Cardiff School of Sport

DISSERTATION ASSESSMENT PROFORMA:

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Comments	Section
	Title and Abstract (5%) Title to include: A concise indication of the research question/problem. Abstract to include: A concise summary of the empirical study undertaken.
	Introduction and literature review (25%) To include: outline of context (theoretical/conceptual/applied) for the question; analysis of findings of previous related research including gaps in the literature and relevant contributions; logical flow to, and clear presentation of the research problem/ question; an indication of any research expectations, (i.e., hypotheses if applicable).
	Methods and Research Design (15%) To include: details of the research design and justification for the methods applied; participant details; comprehensive replicable protocol.
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The Effect Exercise Intensity and Duration Has On Substrate Oxidation in Upper Body Aerobic Exercise

Physiology

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Abstract

Purpose: The purpose of this study was to determine the optimum intensity and duration to oxidise free fatty acids (FFA) during upper body arm ergometry over a 30-min exercise bout. **Method:** The sample population for this investigation included 5 voluntary, physically active and able-bodied male participants who were recruited from Cardiff School of Sport. The testing was carried out at Cardiff Metropolitan University physiology lab. The participants were required to attend three separate sessions, one week apart. They carried out the test seated using an electronically braked arm ergometer. On the first visit maximal oxygen consumption (VO_2max) was assessed using a graded exercise test with 20 Watt power increments every 2-min until the point of fatigue or exhaustion. The following sessions consisted of a prolonged 30-min steady-state exercise bout at 40 and 50% VO_2max. RER, VO_2 and VCO_2 values were collected from the gas analysis system at 2-min intervals throughout the 30-min duration to assess the influence exercise duration and intensity had on fat oxidation and to determine maximal fat oxidation (Fatmax). A one-way repeated measure ANOVA was used to determine significant differences in the energy derived from fat (kJ) during exercise duration, the different exercise intensities and interaction between the two. **Results**: Fat oxidation (kJ.min) increased during 0-30min and the data trend indicated a positive correlation between fat oxidation and exercise duration. This was deemed to be statistically significant ($p<0.05$). The data suggested that 50%VO_2max was the more efficient intensity for greater fat oxidation to occur. However there was no statistical significance found between the two intensities and interaction between intensity and duration ($p>0.05$). Results also suggested that over the 30-min carbohydrate (CHO) oxidation decreased over exercise duration. **Conclusion:** The general trend drawn from the results of this study indicate that there is a significant difference between fat oxidation 0-30min. The findings suggest that populations looking to partake in upper body aerobic exercise should look to exercise for >20-min at a 50%VO_2max intensity in order to elicit optimal fat oxidation, no significance however was found between the two intensities.

Chapter One

Introduction

Introduction

1.1 Introduction

Stores of body fat in the body are abundant in the form of triglycerides (TG), however these need to be transformed into non-esterified free fatty acids (FFAs) in order to be oxidised and used as an energy source (Fredrickson & Gordon, 1957). Free fatty acid oxidation is vital in providing the body with the metabolic needs that prolonged exercise exerts on the body because other fuel sources such as glucose and glycogen are unable to provide energy over sustained periods, where the supplementation or feeding of carbohydrates (CHO) is unavailable. However this is only true for moderate exercise intensities; increasing intensity results in a greater reliance upon CHO, and a greater proportional utilisation of carbohydrates and a lower utilisation of muscle TGs (Romolo *et al*., 1998). Evidently, muscle TGs are highly reliant on exercise duration, intensity and mode (Carlson et al., 1971). Despite the importance of FFAs for energy metabolism if TGs are not broken down into FFAs and oxidised then TGs can accumulate and cause cardiovascular and respiratory problems (Kelly et al., 1999). This highlights the health and physiological importance of investigating FFA oxidation.

Studies have previously investigated FFA oxidation and reported the separate affects intensity and duration have on substrate utilisation (Crisp *et al*., 2012, Chenevíére *et al*., 2009); however there is a paucity of research examining both variables simultaneously. Furthermore, the exercise mode for the collection of FFA oxidation data has mainly used cycle ergometry as the preferred method of exercise. This, although salient to the majority of the population excludes many people who cannot use their lower extremities for exercise due to obesity, injuries and/or other physical disabilities. Arm ergometry offers data on physiological responses to exercise, similar to the results collected from cycling ergometry or treadmill testing. It is a valid method which can be used to assess cardiorespiratory fitness (Price & Campbell, 1997). Furthermore, it offers information for populations who partake in upper body dominated sports such as kayaking and swimming.

Knechtle *et al.* (2004) investigated the optimal exercise intensity for FFA oxidation to occur and deemed it to be around 55% in well trained handcyclists. A major problem however with this study was that the protocol only collected data during the first 10-min of exercise. Horowitz (2001) suggested that 10 minutes of exercise is not long enough to maximise fat oxidation because the use of the FFA as an energy substrate during exercise is dependent upon its availability from the blood plasma. In order to liberate FFA's in the muscle from the intra muscular triglycerides (IMTG) stores, lipase needs to stimulate the oxidation (Jeukendrup et al., 1988). In the muscle cell, fatty acids are then transported by carrier proteins, and after stimulation, fatty acyl CoA crosses the mitochondrial membrane through the carnitine palmytoyl transferase system, after which the acyl CoA will be degraded to acetyl CoA for oxidation (Jeukendrup *et al*., 1988).

Achten *et al.* (2003) and Venables *et al*. (2005) suggested that a single graded exercise protocol with 3-min stages is the most commonly utilised protocol for determining maximal fat oxidation (Fatmax) in adults and found that highest fat oxidation rates occur at low to moderate intensity exercise, however a problem with using graded incremental protocol is that there is often scope for an overlap in intensities when moving from one intensity to the next and causing a metabolic carry over. Furthermore, Achten *et al*. (2003) only tested lower body exercise. A prolonged continuous protocol analysing upper body FFA oxidation has not previously been investigated. Brandou *et al*. (2003) identified that finding a Fatmax zone is extremely important when undergoing an intervention in preventing further obesity. This is defined as the range of exercise intensity and duration where fat oxidation rates are within 10% of maximal fat oxidation (MFO) (Achten *et al*., 2002).

The majority of the studies that have looked into exercise duration and its effect on FFA oxidation and Fatmax have ignored the impact Carbohydrate feeding has on FFA oxidation (Knechtle *et al*.,2004, Chenevie´re *et al.,* 2009, Crisp *et al.,*2012,) as this variable has not been controlled; this greatly reduces the validity of the data that has been previously collected. It is well documented that CHO feeding prior to exercise greatly decreases the FFA oxidation rate in lower body exercise (Achten and Jeukendrup, 2003). This investigation will control CHO feeding prior to exercise by ensuring all participants partake in testing in a fasted condition, in order to guarantee that the ingestion of CHO does not affect the results.

The purposes of this investigation will be to assess the influence intensity and duration has on FFA oxidation by analysing the respiratory exchange ratio (RER), VO_2 and

VCO_2 of the participants. These RER values are derived and substrate utilisation levels can be found. The continuous test will be carried out at 40 and 50% VO_2max centred around Riddell *et al.* (2008) findings that suggest Fatmax occurs between 40-56 % VO_2max. The aim is to establish a Fatmax zone where maximal fat oxidation occurs. The importance of this is to suggest the optimum training intensity and duration for populations looking to metabolise FFA and consequently reduce body fat levels. This information could be particularly salient to the clinically obese, people undergoing rehabilitation, and individuals who cannot exercise using their lower extremities.

1.2Hypothesis

1. (a) The first null hypothesis is that there will be no significant difference between exercise duration and FFA oxidation.

   (b) The first alternative hypothesis is that there will be a significant difference between exercise duration and FFA oxidation.
2. (a) The second null hypothesis is that there will be no significant difference between exercise intensity and FFA oxidation.

   (b) The second alternative hypothesis is that there will be a significant difference between exercise intensity and FFA oxidation.

Chapter Two

Literature Review

Literature Review

2.1 Introduction

Much of the classic literature regarding substrate metabolism has largely focused on the role of CHO during exercise, leading to a comprehensive understanding in this field, however leaving gaps in the research regarding fat metabolism. In recent years much more research has explored this topic as its salience is becoming more widely understood, perhaps due to the ergogenic benefits fatty acids have over CHO. For example, fat contains twice the energy per gram than CHO (4 $kcal.g^{-1}$ for CHO and 9 $kcal.g^{-1}$, respectively) and can be stored almost anhydrously (*i.e.* without the presence of water: Jeukendrup *et al.,* 1998). It would, therefore, be suggested that FFA is a beneficial substrate to use during exercise compared to CHO, however there are many health implications that can arise from storing too much fat in the form of triglycerides (Higgins *et al.*, 1988). It is clear that the research regarding the importance and efficacy of fat as a substrate is significant in both exercise and health. One particular research area that has not received much focus is the oxidation of FFA during upper body exercise. In this regard it would be pertinent to identify the optimal intensity and duration to promote lipid metabolism. This literature review will highlight the key areas surrounding this topic and critically appraise them.

