 ± 0.39	13.26 ± 1.72*	-2.521	0.012	-0.89
Training 6	1.05 ± 0.31	12.90 ± 2.16*	-2.521	0.012	-0.89

Values are mean ± SD; differences in all variables examined using Wilcoxon signed rank test;
*p<0.05 vs. pre exercise

Table 7.6: Blood lactate concentration before and after each HVET training session

	Experimental Condition				
	HVET				
	Pre Exercise	**Post Exercise**	**Z**	**p-Value**	**Partial Eta Squared**
Training 1	1.03 ± 0.26	5.64 ± 3.36*	-2.371	0.018	-0.89
Training 2	1.09 ± 0.20	4.54 ± 3.30*	-2.366	0.018	-0.89
Training 3	0.97 ± 0.15	4.66 ± 3.51*	-1.992	0.046	-0.75
Training 4	0.90 ± 0.17	2.97 ± 2.27*	-2.201	0.028	-0.83
Training 5	1.01 ± 0.38	3.64 ± 2.39*	-2.201	0.028	-0.83
Training 6	0.93 ± 0.34	3.94 ± 2.14*	-2.371	0.018	-0.89

Values are mean ± SD; differences in all variables examined using Wilcoxon signed rank test;
*$p<0.05$ vs. pre exercise

Table 7.7: Blood lactate concentration before each LS-HIT and HVET session

	Experimental Condition				
	LS-HIT	HVET			
	Pre Exercise	Pre Exercise	Z	p-Value	Partial Eta Squared
Training 1	1.20 ± 0.36	11.41 ± 0.50	-0.823	0.410	-0.29
Training 2	1.03 ± 0.21	12.19 ± 1.32	-0.656	0.512	-0.23
Training 3	1.23 ± 0.41	12.45 ± 1.59	-1.113	0.266	-0.39
Training 4	1.29 ± 0.36	11.88 ± 1.69[a]	-2.261	0.024	-0.80
Training 5	1.29 ± 0.39	13.26 ± 1.72	-1.377	0.168	-0.49
Training 6	1.05 ± 0.31	12.90 ± 2.16	-1.104	0.270	-0.39

Values are mean ± SD; differences in all variables examined using Mann Whitney U test;
[a]$p<0.05$ vs. pre LS-HIT

Table 7.8: Blood lactate concentration after each LS-HIT and HVET session

	Experimental Condition				
	LS-HIT	HVET			
	Post Exercise	Post Exercise	Z	p-Value	Partial Eta Squared
Training 1	11.41 ± 0.50	5.64 ± 3.36[c]	-3.249	0.001	-1.15
Training 2	12.19 ± 1.32	4.54 ± 3.30[b]	-3.012	0.003	-1.06
Training 3	12.45 ± 1.59	4.66 ± 3.51[b]	-3.127	0.002	-1.10
Training 4	11.88 ± 1.69	2.97 ± 2.27[c]	-3.243	0.001	-1.15
Training 5	13.26 ± 1.72	3.64 ± 2.39[c]	-3.240	0.001	-1.14
Training 6	12.90 ± 2.16	3.94 ± 2.14[c]	-3.240	0.001	-1.14

Values are mean ± SD; differences in all variables examined using Mann Whitney U test;
[b]$p<0.05$ vs. pre LS-HIT, [c]$p<0.05$ vs. pre LS-HIT

Table 7.9: Treadmill velocity, %V̇O2 and heart rate at the LT and 2.0 mmol·L^{-1} and 4.0 mmol·L^{-1} fixed blood lactate concentrations in the LS-HIT group before and after training.

	Experimental Condition				
	LS-HIT				
	Pre-Training	**Post Training**	**Z**	**p-Value**	**Partial Eta Squared**
Treadmill velocity at LT	10.4 ± 1.3	10.8 ± 0.8	-0.577	0.564	-0.20
Velocity of treadmill at 2.0 mmol·L^{-1}	10.5 ± 1.7	10.3 ± 1.2	-0.544	0.586	-0.19
Velocity of treadmill at 4.0 mmol·L^{-1}	12.5 ± 1.4	12.2 ± 1.9	-0.656	0.526	-0.23
%V̇O$_2$ at LT	74.2 ± 11.0	67.8 ± 11.5	-0.943	0.345	-0.33
%V̇O$_2$ at 2.0 mmol·L^{-1}	73.1 ± 13.7	68.9 ± 6.4	-1.483	0.138	-0.52
%V̇O$_2$ at 4.0 mmol·L^{-1}	86.9 ± 8.5	77.5 ± 9.4	-1.521	0.128	-0.54
%HR at LT	84.0 ± 6.4	83.1 ± 6.4	-0.105	0.917	-0.04
%HR at 2.0 mmol·L^{-1}	81.7 ± 9.6	82.8 ± 5.2	-0.135	0.893	-0.05
%HR at 4.0 mmol·L^{-1}	93.4 ± 3.4	93.4 ± 3.3	-0.000	1.000	0.00

Values are mean ± SD; differences in all variables examined using Wilcoxon signed rank test

Table 7.10: Treadmill velocity, %V̇O2 and heart rate at the LT and 2.0 mmol·L^{-1} and 4.0 mmol·L^{-1} fixed blood lactate concentrations in the HVET group before and after training.

	Experimental Condition				
	HVET				
	Pre-Training	**Post Training**	**Z**	**p-Value**	**Partial Eta Squared**
Treadmill velocity at LT	11.0 ± 0.7	10.7 ± 1.5	-0.816	0.414	-0.31
Velocity of treadmill at 2.0 mmol·L^{-1}	10.9 ± 0.2	10.7 ± 1.5	-1.342	0.180	-0.51
Velocity of treadmill at 4.0 mmol·L^{-1}	11.4 ± 1.4	12.8 ± 1.2*	-1.992	0.046	-0.75
%$\dot{V}O_2$ at LT	75.6 ± 8.8	75.0 ± 12.5	-0.674	0.500	-0.25
%$\dot{V}O_2$ at 2.0 mmol·L^{-1}	79.0 ± 13.1	73.2 ± 12.2	-1.447	0.655	-0.55
%$\dot{V}O_2$ at 4.0 mmol·L^{-1}	80.2 ± 11.6	86.1 ± 7.9*	-1.992	0.046	-0.75
%HR at LT	86.6 ± 8.3	84.9 ± 9.4	-0.674	0.500	-0.25
%HR at 2.0 mmol·L^{-1}	87.5 ± 2.6	83.2 ± 9.8	-0.447	0.655	-0.17
%HR at 4.0 mmol·L^{-1}	91.6 ± 9.9	94.3 ± 5.2	-0.734	0.463	-0.28

Values are mean ± SD; differences in all variables examined using Wilcoxon signed rank test;
*p<0.05 vs. pre-training

Table 7.11: Treadmill velocity, %V̇O2 and heart rate at the LT and 2.0 mmol·L^{-1} and 4.0 mmol·L^{-1} fixed blood lactate concentrations in the LS-HIT and HVET group before training.

	Experimental Condition				
	LS-HIT	**HVET**			
	Pre-Training	**Pre-Training**	**Z**	**p-Value**	**Partial Eta Squared**
Treadmill velocity at LT	10.4 ± 1.3	11.0 ± 0.7	-0.788	0.431	-0.28
Velocity of treadmill at 2.0 mmol·L^{-1}	10.5 ± 1.7	10.9 ± 0.2	-0.168	0.867	-0.06
Velocity of treadmill at 4.0 mmol·L^{-1}	12.5 ± 1.4	11.4 ± 1.4	-1.359	0.174	-0.48
%V̇O$_2$ at LT	74.2 ± 11.0	75.6 ± 8.8	-0.081	0.935	-0.03
%V̇O$_2$ at 2.0 mmol·L^{-1}	73.1 ± 13.7	79.0 ± 13.1	-0.333	0.739	-0.12
%V̇O$_2$ at 4.0 mmol·L^{-1}	86.9 ± 8.5	80.2 ± 11.6	-1.143	0.253	-0.40
%HR at LT	84.0 ± 6.4	86.6 ± 8.3	-0.244	0.808	-0.09
%HR at 2.0 mmol·L^{-1}	81.7 ± 9.6	87.5 ± 2.6	-0.667	0.505	-0.24
%HR at 4.0 mmol·L^{-1}	93.4 ± 3.4	91.6 ± 9.9	-0.000	1.000	0.00

Values are mean ± SD; differences in all variables examined using Mann Whitney U test

Table 7.12: Treadmill velocity, %V̇O2 and heart rate at the LT and 2.0 mmol·L^{-1} and 4.0 mmol·L^{-1} fixed blood lactate concentrations in the LS-HIT and HVET group after training.

	Experimental Condition				
	LS-HIT	**HVET**			
	Post-Training	**Post-Training**	**Z**	**p-Value**	**Partial Eta Squared**
Treadmill velocity at LT	10.8 ± 0.8	10.7 ± 1.5	-0.149	0.881	-0.05
Velocity of treadmill at 2.0 mmol·L^{-1}	10.3 ± 1.2	10.7 ± 1.5	-0.562	0.574	-0.20
Velocity of treadmill at 4.0 mmol·L^{-1}	12.2 ± 1.9	12.8 ± 1.2	-0.696	0.486	-0.25
%V̇O$_2$ at LT	67.8 ± 11.5	75.0 ± 12.5	-1.143	0.253	-0.40
%V̇O$_2$ at 2.0 mmol·L^{-1}	68.9 ± 6.4	73.2 ± 12.2	-0.801	0.423	-0.28
%V̇O$_2$ at 4.0 mmol·L^{-1}	77.5 ± 9.4	86.1 ± 7.9	-1.736	0.083	-0.61
%HR at LT	83.1 ± 6.4	84.9 ± 9.4	-0.429	0.668	-0.15
%HR at 2.0 mmol·L^{-1}	82.8 ± 5.2	83.2 ± 9.8	-0.160	0.873	-0.06
%HR at 4.0 mmol·L^{-1}	93.4 ± 3.3	94.3 ± 5.2	-0.694	0.487	-0.25

Values are mean ± SD; differences in all variables examined using Mann Whitney U test;

Table 7.13: RE expressed as $\dot{V}O_2$ in $ml \cdot kg^{-1} \cdot min^{-1}$, $ml \cdot kg^{-1} \cdot km^{-1}$, $kcal \cdot kg^{-1} \cdot km^{-1}$ in the LS-HIT group before and after training.

	Experimental Condition				
	LS-HIT				
	Pre Training	**Post Training**	**Z**	**p-Value**	**Partial Eta Squared**
$ml \cdot kg^{-1} \cdot min^{-1}$					
8.0 ($km \cdot h^{-1}$)	30.7 ± 4.0	29.7 ± 4.3	-0.560	0.575	-0.20
9.0 ($km \cdot h^{-1}$)	34.9 ± 4.0	33.1 ± 3.9	-0.840	0.401	-0.30
10.0 ($km \cdot h^{-1}$)	35.5 ± 5.4	37.1 ± 5.0	-0.981	0.326	-0.35
11.0 ($km \cdot h^{-1}$)	40.3 ± 4.6	39.8 ± 5.3	-0.420	0.674	-0.15
$ml \cdot kg^{-1} \cdot km^{-1}$					
8.0 ($km \cdot h^{-1}$)	230.0 ± 30.1	222.4 ± 32.2	-0.560	0.575	-0.20
9.0 ($km \cdot h^{-1}$)	232.4 ± 26.6	220.8 ± 26.3	-0.840	0.401	-0.30
10.0 ($km \cdot h^{-1}$)	213.0 ± 32.4	222.8 ± 29.8	-0.981	0.326	-0.35
11.0 ($km \cdot h^{-1}$)	219.8 ± 24.9	217.2 ± 28.8	-0.420	0.674	-0.15
$kcal \cdot kg^{-1} \cdot km^{-1}$					
8.0 ($km \cdot h^{-1}$)	1.02 ± 0.13	1.03 ± 0.12	-0.700	0.484	-0.25
9.0 ($km \cdot h^{-1}$)	1.08 ± 0.07	1.04 ± 0.09	-1.120	0.263	-0.40
10.0 ($km \cdot h^{-1}$)	0.95 ± 0.11	1.03 ± 0.10	-1.400	0.161	-0.49
11.0 ($km \cdot h^{-1}$)	0.99 ± 0.06	1.01 ± 0.14	-0.280	0.779	-0.10

Values are mean ± SD; differences in all variables examined using Wilcoxon signed rank test

Table 7.14: RE expressed as $\dot{V}O_2$ in $ml \cdot kg^{-1} \cdot min^{-1}$, $ml \cdot kg^{-1} \cdot km^{-1}$, $kcal \cdot kg^{-1} \cdot km^{-1}$ in the HVET group before and after training.