2.2 Paucity and confusion in research

Research into substrate oxidation is salient in the contexts of both sports performance as well as exercise for the purpose of developing and maintaining health and fitness. Research has attempted to identify how best to reduce fat stores in the body, how to optimise carbohydrate utilisation for the purpose of optimising athletic performance or simply how to regulate or lose body mass by either expending an equivalent number, or more calories than consumed, respectively. Crisp *et al.* (2012) defined substrates use as; 'The absolute and relative contributions of fat and carbohydrate oxidation to support energy demands during exercise and how they are influenced by exercise intensity'. It is generally considered that the oxidation of FFAs is most effective at low-to-moderate exercise intensities (Sidossis *et al., 1997)*. However, a shift towards a greater contribution from CHO is observed at higher exercise intensities. This is due, in part, to the fact that fat cannot be oxidised rapidly enough to meet the increasing energy requirements of the muscles (Brooks and Mercier 1994; Venables *et al.,* 2005). Despite this, literature contradicts the fact that intensity alone is the main contributor to fat oxidation and that exercise duration plays an important part too (Chenevière *et al.,* 2009). This could be because in order to liberate FFA's in the muscle from the intra muscular triglycerides (IMTG) stores, lipase needs to stimulate the oxidation and the time this takes is unclear (Jeukendrup et al., 1988). Furthermore, there are physiological changes that occur during prolonged exercise such as alterations in hormone release such as catecholamine, noradrenaline and adrenaline production which have been demonstrated to influence FFA oxidation (Romollo *et al*., 1998). However there is contradictory research surrounding the hormonal influence on FFA oxidation. One study found that optimum FFA oxidation was at 25%VO_2max and catecholamine's increased by 50% compared to resting values. Despite this, contradicting findings in this study found that exercise at 65-85%VO_2 max oxidised less FFA, but the plasma catecholamine levels were significantly greater than the 25% findings. (Romijn, Coyle, Sidossis, *et al*., 1993). This shows the ambiguity in research surrounding this area and suggests there are other physiological factors that influence FFA oxidation. Research into substrate oxidation predominantly focuses on lower extremity research and there is a clear paucity of data with respect to upper body, aerobic work.

Due to physical disabilities or other, long-standing conditions like peripheral artery disease many individuals find it difficult or impossible to perform exercise using their lower extremities. In these situations upper-body exercise provides a practical means by which exercise can be undertaken, leading to the development and/or maintenance of cardio-respiratory fitness. It is also a valid test for individuals who are specifically trained and partaking in sports heavily upper body dominated such as swimming or kayaking (Schrieks *et al*., 2011). Although this data has been collected for lower body research, the results however cannot be generalised to upper body exercise.

The protocol adopted for much of the methodology carried out in this area of research ignores the influence carbohydrate feeding prior to exercise can have on the results of the study. For example, Chenevière *et al*. (2009) investigated the effect a 1-hr bout of exercise had on lipid oxidation and asked their participants to keep a food diary before a preliminary test. They then asked their participants to reproduce the same diet for the second test. Although this controls their diet, it does not control their CHO intake. Carbohydrate feeding prior to exercise has been suggested to influence FFA oxidation (Horowitz *et al*., 1997). This could be because the ingestion of CHO before exercise stimulates an increase in insulin concentration, which inhibits lipolysis (Achten and Jeukendrup, 2003)

2.3 Limitations when considering exercise intensity alone

There is a wide range of literature on the different variables that constitute to substrate oxidation. As exercise intensity increases past 65% VO_2max there is a noticeable decrease of FFA availability in the blood plasma (van Loon *et al*., 2007). When looking at FFA oxidation it is often exercise intensity that is manipulated as the main variable. Achten (2002) implemented a graded exercise test with 3-min stages to identify the optimal rate of fat metabolism and usage (Fatmax). Fat oxidation and exercise intensity were plotted against each other to determine the Fatmax zone and the authors found no differences in substrate oxidation when stage duration was reduced. Chenevière *et al*. (2009) however employed a low-to-moderate exercise intensity for 1-hr and suggested that as exercise duration increased, so did Fatmax. Therefore, by only exploring the impact of different exercise intensities over consecutive 10-min duration, constant load bouts of exercise may not be of a sufficient duration to observe any potential variations in fat oxidation rate over time. Indeed, it has been concluded that longer duration exercise bouts performed at a lower intensity are more beneficial at utilising FFAs for energy (Chenevière *et al.,* 2009). This enhanced fat oxidation is probably due to stimulation of adipose tissue lipolysis, which leads to an increased plasma FFA concentration (Weltan et al, 1998) Hormonal factors such as an increase in catecholamine production causes an increase in lipolysis over exercise duration, causing acceleration in lipolysis in the fat cells (Lafontan et al., 2005), supporting the need to investigate duration as well as intensity.

Furthermore during the graded exercise tests such as Achten's (2002); as the intensity increases from one to the next, it is possible that there could be a metabolic carry over from one stage to the next. Therefore, a suggestion to prevent this would be to only look at a single intensity per test in order to prevent any carry over effects. Despite this limitation, Achten (2002) validated the protocol against 35 to 80-min of steady-state exercise protocols at intensities corresponding to each stage of the graded exercise test and concluded that the graded tests provided a valid Fatmax predictor. Crisp *et al*., (2011) however disputed this validation and suggested that the rate of fat oxidation used for comparison between the protocols was averaged across the duration of each steady state exercise bout (*i.e*., fat oxidation rate across time was not reported), therefore, not rejecting the possibility that fat oxidation rate and Fatmax, may change as the duration of exercise increases. Crisp *et al*. (2011) carried out a study on exercise duration on fat oxidation in overweight boys. The results showed no correlation between exercise duration and substrate oxidation. It is however worth noting that the reason why this study did not support the findings of Chenevière *et al.* (2009) is perhaps due to the sample being overweight teenage boys (Riddell *et al*., 2008).

2.4 Lower body exercise compared with upper body exercise

Despite the research on exercise duration and substrate oxidation, it is not valid to conclude that these results are applicable, and can be translated to upper body exercise. There are a multitude of reasons for this, including; variations in muscle mass and proportional fibre type distribution, haemodynamic considerations of blood flow and plasma catecholamine levels (Flynn *et al*., 1987; Couts, 1983; Romolo *et al*., 1998). The distribution of type of muscle fibre and the change of muscle fibre recruitment during endurance exercise may play a role in substrate metabolism (Flynn *et al*., 1987). The shoulder, bicep and pectorals are the dominant muscle groups for propulsion of a hand bike and arm ergometer (Warpeha, 2005). Flynn *et al*. (1987) suggested that; 'The anterior part of the deltoid muscle consists of more type I fibres than type II fibres'. Type I fibres are high oxidative fibres and have better fat oxidation properties than type II fibres. It can, therefore, be assumed that hand biking would be more efficient at substrate oxidation, however it has been shown that during arm cranking a greater number of type II fibres are recruited compared to leg cycling (Koppo *et al*, 2002). The reason for this is likely to do with the mass difference of the two extremities and although the upper body is more type I dependent, they still have less overall type I fibres compared to the lower limbs. Type I fibres have the potential to utilise more FFAs in relation to exercise intensity (Terjung, 1983). Furthermore, catecholamine release, which has been is linked to FFA oxidation is found to be released in larger levels during lower body exercise as it engages more muscle mass (Romolo *et al*., 1998). Upper body exercise uses less muscle mass and consequently the catecholamine concentration is less prevalent in the plasma (Davies *et al*., 1974).

It is well documented that lower body aerobic exercise is superior for FFA oxidation; however, there may be certain health benefits of upper body aerobic exercise that lower body exercise is unable to confer. Findings from a study published by Almeidaa *et al*. (2010) reported a reduction in post-exercise hypertension, systolic and diastolic blood pressure, and mean arterial pressure following 1-hr after incremental arm ergormetry in young healthy individuals, therefore indicating that the arm-cranking exercise could be as effective as lower body cycle ergometry in helping to reduce post-exercise blood pressure. On top of this, there is evidence to suggest that upper body exercise can be a more effective method of exercise in the moderate-chronic obstructive lung disease population (Gregory *et al.*, 1988). Results from Gregory *et al.* (1988) suggested that upper body exercise testing elicits maximum ventilation and heart rate responses comparable to those produced by lower body testing. The findings, however, were less prevalent in the healthy and active population. Franklin et al. (1994) looked into training ability of arms vs legs in men with previous myocardial infarction. Findings suggested that both arms and legs respond in a similar manner in relation to quantitative and qualitative attributes, giving support to further research in this field. The following chapter will highlight the salience of researching upper body aerobic exercise and the key variables that will elicit Fatmax and maximal fat oxidation (MFO).

2.5 Salience for hand biking; rehab, disabled and overweight population

Hand biking can offer a rehabilitation method to prevent obesity to those who have sustained a spinal cord, hip or leg injury (Mendelsohn *et al*.,2008). Hicks *et al*. (2003) found that patients that had undergone spinal injuries and were partaking twice weekly in arm ergometery exercises had a much higher standard of physiological and psychological wellbeing. Mendelsohn *et al*. (2008) investigated the improvement of aerobic fitness during rehabilitation of hip fracture patients. The results found that patients that took part in upper body exercise had better cardiorespiratory levels and better lower body capacity when they returned to fitness. This gives further salience to the importance of finding an effective alternative to lower extremity aerobic work to utilise substrates. However the sample size of this study was small and only included participants that were physically active prior to injury, this therefore reduces the generalisability of the study.