	Experimental Condition				
	HVET				
	Pre Training	**Post Training**	**Z**	**p-Value**	**Partial Eta Squared**
$ml \cdot kg^{-1} \cdot min^{-1}$					
8.0 ($km \cdot h^{-1}$)	29.3 ± 2.4	30.5 ± 3.1	-1.183	0.237	-0.45
9.0 ($km \cdot h^{-1}$)	32.9 ± 3.6	34.3 ± 3.7	-0.845	0.398	-0.32
10.0 ($km \cdot h^{-1}$)	36.9 ± 3.1	36.8 ± 3.8	-0.000	1.000	0.00
11.0 ($km \cdot h^{-1}$)	39.7 ± 3.2	41.1 ± 2.9	-0.676	0.499	-0.26
$ml \cdot kg^{-1} \cdot km^{-1}$					
8.0 ($km \cdot h^{-1}$)	220.0 ± 18.3	228.8 ± 22.9	-1.183	0.237	-0.45
9.0 ($km \cdot h^{-1}$)	219.1 ± 24.2	228.8 ± 24.5	-0.845	0.398	-0.32
10.0 ($km \cdot h^{-1}$)	221.7 ± 18.5	220.5 ± 22.9	-0.000	1.000	0.00
11.0 ($km \cdot h^{-1}$)	216.4 ± 17.7	224.2 ± 15.9	-0.676	0.499	-0.26
$kcal \cdot kg^{-1} \cdot km^{-1}$					
8.0 ($km \cdot h^{-1}$)	1.01 ± 0.08	1.07 ± 0.09	-0.845	0.398	-0.32
9.0 ($km \cdot h^{-1}$)	1.03 ± 0.08	1.09 ± 0.10	-1.014	0.310	-0.38
10.0 ($km \cdot h^{-1}$)	0.99 ± 0.06	1.07 ± 0.09	-1.352	0.176	-0.51
11.0 ($km \cdot h^{-1}$)	1.00 ± 0.07	1.08 ± 0.09	-1.183	0.237	-0.45

Values are mean ± SD; differences in all variables examined using Wilcoxon signed rank test

Table 7.15: RE expressed as $\dot{V}O_2$ in $ml \cdot kg^{-1} \cdot min^{-1}$, $ml \cdot kg^{-1} \cdot km^{-1}$, $kcal \cdot kg^{-1} \cdot km^{-1}$ in the LS-HIT and HVET group before training.

	Experimental Condition				
	LS-HIT	HVET			
	Pre Training	Pre Training	Z	p-Value	Partial Eta Squared
$ml \cdot kg^{-1} \cdot min^{-1}$					
8.0 ($km \cdot h^{-1}$)	29.3 ± 2.4	30.5 ± 3.1	-0.463	0.643	-0.16
9.0 ($km \cdot h^{-1}$)	32.9 ± 3.6	34.3 ± 3.7	-0.926	0.926	-0.33
10.0 ($km \cdot h^{-1}$)	36.9 ± 3.1	36.8 ± 3.8	-0.579	0.563	-0.20
11.0 ($km \cdot h^{-1}$)	39.7 ± 3.2	41.1 ± 2.9	-0.579	0.563	-0.20
$ml \cdot kg^{-1} \cdot km^{-1}$					
8.0 ($km \cdot h^{-1}$)	220.0 ± 18.3	228.8 ± 22.9	-0.463	0.643	-0.16
9.0 ($km \cdot h^{-1}$)	219.1 ± 24.2	228.8 ± 24.5	-0.926	0.355	-0.33
10.0 ($km \cdot h^{-1}$)	221.7 ± 18.5	220.5 ± 22.9	-0.579	0.563	-0.20
11.0 ($km \cdot h^{-1}$)	216.4 ± 17.7	224.2 ± 15.9	-0.579	0.563	-0.20
$kcal \cdot kg^{-1} \cdot km^{-1}$					
8.0 ($km \cdot h^{-1}$)	1.01 ± 0.08	1.07 ± 0.09	-0.810	0.418	-0.29
9.0 ($km \cdot h^{-1}$)	1.03 ± 0.08	1.09 ± 0.10	-1.389	0.165	-0.49
10.0 ($km \cdot h^{-1}$)	0.99 ± 0.06	1.07 ± 0.09	-1.042	0.298	-0.37
11.0 ($km \cdot h^{-1}$)	1.00 ± 0.07	1.08 ± 0.09	-0.463	0.643	-0.16

Values are mean ± SD; differences in all variables examined using Mann Whitney U test

Table 7.16: RE expressed as $\dot{V}O_2$ in $ml \cdot kg^{-1} \cdot min^{-1}$, $ml \cdot kg^{-1} \cdot km^{-1}$, $kcal \cdot kg^{-1} \cdot km^{-1}$ in the LS-HIT and HVET group after training.

	Experimental Condition				
	LS-HIT	HVET			
	Post Training	Post Training	Z	p-Value	Partial Eta Squared
$ml \cdot kg^{-1} \cdot min^{-1}$					
8.0 ($km \cdot h^{-1}$)	29.7 ± 4.3	30.5 ± 3.1	-0.579	0.563	-0.20
9.0 ($km \cdot h^{-1}$)	33.1 ± 3.9	34.3 ± 3.7	-0.694	0.487	-0.25
10.0 ($km \cdot h^{-1}$)	37.1 ± 5.0	36.8 ± 3.8	-0.347	0.728	-0.12
11.0 ($km \cdot h^{-1}$)	39.8 ± 5.3	41.1 ± 2.9	-0.579	0.563	-0.20
$ml \cdot kg^{-1} \cdot km^{-1}$					
8.0 ($km \cdot h^{-1}$)	222.4 ± 32.2	228.8 ± 22.9	-0.579	0.563	-0.20
9.0 ($km \cdot h^{-1}$)	220.8 ± 26.3	228.8 ± 24.5	-0.694	0.487	-0.25
10.0 ($km \cdot h^{-1}$)	222.8 ± 29.8	220.5 ± 22.9	-0.347	0.728	-0.12
11.0 ($km \cdot h^{-1}$)	217.2 ± 28.8	224.2 ± 15.9	-0.579	0.563	-0.20
$kcal \cdot kg^{-1} \cdot km^{-1}$					
8.0 ($km \cdot h^{-1}$)	1.03 ± 0.12	1.07 ± 0.09	-1.157	0.247	-0.41
9.0 ($km \cdot h^{-1}$)	1.04 ± 0.09	1.09 ± 0.10	-0.926	0.355	-0.33
10.0 ($km \cdot h^{-1}$)	1.03 ± 0.10	1.07 ± 0.09	-0.695	0.487	-0.25
11.0 ($km \cdot h^{-1}$)	1.01 ± 0.14	1.08 ± 0.09	-1.042	0.298	-0.37

Values are mean ± SD; differences in all variables examined using Mann Whitney U test

Appendix D

Table 7.17: Anthropometric characteristics: Two-way ANOVA F, P and R values for main effects, interactions and effect size

	Effect	F	p-Value	Partial Eta Squared
Weight (kg)	Time	0.000	0.990	0.000
	Time*Group	0.016	0.902	0.026
BMI ($kg \cdot m^{-2}$)	Time	0.007	0.935	0.000
	Time*Group	0.021	0.887	0.149
Body fat (%)	Time	3.449	0.077	0.141
	Time*Group	0.105	0.749	0.121

Table 7.18: Max Data: Two-way ANOVA F, P and R values for main effects, interactions and effect size

	Effect	F	p-Value	Partial Eta Squared
$\dot{V}O_2$ max ($ml \cdot kg^{1} \cdot min^{1}$)	Time	14.44	0.001‡	0.386
	Time*Group	0.002	0.966	0.002
Ventilation ($L \cdot min^{1}$)	Time	3.120	0.091	0.124
	Time*Group	0.151	0.702	0.006
HR ($beats \cdot min^{1}$)	Time	15.69	0.001‡	0.428
	Time*Group	0.593	0.450	0.004
RPE	Time	2.474	0.129	0.097
	Time*Group	2.474	0.129	0.023
Lactate ($mmol \cdot L^{1}$)	Time	2.444	0.132	0.100
	Time*Group	0.077	0.784	0.000
$v\dot{V}O_2$ max ($km \cdot h^{1}$)	Time	14.63	0.001‡	0.411
	Time*Group	0.785	0.461	0.004

‡p<0.001.

Table 7.19: Blood lactate analysis: Two-way ANOVA F, P and R values for main effects, interactions and effect size

	Effect	F	p-Value	Partial Eta Squared
Treadmill velocity at LT	Time	0.303	0.558	0.014
	Time*Group	6.700	0.017*	0.001
Treadmill velocity at 2.0 mmol·L^{-1}	Time	0.477	0.502	0.035
	Time*Group	0.784	0.392	0.089
Treadmill velocity at 4.0 mmol·L^{-1}	Time	1.580	0.221	0.064
	Time*Group	2.701	0.114	0.044
%$\dot{V}O_2$ at LT	Time	4.257	0.051	0.162
	Time*Group	3.179	0.088	0.002
%$\dot{V}O_2$ at 2.0 mmol·L^{-1}	Time	0.354	0.566	0.038
	Time*Group	0.748	0.410	0.013
%$\dot{V}O_2$ at 4.0 mmol·L^{-1}	Time	3.852	0.062	0.149
	Time*Group	3.945	0.060	0.048
%HR at LT	Time	1.015	0.326	0.051
	Time*Group	7.181	0.015*	0.101
%HR at 2.0 mmol·L^{-1}	Time	2.236	0.173	0.218
	Time*Group	1.337	0.281	0.038
%HR at 4.0 mmol·L^{-1}	Time	2.610	0.122	0.115
	Time*Group	3.055	0.096	0.005

*$p<0.05$.

Table 7.20: Running Economy: Two-way ANOVA F, P and R values for main effects, interactions and effect size

	Effect	F	p-Value	Partial Eta Squared
ml·kg^{-1}·min^{-1}				
8.0 (km·h^{-1})	Time	1.085	0.308	0.045
	Time*Group	0.858	0.364	0.002
9.0 (km·h^{-1})	Time	3.272	0.084	0.125
	Time*Group	2.396	0.135	0.014
10.0 (km·h^{-1})	Time	1.730	0.201	0.070
	Time*Group	0.006	0.939	0.028
11.0 (km·h^{-1})	Time	3.222	0.086	0.123
	Time*Group	0.691	0.414	0.020
ml·kg^{-1}·km^{-1}				
8.0 (km·h^{-1})	Time	1.085	0.308	0.045
	Time*Group	0.858	0.364	0.002
9.0 (km·h^{-1})	Time	3.272	0.084	0.125
	Time*Group	2.396	0.135	0.014
10.0 (km·h^{-1})	Time	1.730	0.201	0.070
	Time*Group	0.006	0.939	0.028
11.0 (km·h^{-1})	Time	3.222	0.086	0.123
	Time*Group	0.691	0.414	0.020
kcal·kg^{-1}·km^{-1}				
8.0 (km·h^{-1})	Time	2.058	0.165	0.082
	Time*Group	0.000	0.991	0.000
9.0 (km·h^{-1})	Time	4.161	0.053	0.153
	Time*Group	0.009	0.924	0.003
10.0 (km·h^{-1})	Time	3.487	0.075	0.132
	Time*Group	0.866	0.362	0.014
11.0 (km·h^{-1})	Time	5.066	0.034*	0.181
	Time*Group	0.070	0.794	0.005

*p<0.05.

Table 7.21: Speed and power characteristics: Two-way ANOVA F, P and R values for main effects, interactions and effect size

	Effect	F	p-Value	Partial Eta Squared
CMJ (cm)	Time	2.475	0.129	0.097
	Time*Group	0.368	0.550	0.041
CMJ flight time (sec)	Time	2.426	0.133	0.095
	Time*Group	0.425	0.521	0.038
VJ (cm)	Time	5.290	0.031*	0.187
	Time*Group	0.475	0.497	0.026
VJ flight time (sec)	Time	4.972	0.036*	0.178
	Time*Group	0.746	0.397	0.027
5 m (sec)	Time	0.314	0.581	0.015
	Time*Group	0.309	0.584	0.001
20 m (sec)	Time	4.200	0.053	0.160
	Time*Group	5.880	0.024*	0.021

*p<0.05.