Hand biking is also considered to be a key exercise technique for disabled individuals with reduced or no mobility. Durstine *et al*.,(2000) carried out a study looking into physical activity for the chronically disabled and found that prolonged inactivity and bed rest can cause numerous physical and psychological conditions to occur including; reduced cardiorespiratory fitness, reduced self-concept and impaired blood circulation. It was also noted that regular exercise of 50% VO_2 max has certain health benefits including; increased bone density, enhanced glucose tolerance, improved coronary risk factor profile and reduced cardiovascular-related mortality. However it is worth noting that these health benefits are only prominent in long term aerobic exercise. Durstine *et al*., (2000) findings also suggest that the optimum intensity threshold for disabled and unconditioned persons is between 40-60% VO_{2max}, further supporting the experimental design in this investigation.

The morbidly overweight population which cannot partake in lower body exercise due to the potential health risks could use arm ergometry as an alternative. Pimental *et al*., (1984) carried out an investigation to examine the physiological effects prolonged upper body exercise has. The results reported that both arm cranking and cycling produced the same oxygen uptake, therefore it could be suggested that arm cranking over a 60minute period could be sufficient to elicit cardiovascular adaptions and allow morbidly overweight individuals to partake in aerobic exercise. However due to the heart rates being lower during upper body than lower body exercise at the same relative intensity it would be suggested that upper body exercise alone is not a perfect substitute for aerobic exercise. It has been presented that an exercise programme of continuous exercise performed at Fatmax efficiently increased fat oxidation and insulin sensitivity in an obese sample (Venables & Jeukendrup, 2008). This study however, was carried out using a lower body training program so further research needs to examine whether the same results are elicited during upper body exercise.

2.6 Impact of carbohydrate on fat oxidation

It is worth noting that carbohydrate feeding prior to exercise can significantly alter the amount of FFAs that can be readily oxidised (Horowitz *et al*., 1997). A study conducted by Achten & Jeukendrupn (2003) investigated the effect of pre exercise carbohydrate feeding on fat oxidation and found that fat oxidations rates significantly decreased when carbohydrates were consumed before testing (0.46+0.06 to 0.33+0.06 $gmin^{-1}$). Carbohydrate ingestion before exercise is said to inhibit the oxidation of FFAs as the participant uses the glycogen sooner at lower intensities, FFAs become less intramuscularly available and oxidation rates reduce (Achten and Jeukendrup, 2003). The ingestion of carbohydrate before exercise in the Achten and Jeukendrup's (2003) study decreased maximal fat oxidation by 28%. This suggests that testing should be carried out in the morning before any CHO consumption, in order to eliminate CHO influencing the oxidation of FFAs. However there are obvious health implications when exercising in a fasted condition, such as hypoglycaemia which is said to occur when blood glucose is too low (NHS, 2013). The risks of undergoing a bout of exercise in a fasted state will need to be highlighted to participants.

The FFA oxidation can also be influenced by the type of CHO. The glycemic index (GI) of the CHO when ingested before exercise can affect FFA oxidation. It is suggested that FFA availability was greater after consuming a low GI meal, rather than a high GI meal (Wee, 2005), however this was not supported in all studies (Chen, 2008). Furthermore, studies have demonstrated inducing hyperglycemia and hyperinsulinamia will inhibit long-chain fatty acid oxidation (Sidosis *et al*., 1997).

2.7 Exercise duration and rationale for using 30 minutes

Research that has investigated Fat_{max} has examined the substrate utilisation of the individual up to 10-min of exercise (Achten & Jeaukendrup, 2003). This has been reported to be not long enough to elicit maximal FFA oxidation because FFAs firstly need to enter the blood stream and be released from the triglycerides within the adypocytes (Fredrickson & Gordon, 1957). Over prolonged exercise at a moderate intensity, it has been suggested that FFAs become the dominant fuel source. However this has been said to occur around the 1-2 hour stage at around 65% $VO_{2}max$ in upper body exercise (Romolo *et al*., 1998). Higher intensities over this duration (85%) tend to utilise higher levels of carbohydrates as the main energy source (Nobuo *et al*., 2006). This could be due to a change in the recruitment of type 1 muscles fibres to type 11a or type 11b muscle fibres. Analysing FFA availability for over 1-2 hours maybe beneficial to indicate whether Fat_{max} is achieved during prolonged activity, however it is worth noting that certain hormonal factors may inhibit lipolysis. The action of insulin is antilipolytic and opposite to catecholamines. Therefore insulin prevents lipolysis by sympathoadrenally mediated α-adrenergic stimulation (Galster *et al*., 1981). Hurley *et al*., 1986 demonstrated on a group of untrained males that insulin levels decreased by 25-30% during the first 30-min of exercise on a cycle ergometer. For the remainder of the 2-hour exercise bout, lipolysis remained almost the same. This suggests that insulin is a controlling mechanism for lipolysis and post 30-min of aerobic exercise its release could inhibit lipolysis.

A second rationale for using a 30-min exercise bout is due to the fatigue rate of the upper extremities. Almeidaa *et al*. (2010) carried out a comparison of post exercise responses of lower and upper extremities and reported that on average the upper extremities could not sustain the bout of exercise for as long as the lower extremities. However the protocol for this study was incremental arm ergometry as opposed to a continuous bout, so it is worth noting that that this may not necessarily reflect that traits of a continuous 30-min bout.

2.8 Conclusion

In conclusion there is large amount of research on the impact exercise intensity has on substrate usage, however less research on exercise duration. Studies have attempted to validate their short 10-min graded exercise tests and suggested that substrate utilisation is unaffected by duration, however contradictory research in this field suggests that as exercise duration increases, so does fat oxidation (Meyer *et al*.,2007). Relevant literature (Flynn *et al.*, 1987) states that deltoids are the dominant muscles in arm ergometery and consist predominantly of type I fibres which are more effective at substrate utilisation due to the higher oxygen levels. Research however proposes that for arm cranking more type II muscles fibres are recruited and are therefore less efficient at substrate oxidation. Based on the relevant literature it is clear that there is a need for further arm ergometer research due to its vast importance in today's society (Schrieks *et al*., 2011). The feeding of CHO is a variable that has been overlooked in this area. Many studies have failed to control CHO feeding in their studies perhaps implying that the implications CHO has on FFA oxidation rates are overlooked. From rehabilitation to paraplegics and fully functioning performers engaging in upper body sport, there is a need to research this field. Future literature should look to answer the contradicting and ambiguous areas in this topic that have been highlighted in this literature review. Moreover the testing should be carried out over different days in order to avoid any overlap and should also be continuous. Studies should also look to control factors such as caffeine intake or any other substances that are likely to impact on regular substrate oxidation levels.

Chapter Three

Methodology

Methodology

3.1 Subjects

The sample population for this investigation included five voluntary, physically active and able-bodied male participants who were recruited from Cardiff School of Sport. The mean age, body mass and stature of the group is displayed in table 1. The sample was all non-smokers, free of disease and not undergoing any medication. The rationale behind the sample selection is to ensure consent of the participants. Furthermore they were required to be physically active and healthy, in order to reduce any risks when undergoing an initial VO_{2max} test, as well as the more prolonged endurance testing. Ethical approval and informed consent was received before any data collection was carried out. The participants were told that they could withdraw from the testing at any time and that their names will remain anonymous throughout. Before any data collection was carried out the participants completed a pre-exercise health questionnaire, to ensure they were fit to partake in the study. The participants were asked to attend the Cardiff Metropolitan physiology laboratory at the same time for each data collection at 9-11 o'clock to avoid any circadian variance.

Table 1. Participant characteristics.

Subject characteristics	Mean (S ±)
Age	21 ±0.5
Height (cm)	1.83 ±0.06
Body Mass (kg)	86.39 ±9.01
BMI	25.98 ± 3.13
VO_{2}max (ml·min-1·kg -1)	45.40 ± 9.67

3.2 Body Anthropometrics

Height was measured to the nearest 0.01m on a standardised, wall-mounted stadiometer (Holtain Fixed Stadiometer, Crymych, Pembs) with participants standing bare foot and their head in the Frankfort plane. Body mass was determined to the nearest 0.01 kg using digital scales (SECA-Model 770, Hamburg, Germany) , wearing light clothing and without shoes. Body mass index (BMI) was calculated as body mass (kg) divided by stature (m) squared (Cole *et al*., 2000).