Table 7.22: Wingate test: Two-way ANOVA F, P and R values for main effects, interactions and effect size

	Effect	F	p-Value	Partial Eta Squared
Mean power (W)	Time	14.31	0.001‡	0.408
	Time*Group	0.002	0.967	0.043
Peak power (W)	Time	20.04	0.000‡	0.415
	Time*Group	0.820	0.375	0.000
Fatigue index (W)	Time	0.176	0.679	0.008
	Time*Group	0.586	0.452	0.005

‡p<0.001.

Table 7.23: Intermittent test: Two-way ANOVA F, P and R values for main effects, interactions and effect size

	Effect	F	p-Value	Partial Eta Squared
Number of intervals (N)	Time	35.82	0.000‡	0.609
	Time*Group	4.74	0.040*	0.000
Baseline lactate ($mmol \cdot L^{-1}$)	Time	0.053	0.819	0.003
	Time*Group	0.368	0.551	0.123
Peak lactate ($mmol \cdot L^{-1}$)	Time	1.512	0.233	0.070
	Time*Group	4.646	0.043*	0.072

*p<0.05. ‡p<0.001.

Appendix E

Table 7.24: Anthropometric characteristics

	Playing Level			
	County	**Club**	**t**	**p-Value**
Age (y)	21.1 ± 1.6*	19.9 ± 1.2	2.247	0.033
Height (cm)	1.9 ± 0.1*	1.8 ± 0.0	2.711	0.011
Weight (kg)	86.2 ± 8.2*	80.4 ± 6.0	2.230	0.034
BMI ($kg \cdot m^{-2}$)	25.0 ± 1.7	24.6 ± 1.6	0.630	0.529
Body fat (%)	10.0 ± 2.1	9.7 ± 3.4	0.243	0.810

Values are mean ± SD; differences in all variables examined using independent t-tests; *p<0.05 vs. club.

Table 7.25: Physiological and metabolic responses at maximal exercise

	Playing Level			
	County	**Club**	**t**	**p-Value**
$\dot{V}O_2max$ ($ml \cdot kg^{-1} \cdot min^{-1}$)	53.5 ± 4.0	56.7 ± 4.7	-1.967	0.059
Heart rate ($beats \cdot m^{-1}$)	184.7 ± 6.5†	193.6 ± 7.6	-3.441	0.002
RPE	19.5 ± 0.7	19.6 ± 0.7	0.493	0.626
Peak lactate ($mmol \cdot L^{-1}$)	8.4 ± 2.2	8.0 ± 1.3	0.567	0.576
$v\dot{V}O_2max$ ($km \cdot h^{-1}$)	14.7 ± 1.6	15.1 ± 1.6	-0.717	0.479
Performance test (sec)	342.9 ± 109.7	339.2 ± 211.3	0.058	0.954

Values are mean ± SD; differences in all variables examined using independent t-tests; †p ≤ 0.01 vs. club

Table 7.26: Blood lactate concentration

	Playing Level			
	County	**Club**	**t**	**p-Value**
Treadmill velocity at LT	11.0 ± 0.6	10.6 ± 0.8	1.511	0.144
Treadmill velocity at 2.0 $mmol \cdot L^{-1}$	11.6 ± 1.4	11.2 ± 0.7	0.835	0.413
Treadmill velocity at 4.0 $mmol \cdot L^{-1}$	13.1 ± 1.5	13.0 ± 1.2	0.047	0.963
%$\dot{V}O_2$ at LT	80.6 ± 9.1	74.0 ± 7.9	1.982	0.059
%$\dot{V}O_2$ at 2.0 $mmol \cdot L^{-1}$	82.6 ± 5.9	78.5 ± 7.0	1.509	0.146
%$\dot{V}O_2$ at 4.0 $mmol \cdot L^{-1}$	91.6 ± 6.5	89.0 ± 7.7	0.964	0.344
% HR at LT	85.8 ± 3.1	83.7 ± 4.6	1.371	0.184
% HR at 2.0 $mmol \cdot L^{-1}$	87.6 ± 4.7	86.4 ± 4.0	0.724	0.477
% HR at 4.0 $mmol \cdot L^{-1}$	94.0 ± 2.9	95.7 ± 1.7	1.934	0.064

Values are mean ± SD; differences in all variables examined using independent t-tests;

Table 7.27: RE expressed as $\dot{V}O_2$ in $ml \cdot kg^{-1} \cdot min^{-1}$, $ml \cdot kg^{-1} \cdot km^{-1}$, $Kcal \cdot kg^{-1} \cdot km^{-1}$

	County	Club	t	p-Value
	$ml \cdot kg^{-1} \cdot min^{-1}$			
8.0 ($km \cdot h^{-1}$)	32.5 ± 0.8	33.1 ± 2.1	-0.821	0.419
9.0 ($km \cdot h^{-1}$)	35.8 ± 1.3	37.6 ± 3.1	-1.902	0.069
10.0 ($km \cdot h^{-1}$)	39.7 ± 3.9	40.2 ± 3.6	-0.427	0.673
11.0 ($km \cdot h^{-1}$)	43.5 ± 4.2	44.1 ± 4.4	-0.402	0.691
	$ml \cdot kg^{-1} \cdot km^{-1}$			
8.0 ($km \cdot h^{-1}$)	243.9 ± 5.6	248.1 ± 16.0	-0.821	0.419
9.0 ($km \cdot h^{-1}$)	268.4 ± 9.7	282.0 ± 23.0	-1.902	0.069
10.0 ($km \cdot h^{-1}$)	297.4 ± 29.2	301.8 ± 27.2	-0.427	0.673
11.0 ($km \cdot h^{-1}$)	326.0 ± 31.4	330.8 ± 33.3	-0.402	0.691
	$Kcal \cdot kg^{-1} \cdot km^{-1}$			
8.0 ($km \cdot h^{-1}$)	1.1 ± 0.1	1.1 ± 0.0	0.544	0.591
9.0 ($km \cdot h^{-1}$)	1.1 ± 0.1	1.1 ± 0.1	-0.132	0.896
10.0 ($km \cdot h^{-1}$)	1.1 ± 0.1	1.1 ± 0.1	-0.370	0.714
11.0 ($km \cdot h^{-1}$)	1.1 ± 0.1	1.1 ± 0.1	-0.650	0.521

Values are mean ± SD; differences in all variables examined using independent t-tests;

Table 7.28: Jump performance, Speed, Margaria-Kalamen test and Wingate test results

	Playing Level			
	County	**Club**	**t**	**p-Value**
Vj (cm)	46.8 ± 2.5†	42.1 ± 4.9	3.209	0.003
Cmj (cm)	38.6 ± 4.3	36.9 ± 4.3	1.111	0.276
5 m (sec)	1.0 ± 0.1	1.1 ± 0.1	1.782	0.116
20 m (sec)	3.0 ± 0.1*	3.1 ± 0.1	2.140	0.047
Dj (cm)	39.4 ± 4.1	38.0 ± 4.6	0.860	0.397
Djrsi (sec)	1.0 ± 0.3	1.0 ± 0.4	-0.145	0.886
Margaria-Kalamen (sec)	0.6 ± 0.1	0.6 ± 0.1	-0.214	0.832
Margaria-Kalamen (W)	1644.7 ± 198.4	1525.0 ± 193.6	1.672	0.106
Wingate -mean power (W)	1013.9 ± 118.7*	895.3 ± 120.6	2.714	0.011
Wingate - peak power (W)	1131.5 ± 123.5*	1010.4 ± 143.5	2.652	0.013
Wingate - fatigue Index (W)	318.4 ± 72.9	274.1 ± 74.0	1.649	0.110

Values are mean ± SD; differences in all variables examined using independent t-tests;
*$p \leq 0.05$ vs. club; †$p \leq 0.01$ vs. club

Table 7.29: Isokinetic quadriceps strength

	Quadriceps			
	County	**Club**	**t**	**p-Value**
		60°·sec^{-1}		
Peak torque dom (N·m^{-1})	266.0 ± 40.0†	218.8 ± 50.2	2.848	0.008
Peak torque non-dom (N·m^{-1})	260.7 ± 31.2†	210.6 ± 49.9	3.298	0.003
		180°·sec^{-1}		
Peak torque dom (N·m^{-1})	188.0 ± 30.1*	160.4 ± 30.4	2.500	0.019
Peak torque non-dom (N·m^{-1})	178.8 ± 25.9*	151.3 ± 33.5	2.511	0.018
		300°·sec^{-1}		
Peak torque dom (N·m^{-1})	148.4 ± 24.4*	129.0 ± 25.8	2.089	0.046
Peak torque non-dom (N·m^{-1})	143.0 ± 23.2	127.7 ± 31.6	1.513	0.142

Values are mean ± SD: differences in all variables examined using independent t-tests; *p<0.05 vs. club, †p<0.01 vs. club

Table 7.30: Isokinetic hamstring strength

	Hamstring			
	County	**Club**	**t**	**p-Value**
		60°·sec^{-1}		
Peak torque dom (N·m^{-1})	122.7 ± 18.3*	107.3 ± 16.0	2.455	0.021
Peak torque non-dom (N·m^{-1})	116.8 ± 21.3*	100.7 ± 18.2	2.231	0.034
		180°·sec^{-1}		
Peak torque dom (N·m^{-1})	104.9 ± 18.0*	90.8 ± 21.3	2.500	0.019
Peak torque non-dom (N·m^{-1})	98.1 ± 17.9*	89.8 ± 18.9	2.511	0.018
		300°·sec^{-1}		
Peak torque dom (N·m^{-1})	107.0 ± 18.8*	90.8 ± 22.4	2.137	0.041
Peak torque non-dom (N·m^{-1})	104.9 ± 19.6	91.7 ± 19.0	1.869	0.072

Values are mean ± SD: differences in all variables examined using independent t-tests; *p<0.05 vs. club

Table 7.31: Isometric quadriceps strength

	$60°\cdot sec^{-1}$			
	Quadriceps			
	County	**Club**	**t**	**p-Value**
Peak torque dom ($N\cdot m^{-1}$)	46.8 ± 2.5	46.8 ± 2.5	1.399	0.173
Peak torque non-dom ($N\cdot m^{-1}$)	38.6 ± 4.3	38.6 ± 4.3	1.797	0.083

Values are mean ± SD; differences in all variables examined using independent t-tests;

Table 7.32: Correlation coefficient between average time of different RSA tests and anthropometric characteristics

	RSA Test			
	RSA 1	**RSA 2**	**RSA 3**	**RSA 4**
Age (y)	r = -0.225	r = -0.153	r = -0.219	r = -0.316
	(p = 0.240)	(p = 0.437)	(p = 0.253)	(p = 0.095)
Height (cm)	r = -0.204	r = -0.289	r = -0.183	r = 0.117
	(p = 0.279)	(p = 0.129)	(p = 0.334)	(p = 0.539)
Weight (kg)	r = -0.016	r = 0.002	r = -0.123	r = -0.093
	(p = 0.935)	(p = 0.991)	(p = 0.518)	(p = 0.626)
BMI ($kg \cdot m^{-2}$)	r = 0.160	r = 0.250	r = 0.005	r = 0.034
	(p = 0.399)	(p = 0.190)	(p = 0.980)	(p = 0.860)
Body fat (%)	r = 0.312	r = 0.280	r = 0.313	r = 0.326
	(p = 0.100)	(p = 0.149)	(p = 0.099)	(p = 0.085)

Table 7.33: Correlation coefficient between average time of different RSA tests and physiological and metabolic responses at maximal exercise