<u>3.3 Equipment</u>

The test was conducted at Cardiff Metropolitan University physiology lab. A stadiometer (Holtain Fixed Stadiometer, Crymych, Pembs) and digital scales (SECA-Model 770, Hamburg, Germany) were used to measure height and body mass, respectively. All exercise testing was performed on an electronically braked arm crank ergometer (Lode Arm Ergometer, Groningen, the Netherlands). Breath by breath analysis was conducted using an online gas analysis system in order to determine RER, VO_2 and VCO_2 (Breath by breath Analysis System, Jeager, Warwick, Warwickshire, UK.). Other equipment needed included; heart-rate monitors (Polar Electro. RS4000, Kemple, Finland), and a two way breathing valve (Salford valve, two way breathing valve, Birmingham, UK)

<u>3.4 Experimental protocol</u>

The testing was carried out at Cardiff Metropolitan University physiology lab. The participants were required to attend three separate sessions one week apart. On the first visit, body anthropometrics and VO_2max results were collected. Body anthropometrics were collected using a stadiometer (Holtain Fixed Stadiometer, Crymych, Pembs) for height and digital scales (SECA- Model 770, Hamburg, Germany) for weight. Before each session they were reminded not to engage in any strenuous exercise 24-hr prior to the testing and arrive for testing in a fasted state. Bergman & Brooks (1999) showed ingesting CHO 4-hrs prior to exercise affects substrate metabolism specifically during low-moderate exercise intensity. Therefore participants were asked to refrain from eating breakfast on the day of the testing. The electronically-braked arm ergometer was specifically set up for each participant. The hand bike-shoulder angle was standardised at 90° to ensure all the participants engaged the same muscles during the testing. This angle was repeated in every test to avoid within-participant variability. The significance of this was highlighted by Leicht and Spinks (2007) whom compared the cardiovascular effects of the shoulder angle during arm ergometry at 45° and 90°. A much higher heart rate was noticed in participants with the 45° shoulder angle, however there was no variance in oxygen consumption. Leicht and Spinks (2007) concluded that due to the large inter-test variability; arm ergometry should be conducted using the same seated position. RER was collected automatically on a breath-by-breath basis and displayed throughout the duration of the testing.

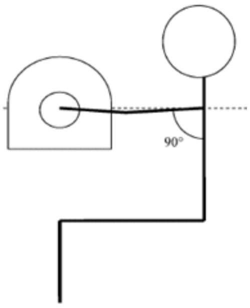

Fig 1. Standardisation of the arm ergometer-shoulder angle at 90°

3.5 $VO_{2\,max}$ tests

Prior the start of the peak test, participants were asked to carry out a 2-min warm up. Before each test, the oxycon gas analysis was calibrated at the start of each test. Maximal oxygen consumption (VO_{2max}) was assessed using a graded exercise test with 20 Watt power increments every 2-min until the point of fatigue or exhaustion. Participants were asked to maintain 75rpm on the arm ergometer throughout the VO_2max test. The test was carried out on an electronically braked arm ergometer (Lode Arm Ergometer, Groningen, the Netherlands) and respiratory gases were analysed using a breath by breath Analysis System (Jeager, Warwick, Warwickshire, UK). Fatigue was deemed when the participant was unable to sustain the momentum of the arm ergometer, has deemed themselves >20 on the rate of perceived exertion (RPE) chart or their heart rate was greater than 220 minus their age (220-age). Other indications such as dizziness also suggested that VO_{2peak} had occurred and the test was terminated. The participants were then asked to partake in a 5 minute active recovery at 30w. VO_{2max} was defined as the average oxygen consumption found from expiratory data during the final 60s of exercise. One minute power output at VO_{2max} was used to derive the continuous exercise intensities for the participants and the highest VO_2 value was used to determine VO_{2max}. VO_{2max} results are displayed in table 1.

3.6 Continuous exercise tests and gas analysis

Participants were then asked to attend the Cardiff Metropolitan physiology laboratory for two more morning sessions. Participants were requested to attend the testing in an overnight fasted state. They carried out the test seated using an electronically braked arm ergometer (Lode Arm Ergometer, Groningen, the Netherlands). The following two visits consisted of a prolonged 30-min steady-state exercise bout at 40 and 50% VO_{2max}. These intensities are centred on the previous literature that suggests that Fatmax occurs at 40–56% VO_2max (Riddell *et al*., 2008). The participants were asked to maintain the cadence at 75rpm throughout the duration of the continuous exercise bout. An online gas analysis system was used to collect the RER, VO_2 and VCO_2 which were used to derive FFA oxidation, energy derived from fat and energy expenditure (EE). RER values were collected from the gas analysis system at 2 minute intervals throughout the 30-min duration to determine Fatmax. This was done so using an RER conversion chart taken from McArdle, Katch & Katch (2001). Heart rate was collected at 2-min intervals throughout the duration of the 30-min exercise bout. RPE was collected centrally and peripherally every 10-min using the 6–20-point Borg's scale (Borg, 1973). Energy expenditure (EE) was calculated every 2-min during the exercise. The formula for EE used was:

Total EE (kJ) = [Energy per litre (kJ·l-1) x VO_2 (l·min-1)] x Time (mins)

Once EE had been collected at each 2-min interval, RER was used to determine the total energy derived from fat at each 2-min interval. This allowed the total amount of energy derived from fat at every 2-min interval to be calculated using the following formula:

Total energy derived from fat (kJ) = % (Energy derived from fat at a particular stage x Total EE(kJ))/100

For example, the RER value of one participant during the 10th minute of exercise at the 40% VO_2max exercise bout was 0.94, this equated to 20.82 kJ·l-1 using the RER conversion table taken from McArdle, Katch & Katch (2001). The VO_2 value at this time was calculated to be 1.85 l·min-1. The total accumulative EE over the exercise bout was determined using the following equation:

Total EE (kJ) = [Energy per litre (kJ·l-1) x VO2 (l·min-1)] x duration (mins)

= [20.82 kJ·l-1 x 1.85 l·min-1] x 10 min

=385.17 kJ

The RER value of 0.94 equated to 19.3% of energy derived from fat at the 10th-min.

The total energy derived from fat was calculated using the equation:

$$\text{Total energy derived from fat} = \frac{\text{\% Energy derived from fat x Total EE}}{100}$$

$$= \frac{19.3\% \times 385.17 \text{ kJ}}{100}$$

= 75.88 kJ of energy derived from fat during the first 10-min of exercise at 40% VO_2max for this participant

Lastly, the percentage of energy derived from fat during exercise and recovery combined was calculated using the following equation:

$$\text{Percentage of energy derived from fat} = \frac{\text{Total energy derived from fat (kJ)}}{\text{Total EE (kJ)}}$$

Fat oxidation and CHO oxidation (kJ.min) was plotted every 2-min over the 30-min exercise bout. The formula used was adopted from Frayn (1983):

Fat oxidation=1.67 x VO_2 - 1.67 x VCO_2

CHO oxidation=4.55xVCO_2 - 3.21xVO_2

3.7 Statistical analyses

IBM SPSS statistics software version 20 was used on windows to run the statistical analysis on the collected data. Repeated measures ANOVA was used to examine the significance of exercise intensity and duration on Fatmax and the rate of fat oxidation. It was deemed statistically significant if the *p*-value was less than 0.05 ($P<0.05$). When a significant *p* value was achieved, Bonferroni post-hoc tests were run to determine where the significant differences occurred. A 95% confidence limit was adopted throughout the study.

3.8 Ethical considerations

The data collection protocol was approved by the Cardiff Metropolitan ethics committee. It was highlighted to the participants that their testing results and all other information will remain anonymous and names will not be published. Informed consent was collected from all the participants and any risks were highlighted to them beforehand. The participants were told that they could remove themselves from the study at any point and their results will not be used in the publication.

Chapter Four

Results

Results

4.1 Average values displayed at 40 and 50% VO_2max

The mean (±SD) HR, VO_2, and VCO_2, were derived from the results. This was calculated in order to compare the 40% and 50% VO_2max intensities. These are displayed in the table below with their standard deviation (±).

Table 2. Mean HR, RER, VO_2 and VCO_2 at 40 and 50%VO_2max exercise intensity over the 30-min exercise bout

	HR (BPM)	**RER**	**VO_2**	**VCO_2**
40%	122.98 (±14.9)	0.81 (±0.03)	1430.11 (±118)	1184.06 (±106)
50%	134.75 (±17.3)	0.81 (±0.04)	1847.8 (±252)	1503.45 (±183)

4.2 Energy Expenditure (kJ)

It is clear from Fig.1 that there is a linear relationship between exercise duration and cumulative aerobic energy expenditure during 30-min steady state exercise. Fig .1 Results show that post 8-min, there is a greater energy demand from the 50%VO_2max exercise intensity and therefore an increase in energy expenditure (kJ). Fig.2 depicts EE per min.