	RSA Test			
	RSA 1	**RSA 2**	**RSA 3**	**RSA 4**
$\dot{V}O_2max$ ($ml \cdot kg^{-1} \cdot min^{-1}$)	r = 0.095	r = -0.009	r = -0.030	r = -0.130
	(p = 0.619)	(p = 0.964)	(p = 0.876)	(p = 0.494)
Heart rate ($beats \cdot m^{-1}$)	r = 0.357	r = 0.251	r = 0.223	r = 0.019
	(p = 0.053)	(p = 0.188)	(p = 0.236)	(p = 0.922)
RPE	r = 0.141	r = 0.253	r = 0.042	r = 0.160
	(p = 0.457)	(p = 0.185)	(p = 0.825)	(p = 0.398)
Peak lactate ($mmol \cdot L^{-1}$)	r = -0.039	r = -0.292	r = -0.447	r = -0.400
	(p = 0.839)	(p = 0.124)	(p = 0.013)*	(p = 0.028)
$v\dot{V}O_2max$ ($km \cdot h^{-1}$)	r = 0.063	r = -0.203	r = -0.091	r = -0.049
	(p = 0.741)	(p = 0.290)	(p = 0.631)	(p = 0.798)
Performance test (sec)	r = -0.058	r = 0.107	r = -0.098	r = -0.202
	(p = 0.768)	(p = 0.594)	(p = 0.620)	(p = 0.303)

*$p<0.05$

Table 7.34: Correlation coefficient between average time of different RSA tests and blood lactate concentration

	RSA Test			
	RSA 1	**RSA 2**	**RSA 3**	**RSA 4**
Treadmill velocity at LT	r = 0.117	r = -0.123	r = -0.042	r = -0.079
	(p = 0.577)	(p = 0.557)	(p = 0.841)	(p = 0.708)
Treadmill velocity at 2.0 $mmol \cdot L^{-1}$	r = 0.104	r = 0.065	r = 0.175	r = 0.075
	(p = 0.629)	(p = 0.762)	(p = 0.412)	(p = 0.728)
Treadmill velocity at 4.0 $mmol \cdot L^{-1}$	r = 0.050	r = -0.054	r = -0.091	r = 0.054
	(p = 0.798)	(p = 0.783)	(p = 0.637)	(p = 0.780)
%$\dot{V}O_2$ at LT	r = -0.212	r = -0.141	r = -0.139	r = -0.320
	(p = 0.299)	(p = 0.493)	(p = 0.498)	(p = 0.111)
%$\dot{V}O_2$ at 2.0 $mmol \cdot L^{-1}$	r = 0.049	r = 0.272	r = -0.028	r = -0.177
	(p = 0.819)	(p = 0.199)	(p = 0.896)	(p = 0.409)
%$\dot{V}O_2$ at 4.0 $mmol \cdot L^{-1}$	r = 0.039	r = 0.227	r = 0.103	r = 0.083
	(p = 0.842)	(p = 0.226)	(p = 0.595)	(p = 0.989)
% HR at LT	r = -0.348	r = -0.202	r = 0.129	r = 0.231
	(p = 0.089)	(p = 0.333)	(p = 0.542)	(p = 0.267)
% HR at 2.0 $mmol \cdot L^{-1}$	r = 0.173	r = 0.483	r = 0.002	r = 0.153
	(p = 0.418)	(p = 0.017)*	(p = 0.992)	(p = 0.476)
% HR at 4.0 $mmol \cdot L^{-1}$	r = -0.133	r = 0.395	r = 0.244	r = 0.180
	(p = 0.499)	(p = 0.041)*	(p = 0.211)	(p = 0.360)

*$p<0.05$

Table 7.35: Correlation coefficient between average time of different RSA tests and RE expressed as $\dot{V}O_2$ in $ml \cdot kg^{-1} \cdot min^{-1}$, $ml \cdot kg^{-1} \cdot km^{-1}$, $Kcal \cdot kg^{-1} \cdot km^{-1}$

	RSA Test			
	RSA 1	**RSA 2**	**RSA 3**	**RSA 4**
	$ml \cdot kg^{-1} \cdot min^{-1}$			
8.0 ($km \cdot h^{-1}$)	r = 0.342 (p = 0.087)	r = 0.353 (p = 0.077)	r = 0.135 (p = 0.510)	r = 0.000 (p = 0.999)
9.0 ($km \cdot h^{-1}$)	r = 0.044 (p = 0.827)	r = 0.194 (p = 0.331)	r = 0.026 (p = 0.898)	r = -0.165 (p = 0.410)
10.0 ($km \cdot h^{-1}$)	r = -0.124 (p = 0.515)	r = -0.039 (p = 0.841)	r = -0.014 (p = 0.942)	r = -0.237 (p = 0.208)
11.0 ($km \cdot h^{-1}$)	r = -0.120 (p = 0.528)	r = 0.051 (p = 0.792)	r = -0.015 (p = 0.937)	r = -0.295 (p = 0.114)
	$ml \cdot kg^{-1} \cdot km^{-1}$			
8.0 ($km \cdot h^{-1}$)	r = 0.342 (p = 0.087)	r = 0.353 (p = 0.077)	r = 0.135 (p = 0.510)	r = 0.000 (p = 0.999)
9.0 ($km \cdot h^{-1}$)	r = 0.044 (p = 0.827)	r = 0.194 (p = 0.331)	r = 0.026 (p = 0.898)	r = -0.165 (p = 0.410)
10.0 ($km \cdot h^{-1}$)	r = -0.124 (p = 0.515)	r = -0.039 (p = 0.841)	r = -0.014 (p = 0.942)	r = -0.237 (p = 0.208)
11.0 ($km \cdot h^{-1}$)	r = -0.120 (p = 0.528)	r = 0.051 (p = 0.792)	r = -0.015 (p = 0.937)	r = -0.295 (p = 0.114)
	$Kcal \cdot kg^{-1} \cdot km^{-1}$			
8.0 ($km \cdot h^{-1}$)	r = -0.158 (p = 0.406)	r = 0.051 (p = 0.792)	r = -0.049 (p = 0.799)	r = -0.230 (p = 0.221)
9.0 ($km \cdot h^{-1}$)	r = -0.175 (p = 0.354)	r = 0.070 (p = 0.720)	r = 0.189 (p = 0.316)	r = 0.265 (p = 0.157)
10.0 ($km \cdot h^{-1}$)	r = -0.184 (p = 0.330)	r = -0.052 (p = 0.787)	r = -0.050 (p = 0.791)	r = -0.152 (p = 0.422)
11.0 ($km \cdot h^{-1}$)	r = -0.058 (p = 0.759)	r = 0.159 (p = 0.409)	r = 0.039 (p = 0.837)	r = -0.120 (p = 0.527)