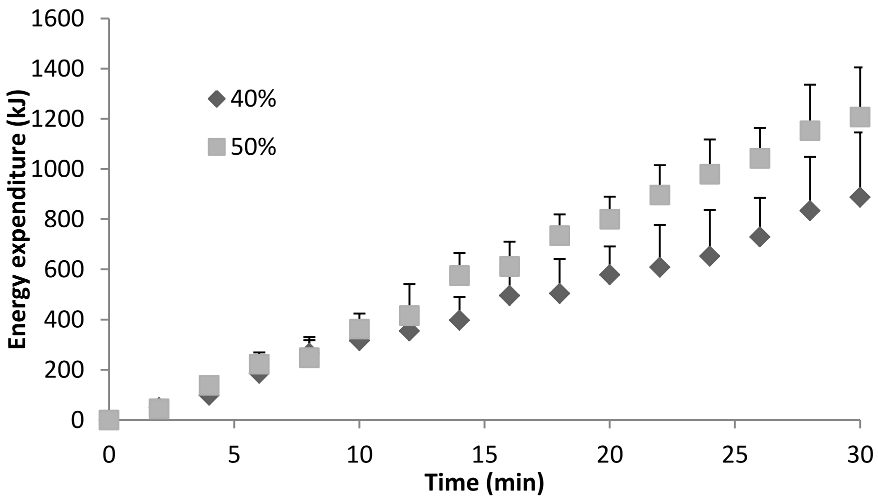

Fig.2 Mean cumulative EE at 40 and 50% VO_2max during the 30-min exercise bout exercise bout

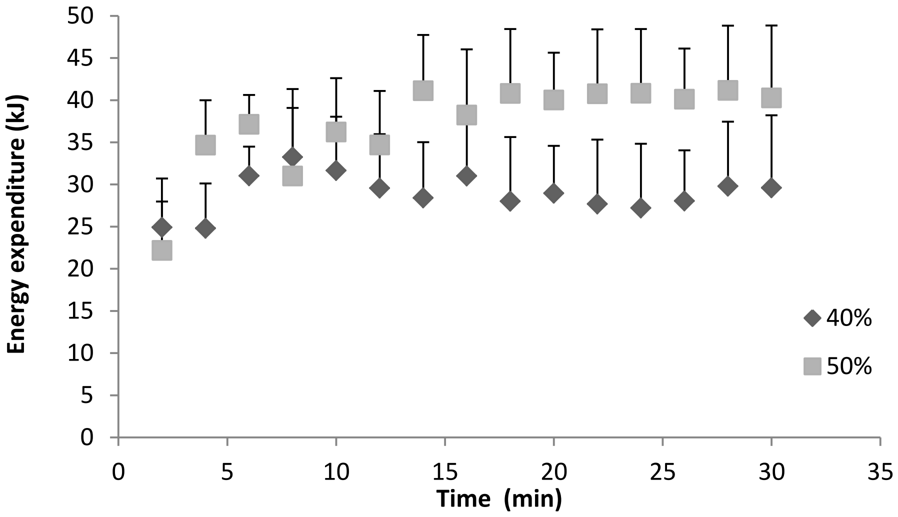

Fig.3 Mean energy expenditure at 40 and 50%VO_2max during the 30-min exercise bout

4.3 Total energy derived from fat (kJ)

Fig. 3 Depicts the effect exercise duration has on the energy derived from fat (kJ) at 40 and 50%VO_2max. The data shows that there is a positive linear relationship between exercise duration and energy derived from fat (kJ). Data also illustrates that post 10-min there is a larger amount of energy derived from fat (kJ) in the 50%VO_2max compared to the 40%VO_2max up to the 30-min period. Up until the 10-min mark the results show a very steady increase in energy derived from fat (kJ) in the 50%VO_2max intensity. Post the 10-min mark the 50%VO_2max intensity has a sharp increase in energy derived from fat. From 0-30min, the 40% VO_2max however continues deriving a steady and continuous amount of energy from fat throughout the duration of the 30-min exercise bout.

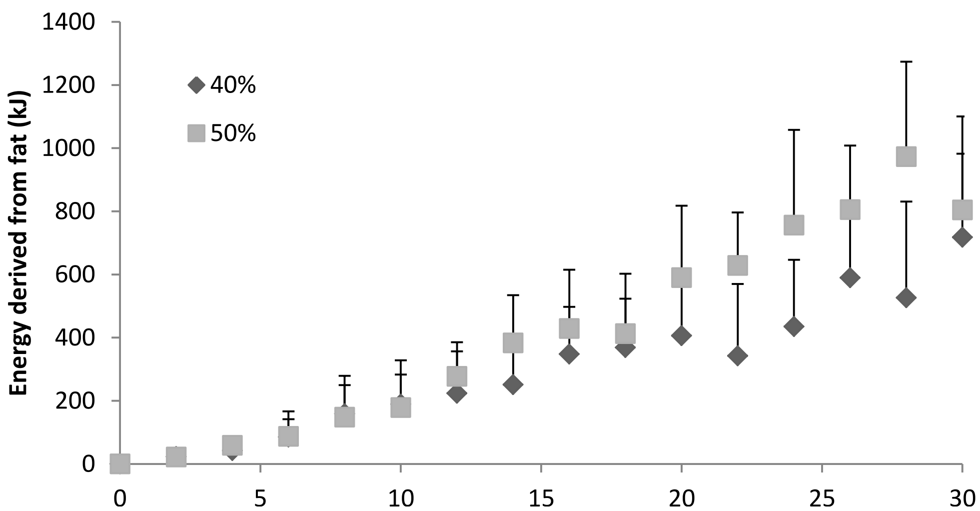

Fig. 4 Mean cumulative effect exercise duration has on the energy derived from fat (KJ) at 40 and 50%VO_2max

4.4 Fat and CHO oxidation (kJ.min)

Fig.3 and Fig.4 demonstrate the effect exercise duration has on fat and CHO oxidation. From the results it can be depicted that as exercise duration increases, fat oxidation correlates positively at both 40 and 50%VO_2max, whereas Fig 4 suggests that as duration increases, CHO oxidation correlates negatively. Fatmax appears to occur at the 28-min mark during the 50%VO_2max intensity. Post this point there is no increase in fat oxidation. In the 40%VO_2max trial however, Fatmax occurs at the 30-min period, suggesting that post this point further fat could be oxidised if the duration was extended.

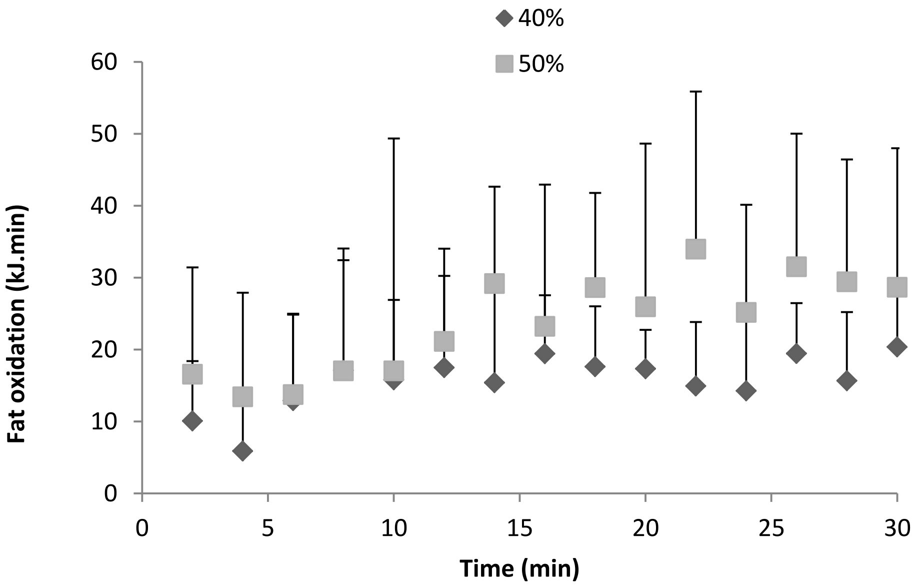

Fig.5 Mean effect exercise duration has on fat oxidation at 40 and 50%VO_2max

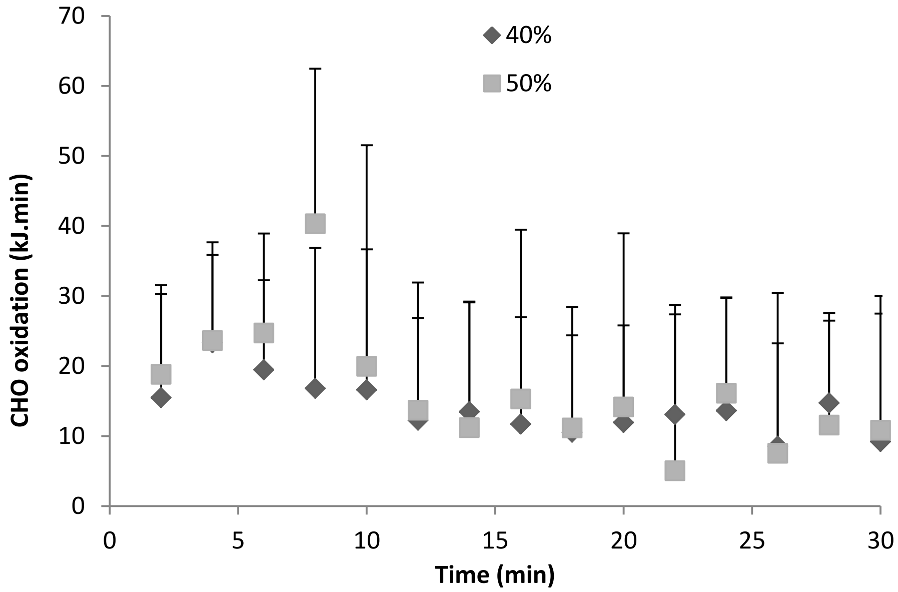

Fig.6 Mean effect exercise duration has on CHO oxidation at 40 and 50%VO_2max

Table 3. Mean EE (kJ), energy derived from fat (kJ) energy percentage derived from fat (%), Fat oxidation (kJ.min) and CHO oxidation (kJ.min) at 40 and 50%VO_2max

	Cumulative EE (kJ)	**Energy derived from fat (kJ)**	**Percentage of energy derived from fat (%)**	**fat oxidation (kJ.min)**	**CHO oxidation (kJ.min)**
40%VO_2max	464.2 ±273	294.09 ±210.8	63.6 ±19	15.6 ±3.6	14 ±8.9
50%VO_2max	629 ±381	409.66 ±317.9	69.5 ±20	23.7 ±6.7	16.3 ±4

Rate of perceived exertion

Rate of perceived exertion recorded at every 10-min (table 4). This was collected centrally and peripherally. The trend from these results suggests that there is a greater fatigue peripherally than centrally over both exercise intensities.

Table 4. Mean RPE recording central and peripheral fatigue at 40&50%VO_2max over 10-min intervals

Time (min)	**Central fatigue (RPE)**		**Peripheral fatigue (RPE)**	
	40%	**50%**	**40%**	**50%**
10	9±2	11±2	11±2	12±2
20	10±2	11±2	12±3	14±2
30	11±2	11±2	12±3	14±3

4.5 Significance of fat oxidation over 30-min at 40 and 50% VO_2max

In order to determine whether there was any significance between the exercise time, intensity and interaction between the two, a repeated measure two way ANOVA was run on SPSS in order to find any significance. Significance was found in the time variable over 0-30 min ($p<0.05$) (Table 5.). No significance was found in the intensity or the interaction (intensity*time) ($p<0.05$) Therefore, a Bonferroni post-hoc test was conducted in order to conclude where the significant differences happened. This is displayed in Table 6. The post-hoc test found that there was a level of significance at 10-30min and 30-10min ($p<0.05$). There was no significance at any other time interval ($p>0.05$).

Table 5. Repeated measure two way ANOVA to determine significance of fat oxidation over 30-min at 40 and 50% VO_2max

Multivariate Tests[a]

Effect		Value	F	Hypothesis df	Error df	Sig.	Partial Eta Squared
intensity	Pillai's Trace	.506	4.104[b]	1.000	4.000	.113	.506
	Wilks' Lambda	.494	4.104[b]	1.000	4.000	.113	.506
	Hotelling's Trace	1.026	4.104[b]	1.000	4.000	.113	.506
	Roy's Largest Root	1.026	4.104[b]	1.000	4.000	.113	.506
time	Pillai's Trace	.899	13.323[b]	2.000	3.000	.032	.899
	Wilks' Lambda	.101	13.323[b]	2.000	3.000	.032	.899
	Hotelling's Trace	8.882	13.323[b]	2.000	3.000	.032	.899
	Roy's Largest Root	8.882	13.323[b]	2.000	3.000	.032	.899
intensity * time	Pillai's Trace	.309	.671[b]	2.000	3.000	.574	.309
	Wilks' Lambda	.691	.671[b]	2.000	3.000	.574	.309
	Hotelling's Trace	.447	.671[b]	2.000	3.000	.574	.309
	Roy's Largest Root	.447	.671[b]	2.000	3.000	.574	.309

a. Design: Intercept
Within Subjects Design: intensity + time + intensity * time

b. Exact statistic

Table 6. Bonferroni post-hoc test conducted on the different time intervals to determine where the significance occurred

(I) Time	(J) Time	Sig.[b]
10	20	.082
	30	.012
20	10	.082
	30	1.000
30	10	.012
	20	1.000

10-20 $p>0.05$ therefore not significant
10-30 $p<0.05$ therefore significant
20-10 $p>0.05$ therefore not significant
20-30 $p>0.05$ therefore not significant
30-10 $p<0.05$ therefore significant
30-20 $p>0.05$ therefore not significant

Chapter Five

Discussion

Discussion

5.1 Discussion

The main finding that can be concluded from this study is that as upper body exercise duration increases from 0-30 min, FFA oxidation (kJ.min) correlates positively (Fig.4). The goal of this study was to investigate the effect upper body exercise duration and intensity had on fat oxidation and to determine the optimum criteria to elicit Fatmax. The identification of Fatmax has been suggested as an exercise technique that maybe the most suitable for reducing body fat (Brandou *et al*., 2003). In this study, the effect upper body exercise duration from 0-30min was deemed to be statistically significant ($p<0.05$), however no significance was found regarding the optimum intensity ($p>0.05$). Therefore the first alternative hypothesis can be accepted. Findings drawn from this investigation suggest that arm ergometry exercise at 50%VO_2max (23.7±6.7kJ.min) is favourable over exercise at 40% VO_2max (15.6±3.6kJ.min). This is supported in other research such as Crisp *et al. (*2012*),* who found that fat oxidation was greater at a moderate intensity (50%VO_2max) compared to a lower intensity (40%VO_2max). However the findings gathered from this study were not statistically significant and therefore this cannot be concluded.

The results of this study offer support for the use of upper body aerobic exercise as a method of exercise. These findings could be salient with populations who cannot use their lower extremities as a method of exercise and therefore need to adopt alternative means in order to prevent cardiovascular health risks associated with a sedentary lifestyle; e.g. high systolic and diastolic blood pressure (Lewington *et al*., 2002). The findings suggest that FFA oxidation increases 0-30 min at both exercise intensities, suggesting that populations that are exercising to prevent weight gain should partake in exercise for a prolonged exercise bout (>20-min) in order to elicit maximal fat oxidation. The general trend from the results suggest that at 40%VO_2max Fatmax occurs at the 30-min mark, therefore suggesting that post this point, if exercise was continued a higher Fatmax could be determined.

Other studies that has investigated the effect exercise duration has on fat oxidation have concluded juxtaposing findings. Meyer *et al.* (2007) reported a significant increase in Fatmax with increasing exercise duration in recreational athletes, whereas Crisp *et al*. (2012) found no increase in fat oxidation over exercise duration in overweight boys. This suggests that the training state of the population could determine their ability to oxidise fat over exercise duration, offering a potential implication with the generalizability of this present study as it was conducted on a physically active population. It is however worth noting that these studies are using lower body exercise, there is a scarcity of research investigating prolonged upper body exercise to determine Fatmax.

Further findings in this study show that RER decreases with exercise duration indicating that fat oxidation increases (Fig.4) with exercise duration and CHO oxidation decreases (Fig.5). Fat oxidation rose from 16.6-30 kJ.min over the 30-min at 50%VO_2max intensity, whereas CHO decreased from 18.8-10.8kJ.min.There are several factors that could explain the increase in lipolysis over exercise duration. Bulow *et al*. (2006) suggested that the increase is due to a higher sympathoadrenergic activity in combination with decreased insulin inhibition, therefore allowing FFA oxidation to increase as the insulin prevents lipolysis occurring. Other hormonal factors such as an increase in catecholamine production which causes an acceleration of the β-adrenoceptor–mediated lipolysis rate in fat cells (Lafontan *et al*., 2005).

Rate of perceived exertion (RPE) was recorded every 10-min centrally and peripherally using Borg's 6-20 scale (table 4). The results indicate that over both intensities, upper body exercise fatigues faster peripherally than centrally, this could be because of the increased lactate production due to the lower oxidative capacity of the recruited muscles used in arm ergometry (Schrieks et al., 2011). This may perhaps be an implication for prolonged upper body exercise as Issekutz et al. (1975) carried out an experiment looking at the effect lactate had on FFA oxidation in dogs and found that lactate accumulation inhibits FFA oxidation stimulated by exercise, these results however cannot be generalised. Despite this, RPE is not an accurate measure of lactate accumulation in the muscles and lactate samples would be needed in order to determine whether lactate levels are significant.

Although optimum intensities and durations can be recommended to individuals looking to achieve Fatmax, the results in this study produced a large range in standard deviation between participants, suggesting that individual difference could be an important factor when determining the optimal criteria to elicit Fatmax. Previous studies (Bircher & Knechtle 2004) have shown that differences in training status can have an influence on the percentage of fat oxidised at different intensities. Therefore individual assessments to determine the optimum criteria to for Fatmax to occur could be carried out. This could be a solution to provide useful information in order to ensure that the exercise used to promote weight loss is as efficient as possible. This however is not always plausible due to equipment requirement and cost issues.

5.2 Limitations

The major methodological limitation in this study is that it only investigated the fat oxidation of two intensities; 40 & 50% VO_2max. This limits the conclusions that can be drawn from the results regarding the optimum intensity to implement when trying to achieve Fatmax. However during the pilot study some participants struggled to complete a 30-min continuous exercise bout at 60% VO_2max , and the participants RER indicated that they were not working in a zone that allowed FFA oxidation to occur (RER >1.00). A suggestion for this is that there is an energy shift from FFA to CHO due to the recruitment of more type IIb muscle fibres from type I and type IIa (Romolo *et al*., 1998). The intensities selected were based upon a study by Riddell *et al*. (2008) which suggested that optimum FFA oxidation occurred between 40-56% VO_2max. The study could have investigated intensities below 40%VO_2max and in between 40-50%VO_2max in order to pin point more specifically the optimum intensity for Fatmax to occur, however this would have required much more extensive testing and lab time which could have deterred participants from wanting to partake in the study. In addition to this, it could be said that the 30-min duration adapted in the protocol could not be long enough to show Fatmax and FFA oxidation could peak even higher post this duration. However from an applied sense in relation to health and exercise, the demographic adopting upper body arm ergometry as a form of exercise may be reluctant to partake in a bout of exercise for longer than a 30-min period.