Table 7.36: Correlation coefficient between average time of different RSA tests and jump performance, speed, Margaria-Kalamen test and Wingate test results

	RSA Test			
	RSA 1	**RSA 2**	**RSA 3**	**RSA 4**
Vj (cm)	r = -0.483	r = -0.272	r = -0.430	r = -0.245
	(p = 0.008)†	(p = 0.162)	(p = 0.020)*	(p = 0.201)
Cmj (cm)	r = -0.471	r = -0.379	r = -0.417	r = -0.303
	(p = 0.009)†	(p = 0.043)*	(p = 0.022)*	(p = 0.104)
5 m (sec)	r = 0.199	r = 0.390	r = 0.276	r = 0.057
	(p = 0.310)	(p = 0.040)*	(p = 0.155)	(p = 0.773)
20 m (sec)	r = 0.361	r = 0.558	r = 0.411	r = 0.351
	(p = 0.054)	(p = 0.002)†	(p = 0.027)*	(p = 0.062)
Dj (cm)	r = -0.480	r = -0.519	r = -0.443	r = -0.350
	(p = 0.007)†	(p = 0.004)†	(p = 0.014)*	(p = 0.058)
Djrsi (sec)	r = -0.133	r = -0.140	r = -0.253	r = -0.191
	(p = 0.493)	(p = 0.478)	(p = 0.185)	(p = 0.322)
Margaria-Kalamen (sec)	r = 0.349	r = 0.396	r = 0.282	r = 0.463
	(p = 0.059)	(p = 0.034)*	(p = 0.131)	(p = 0.010)†
Margaria-Kalamen (W)	r = -0.248	r = -0.287	r = -0.300	r = -0.288
	(p = 0.186)	(p = 0.131)	(p = 0.107)	(p = 0.123)
Wingate -mean power (W)	r = -0.399	r = -0.270	r = -0.362	r = -0.222
	(p = 0.029)*	(p = 0.156)	(p = 0.049)*	(p = 0.238)
Wingate - peak power (W)	r = -0.392	r = -0.261	r = -0.354	r = -0.210
	(p = 0.032)*	(p = 0.172)	(p = 0.055)	(p = 0.264)
Wingate - fatigue Index (W)	r = -0.487	r = -0.201	r = -0.198	r = -0.173
	(p = 0.006)†	(p = 0.295)	(p = 0.294)	(p = 0.360)

*p<0.05, †p<0.01

Table 7.37: Correlation coefficient between average time of different RSA tests and isokinetic quadriceps strength

	Quadriceps			
	RSA 1	**RSA 1**	**RSA 1**	**RSA 1**
			60°·sec^{-1}	
Peak torque dom (N·m^{-1})	r = -0.147	r = 0.010	r = -0.212	r = -0.086
	(p = 0.438)	(p = 0.961)	(p = 0.262)	(p = 0.652)
Peak torque non-dom (N·m^{-1})	r = -0.177	r = -0.085	r = -0.220	r = -0.099
	(p = 0.351)	(p = 0.663)	(p = 0.244)	(p = 0.601)
			180°·sec^{-1}	
Peak torque dom (N·m^{-1})	r = -0.250	r = -0.080	r = 0.344	r = -0.208
	(p = 0.183)	(p = 0.682)	(p = 0.063)	(p = 0.270)
Peak torque non-dom (N·m^{-1})	r = -0.314	r = -0.112	r = -0.367	r = -0.174
	(p = 0.091)	(p = 0.561)	(p = 0.046)*	(p = 0.358)
			300°·sec^{-1}	
Peak torque dom (N·m^{-1})	r = -0.259	r = -0.086	r = -0.339	r = -0.245
	(p = 0.176)	(p = 0.665)	(p = 0.072)	(p = 0.199)
Peak torque non-dom (N·m^{-1})	r = -0.413	r = -0.264	r = -0.385	r = -0.208
	(p = 0.023)*	(p = 0.166)	(p = 0.036)*	(p = 0.270)

*p<0.05

Table 7.38: Correlation coefficient between average time of different RSA tests and isokinetic hamstring strength

	Hamstring			
	RSA 1	**RSA 2**	**RSA 3**	**RSA 4**
			60°·sec^{-1}	
Peak torque dom (N·m^{-1})	r = -0.337	r = -0.090	r = -0.362	r = -0.316
	(p = 0.069)	(p = 0.641)	(p = 0.049)*	(p = 0.089)
Peak torque non-dom (N·m^{-1})	r = -0.353	r = -0.116	r = -0.292	r = -0.129
	(p = 0.056)	(p = 0.549)	(p = 0.118)	(p = 0.498)
			180°·sec^{-1}	
Peak torque dom (N·m^{-1})	r = -0.123	r = -0.120	r = -0.284	r = -0.326
	(p = 0.517)	(p = 0.534)	(p = 0.129)	(p = 0.078)
Peak torque non-dom (N·m^{-1})	r = -0.246	r = -0.048	r = -0.332	r = -0.192
	(p = 0.189)	(p = 0.805)	(p = 0.073)	(p = 0.310)
			300°·sec^{-1}	
Peak torque dom (N·m^{-1})	r = -0.215	r = 0.161	r = -0.449	r = -0.360
	(p = 0.254)	(p = 0.413)	(p = 0.013)*	(p = 0.051)
Peak torque non-dom (N·m^{-1})	r = -0.230	r = -0.319	r = -0.280	r = -0.183
	(p = 0.222)	(p = 0.092)	(p = 0.134)	(p = 0.332)

*p<0.05

Table 7.39: Correlation coefficient between average time of different RSA tests and isometric quadriceps strength

	Quadriceps			
	60°·sec^{-1}			
	RSA 1	**RSA 2**	**RSA 3**	**RSA 4**
Peak torque dom (N·m^{-1})	r = -0.249	r = -0.068	r = -0.163	r = -0.136
	(p = 0.185)	(p = 0.726)	(p = 0.389)	(p = 0.474)
Peak torque non-dom (N·m^{-1})	r = -0.188	r = -0.054	r = -0.156	r = -0.123
	(p = 0.319)	(p = 0.780)	(p = 0.410)	(p = 0.517)