The type of exercise used for the design of this study was continuous. This was adopted so different intensities could be compared separately. However this study neglects the fact that alternative training methods such as interval training could be more efficient at FFA oxidation. Findings from Williams *et al*. (2013) study however concluded that increases in fat oxidation following high intensity interval training appears unlikely to be superior at FFA oxidation compared with continuous exercise. Despite this, there is an evidence to suggest that during post exercise recovery after interval training; there is an increase in lipid oxidation compared to a continuous exercise control group (Malatesta *et al.,* 2009).

This highlights a further limitation in this study which is that FFA oxidation was only recorded during the bout of exercise and no post exercise data was recorded. Malatesta et al. (2009) demonstrated that FFA oxidation remains elevated post exercise and during recovery due to an increase in catecholamine in the blood. Therefore recording post exercise oxygen consumption would provide a more complete picture as to the optimum exercise duration and intensity to work at to elicit maximal post exercise lipid oxidation and attribute to weight loss.

Increased validity and generalizability could have been drawn from this study if the sample size was larger. Furthermore, when the statistical analysis was conducted a larger sample would have allowed a smaller error margin. However, due to the protocol and design for the testing, participants had to come in for three separate sessions, spaced a minimum of 48hrs apart. The testing proved to be lengthy and deterred some participants from partaking. Furthermore the population that did take part in this study were all active and healthy young adults (21±0.5). This sample did not reflect the type of demographic who would usually adopt arm ergometry as a form of exercise. Typically arm ergometry offers an exercise solution to the obese and disabled, which do not have the use of their lower extremities; therefore upper body exercise is used as an alternative to help these populations exercise. Bircher & Knechtle (2004) compared the FFA oxidation rates between athletes and obese men and women and found that the obese sample had a FFA oxidation rate of 10% less than the athlete sample. This suggests that the results our active sample produced may not be able to be generalised to an obese and/or sedentary populations.

5.3 Strengths

A significant strength of this study was the control of CHO consumption by asking the participant to attend the lab in a fasted state. The importance of this was highlighted by Achten & Jeukendrupn (2003) who suggested that FFA oxidation significantly decreased after CHO consumption (0.46+0.06 to 0.33+0.06 $g.min^{-1}$). In order to eliminate CHO consumption impacting the results of the study, the participants were asked to attend the lab in a fasted state. Prior studies (Venables *et al.,* 2005, Schrieks *et al*., 2011) that have investigated this area of research have neglected the control of CHO and consequently this could have significantly altered the results. Some studies (Chenevière *et al*., 2009) have controlled CHO intake by administering food diaries to ensure the diet was consistent with each test; however this doesn't prevent CHO consumption influencing the results.

Standardising the arm ergometer-shoulder angle is a second strength of the methodology of this study. Prior to every test, the arm ergometer-shoulder angle was set up at 90° to ensure each participant engaged as many as the same muscles as possible. Physiological differences were investigated between two different shoulder angles in a study by Leicht &Spinks (2007). Results found that a significantly higher heart rate was discovered in the 45° angle compared to the 90° angle. Liecht & Spinks (2007) concluded that due to the large inter-test variability, arm ergometry should be carried out using the same seated position and shoulder angle.

5.4 Future Research

Future research should develop this study and use target specific populations to gauge as to the whether the results can be generalised to the clinically obese and disabled populations. Sport specific populations that use upper body strength such as kayakers and wrestlers could also look to partake in this protocol to investigate inter-population differences. Furthermore research could look to expand the exercise duration in order to investigate whether exercise post 30-min impacts FFA oxidation. In addition to this, a range of intensities could be investigated. Examining intensities less than 40%VO_2max could be beneficial to the overweight population who are unable to work at higher intensities due to potential health risks. If lesser intensities could be used efficiently for FFA oxidation, this could eliminate potential health risks that could arise from working at intensities that may be unsuitable for populations with poor fitness levels.

Studies could also investigate whether there is a significant increase in fat oxidation post exercise. It has been highlighted by Sedlock *et al.* (1989) that post exercise, substrate oxidation can remain elevated, and therefore further research in this field could show the optimum criteria to elicit Fatmax after exercise has finished. Many studies that have investigated this area have neglected this and previous findings (Sedlock *et al*., 1989) have warranted further research in this area. Further investigation into alternative training methods such as interval training could be an option to further investigate optimum criteria to attain Fatmax.

CHO consumption was controlled in this study in order to prevent the consumption affecting the validity of the results. However future research should use a control group to allow the significance of CHO consumption to be tested. Future research could modify the design of the methodology and implement a control group, of which have consumed CHO prior to testing and compare these results to the fasting group. These findings would be salient for populations wishing to lose weight as only focusing on exercise and not diet may be a one-dimensional approach to the matter.

Chapter Six

Conclusion

Conclusion 6.0

In conclusion, there is a significant difference between fat oxidation over 0-30min. The general trend that can be deduced from the results is that as exercise duration increases, there is a positive linear relationship with fat oxidation from 0-30min. The results suggest that 50%VO_2max is the optimum intensity to work at in order to elicit Fatmax, however there was no significant difference found between the two intensities. Furthermore, the results show a negative linear relationship with CHO over exercise duration, suggesting that physiological changes occur as exercise duration increases in order to determine which substrate is most suitable for the bout of exercise being carried out. Populations who cannot partake in lower body exercise looking to reduce body fat levels could use these finding to adapt their training programme in order to make them more efficient at fat oxidation, however it is worth noting that the sample used in this study was a physically active population and therefore makes generalizing the results to a wider population unsuitable. Furthermore, results taken from this study indicate that a higher FFA oxidation could occur post the 30-min period. Therefore if this study were to be replicated, longer exercise duration could be used to investigate this further. Future research should also look to adapt this study to a specific population who need to use upper body exercise as a mode of exercise as they cannot use their lower extremities. Future research should investigate post exercise substrate oxidation in order to determine the optimum exercise intensity, duration and mode to elicit maximal oxidation after the exercise bout has finished. The significance of this has been highlighted by Sedlock *et al*. (1989) and other studies have neglected its importance.

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Appendices

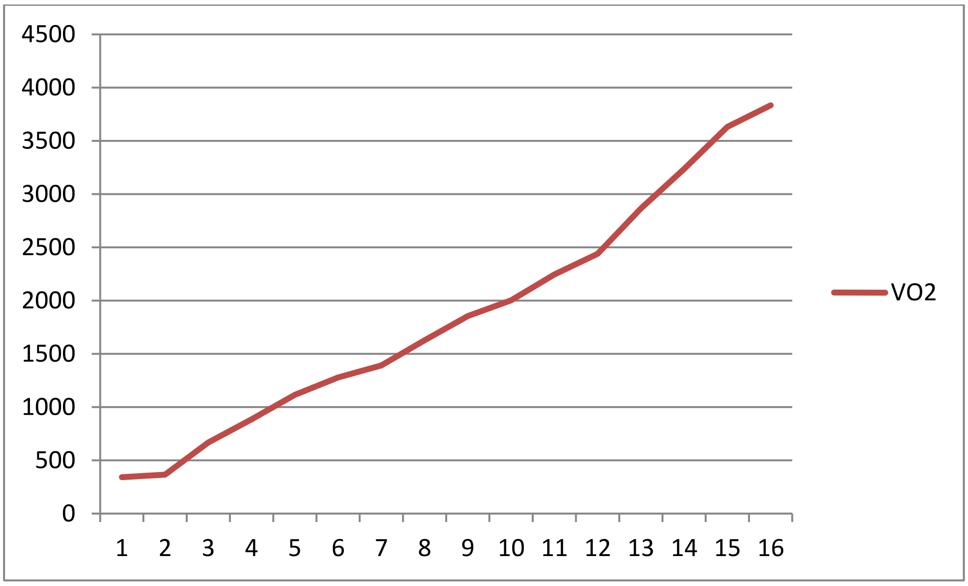
Appendix A

Energy expenditure, substrate use and RER values (McArdle, Katch & Katch, 2001).

Appendix B: Energy expenditure, substrate use and RER values (Taken from McArdle, Katch & Katch, 2001). RER	Energy per litre O2		% energy derived from		grams/litre O2	
	kCal	KJ	CHO	fat	CHO	fat
0.707	4.686	19.62	0.0	100.0	0.000	0.496
0.71	4.690	19.63	1.1	98.9	0.012	0.491
0.72	4.702	19.68	4.8	95.2	0.051	0.476
0.73	4.714	19.73	8.4	91.6	0.090	0.460
0.74	4.727	19.79	12.0	88.0	0.130	0.444
0.75	4.739	19.84	15.6	84.4	0.170	0.428
0.76	4.750	19.88	19.2	80.8	0.211	0.412
0.77	4.764	19.94	22.8	77.2	0.250	0.396
0.78	4.776	19.99	26.3	7,307.0	0.290	0.380
0.79	4.788	20.04	29.9	70.1	0.330	0.363
0.80	4.801	20.10	33.4	66.6	0.371	0.347
0.81	4.813	20.15	36.9	63.1	0.413	0.330
0.82	4.825	20.20	40.3	59.7	0.454	0.313
0.83	4.838	20.25	43.8	56.2	0.496	0.297
0.84	4.850	20.30	47.2	52.8	0.537	0.280
0.85	4.862	20.35	50.7	49.3	0.579	0.263
0.86	4.875	20.41	54.1	45.9	0.621	0.247
0.87	4.887	20.46	57.5	42.5	0.663	0.230
0.88	4.899	20.51	60.8	39.2	0.705	0.213
0.89	4.911	20.56	64.2	35.8	0.749	0.195
0.90	4.924	20.61	67.5	32.5	0.791	0.178
0.91	4.936	20.66	70.8	29.2	0.834	0.160
0.92	4.948	20.71	74.1	25.9	0.877	0.143
0.93	4.961	20.77	77.4	22.6	0.921	0.125
0.94	4.973	20.82	80.7	19.3	0.964	0.108
0.95	4.985	20.87	84.0	16.0	1.008	0.090
0.96	4.998	20.92	87.2	12.8	1.052	0.072
0.97	5.010	20.97	90.4	9.6	1.097	0.054
0.98	5.022	21.02	93.6	6.4	1.142	0.036
0.99	5.035	21.08	96.8	3.2	1.186	0.018
1.00	5.047	21.13	100.0	0.0	1.231	0.000

Appendix B

Determination of the correct intensity for the participants to work at derived from their VO_2max



This participant managed 23s at 15-min. A minute average was taken in order to determine VO_2max.

Therefore the participant worked for 23s at the 170w stage and 37s at the 150w stage. Therefore $\frac{(23x170) + (37x150)}{60}$

:.

40% VO_2max=63w

50%VO_2max = 79w

Appendix C

Raw data taken from the participants of the fat oxidised over exercise duration at 40 and 50%VO_{2}max. This equation was used to determine fat oxidation;

$1.67 \times VO_2 - 1.67 \times VCO_2$

Time	P1 40%	P1 50%	P2 40%	P2 50%	P3 40%	P3 50%	P4 40%	P4 50%	P5 40%	P% 50%
0.0	532.7	267.2	496.0	828.3	121.9	203.6	648.0	454.2	345.7	577.3
2.0	258.9	280.6	-16.7	-27.9	188.7	315.1	445.9	726.5	447.6	747.4
4.0	130.3	290.6	183.7	306.8	76.8	128.3	-217.1	412.5	602.9	1006.8
6.0	-51.8	272.2	278.9	465.7	36.7	61.4	606.2	527.7	826.7	1380.5
8.0	352.4	330.7	389.1	649.8	83.5	139.4	773.2	329.0	651.3	1087.7
10.0	173.7	325.7	315.6	527.1	100.2	167.3	784.9	541.1	703.1	1174.1
12.0	58.5	534.4	322.3	538.3	334.0	557.8	860.1	454.2	723.1	1207.6
14.0	131.9	300.6	309.0	515.9	394.1	658.2	581.2	1072.1	609.6	1017.9
16.0	300.6	277.2	405.8	677.7	427.5	714.0	821.6	799.9	597.9	998.4
18.0	288.9	188.7	507.7	847.8	362.4	605.2	572.8	1422.8	586.2	978.9
20.0	247.2	359.1	414.2	691.6	280.6	468.5	562.8	804.9	773.2	1291.3
22.0	16.7	362.4	339.0	566.1	394.1	658.2	546.1	1391.1	666.3	1112.8
24.0	173.7	275.6	268.9	449.0	330.7	552.2	527.7	1115.6	572.8	956.6
26.0	344.0	370.7	245.5	410.0	467.6	780.9	723.1	1257.5	776.6	1296.8
28.0	267.2	268.9	240.5	401.6	228.8	382.1	644.6	1100.5	679.7	1135.1
30.0	507.7	302.3	444.2	741.8	415.8	694.4	721.4	1230.8	587.8	981.7

Appendix D

Raw VO_2 and VCO_2 data taken from the participants at 40 and 50%VO_2max

		P1 40%	P1 50%	P2 40%	P2 50%	P3 40%	P3 50%	P4 40%	P4 50%	P5 40%	P% 50%
V02	0	1687	1210	1162	1722	1586	1030	1025	684	647	947
	2	784	1613	1327	2307	1553	1508	1263	1525	1133	1569
	4	1638	1763	1341	2038	1453	1987	932	1378	1289	1570
	6	1538	1564	1419	2237	1823	2214	1500	1504	1401	1534
	8	1908	1615	1484	932	2106	2151	1662	1445	1069	1530
	10	1854	1700	1420	2265	1806	1864	1666	1481	1089	1590
	12	1171	1422	1453	2190	1869	2376	1695	1289	1146	1355
	14	1606	1696	1393	2341	1799	2415	1324	1955	927	1825
	16	1590	1755	1391	2024	2063	2397	1685	1657	1005	1706
	18	1454	1672	1387	2219	1993	2263	1205	2056	965	1864
	20	1570	1738	1262	2323	1874	2153	1338	1952	1181	1845
	22	1282	1692	1364	1959	1981	2390	1254	2190	952	1941
	24	1438	1704	1277	2058	1927	2478	1248	2095	882	1899
	26	1421	1714	1116	2332	1911	1961	1348	2132	1259	1923
	28	1722	1679	1370	2378	1963	2406	1369	2088	968	1823
	30	1730	1534	1340	2220	2073	2358	1374	2092	929	1813
VCO2		P1 40%	P1 50%	P2 40%	P2 50%	P3 40%	P3 50%	P4 40%	P4 50%	P5 40%	P% 50%
	0	1368	1050	865	1110	1513	997	637	412	440	731
	2	629	1445	1337	1852	1440	1563	996	1090	865	1267
	4	1560	1589	1231	1598	1407	2000	1062	1131	928	1360
	6	1569	1401	1252	1716	1801	2372	1137	1188	906	1294
	8	1697	1417	1251	1820	2056	2188	1199	1248	679	1324
	10	1750	1505	1231	1726	1746	1839	1196	1157	668	1331
	12	1136	1102	1260	1534	1669	2255	1180	1017	713	1059
	14	1527	1516	1208	1663	1563	2303	976	1313	562	1141
	16	1410	1589	1148	1388	1807	2172	1193	1178	647	1383
	18	1281	1559	1083	1536	1776	2141	862	1204	614	1381
	20	1422	1523	1014	1409	1706	2071	1001	1470	718	1496
	22	1272	1475	1161	1401	1745	1850	927	1357	553	1416
	24	1334	1539	1116	1408	1729	2396	932	1427	539	1483
	26	1215	1492	969	1594	1631	1681	915	1379	794	1435
	28	1562	1518	1226	1536	1826	2139	983	1429	561	1437
	30	1426	1353	1074	1522	1824	2176	942	1355	577	1354

Appendix E

Raw RER values collected from the participants at 40 and 50%VO_2max

RER	P1 40%	P1 50%	P2 40%	P2 50%	P3 40%	P3 50%	P4 40%	P4 50%	P5 40%	P% 50%
0	0.81	0.87	0.74	0.64	0.95	0.97	0.62	0.6	0.68	0.65
2	0.8	0.9	1.01	0.8	0.93	1.04	0.79	0.72	0.76	0.81
4	0.95	0.9	0.92	0.78	0.97	1.01	0.78	0.82	0.72	0.82
6	1.02	0.9	0.88	0.77	0.99	1.07	0.76	0.82	0.65	0.86
8	0.89	0.88	0.84	0.64	0.98	1.02	0.74	0.78	0.63	0.78
10	0.94	0.89	0.87	0.76	0.97	0.99	0.72	0.78	0.61	0.84
12	0.97	0.78	0.87	0.7	0.89	0.95	0.7	0.79	0.62	0.79
14	0.95	0.89	0.87	0.71	0.87	0.95	0.74	0.67	0.61	0.78
16	0.89	0.91	0.83	0.69	0.88	0.91	0.71	0.71	0.64	0.71
18	0.88	0.93	0.78	0.69	0.89	0.95	0.71	0.73	0.64	0.83
20	0.91	0.88	0.8	0.61	0.87	0.96	0.75	0.72	0.61	0.72
22	0.99	0.87	0.85	0.72	0.91	0.87	0.74	0.7	0.64	0.79
24	0.93	0.9	0.78	0.68	0.9	0.97	0.75	0.65	0.64	0.65
26	0.84	0.87	0.82	0.68	0.85	0.86	0.68	0.67	0.63	0.77
28	0.91	0.9	0.89	0.65	0.93	0.89	0.72	0.65	0.62	0.65
30	0.82	0.88	0.8	0.69	0.88	0.92	0.69	0.71	0.62	0.8

Appendix F

Proof of informed consent

DECLARATION: **I confirm that this project conforms with the Cardiff Met Research Governance Framework**	
Signature of the applicant:	Date: 14/10/13
FOR STUDENT PROJECTS ONLY	
Name of supervisor: Paul Smith	Date: 14/10/13
Signature of supervisor: Paul M. Smith.	