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CARDIFF SCHOOL OF SPORT

DEGREE OF BACHELOR OF SCIENCE
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**A comparison of fat metabolism during
submaximal exercise following active, passive
and no warm-up.**

**(Dissertation submitted under the discipline of
Physiology)**

Jennifer Bell

St20002815

**A COMPARISON OF FAT
METABOLISM DURING
SUBMAXIMAL EXERCISE
FOLLOWING ACTIVE,
PASSIVE AND NO WARM-UP.**

Cardiff Metropolitan University
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Abstract

The aim of this study was to determine the effects of pre-warming on the fat oxidation response to subsequent submaximal exercise. Eight university students (M=3, F=5) performed three separate trials following a VO_2 max test to exhaustion which was used to determine subsequent intensities. Each trial consisted of a 30 minute bout of submaximal exercise (55% VO_2 max) preceded by either an active warm-up (intervals of 30s at 100% of VO_2 max and 90s at 40% of VO_2 max), a passive warm-up (local heating of both legs using hot water perfused denim sleeves), or no warm-up. During the exercise bout, no significant difference was observed between heart rate response, average VO_2 , energy expenditure or temperature following the three conditions. An increased amount of fat oxidation was demonstrated in trials where pre-warming had occurred compared to the control however there was no significant difference between all three trials (10.26 \pm 2.88g, 9.18 \pm 3.17g and 8.76 \pm 3.27g in the active, passive and control trials respectively). The results of this study suggest that there are no beneficial effects of using a warm-up, whether it is active or passive, over no warm-up, on the fat metabolising properties of subsequent submaximal exercise.

CHAPTER 1

INTRODUCTION

The human body is fuelled by two main sources of energy from our diet; carbohydrate and fat. These macronutrients are stored in the body and used as substrates to produce adenosine triphosphate (ATP), the basic energy source for all activity. During exercise, substrate utilisation alters depending on a number of factors; however intensity is the main cause (Thompson et al., 1998). During high intensity exercise, for example above 65% of VO_2 max, carbohydrates are the main energy source. However at intensities lower than this, there is a greater reliance on fats to provide this energy (Brookes, 1994). This greater reliance on the metabolism of fat during submaximal exercise has been the foundation for an abundance of research for both exercise and sport physiology. The general population and athletes alike would benefit from the application of training methods which pay specific attention to the physiological mechanisms by which adipose tissue, the main store of fat in the body, is reduced and therefore weight loss or control can be achieved.

Obesity is a growing concern worldwide (Low et al., 2009). In the USA alone, it is estimated that 66% of adults are classified as overweight, 32% as obese, and 5% as morbidly obese (Schroeder, 2010). For the majority of the population, the risks of poor health resulting from inactivity far outweigh the risks associated with exercise participation (Department of Health, 2011). Obesity is associated with a vast array of physical disadvantages, from every day impairments such as limited mobility and joint pain, to life-threatening illnesses including cardiovascular disease, diabetes and several types of cancer (Wadden et al., 2002). Exercise participation is a key tool in combatting this growing epidemic (Schroeder, 2010). For the general population, weight loss is one of the main incentives for exercise and sport participation (Sherwood and Jeffrey, 2000).

From an athlete's perspective, the ability to oxidise fat at an increased rate has been linked to improved performance (Achten et al., 2002). Endurance

athletes in particular often train at a submaximal intensity. Low muscle glycogen concentrations can be a limitation in endurance events as they are associated with fatigue, and therefore an increased capacity to metabolise fat would be beneficial (Yeo et al., 2011). Consequently any means by which fat oxidation can be increased will be instrumental to an athlete's training or competition preparation. One method of achieving this is to train with low levels of carbohydrate in order to enhance the rate of fat oxidation (Cook & Haub, 2007).

Fat, in the form of free fatty acids (FFA) is used as a fuel source for skeletal muscle metabolism during exercise. Fat oxidation occurs in the mitochondria of muscle cells and is the metabolic break-down of FFAs to generate ATP. The fatty acids used for oxidation are principally derived from plasma and have been released as a consequence of lipolysis (Rasmussen and Wolfe, 1999). This process is influenced by stimulation of the sympathetic nervous system and this is markedly elevated during exercise (Shepherd and Bah, 1988). The highest rates of fat oxidation occur at low to moderate exercise intensity, between 35% and 65% of VO_2 max. During exercise at higher intensities than this, energy contribution from fat oxidation is significantly reduced (Achten et al., 2002).

Alterations in the metabolic response to exercise can be attributed to a number of factors including intensity, duration and type of exercise, as well as the training status of the individual. An increase in muscle temperature can also affect metabolism during exercise (Robergs et al., 1991). Increased muscle temperature elevates the oxygen consumption of mitochondria which increases VO_2 levels, as the aerobic processes are more active than at resting temperatures (Koga et al., 1997). At the onset of exercise, muscle metabolism needs a certain time to adapt to the new requirements which can result in a temporary mismatch of O_2 demand and O_2 supply (Brunner-Ziegler et al., 2011). Warm-up prior to the subsequent exercise is one way of minimising this imbalance.

As the name suggests, the main intention of a warm up is to elevate body temperature. This will cause physiological alterations that prepare the athlete's body for the rigors of exercise or competition (Romney, 1993). Alterations achieved through thermoregulatory means include a decreased resistance of muscles and joints which will reduce the risk of muscle cramp or injury, increased nerve conduction rate, greater release of oxygen from haemoglobin and myoglobin, and a speeding of metabolic reactions (Bishop, 2003a). It is this speeding of metabolic reactions which is of particular interest in regards to the current study due to its focus on substrate metabolism. These adaptations can be achieved either through an active warm-up; dynamic warming of the body via exercise, or a passive warm-up; increasing core and muscle temperature through external stimuli e.g. saunas, hot showers or heat pads. Passive warm-up allows for the same temperature increase to be obtained as from an active warm-up, without depleting energy substrates, however it is thought to elicit less of the metabolic changes that occur following an active warm-up (Gray & Nimmo, 2001). When structuring an active warm-up, intensity, duration and specificity of the exercise must be considered. Each of these factors can be manipulated to suit the requirements of the athlete, the environment, and the subsequent exercise (Bishop, 2003b).

Although there is a great deal of research regarding the benefits of warm-up, there is still no conclusive evidence as to the load, intensity or type of an optimal warm-up (Balilionis et al., 2012). Because of the number of variables and combinations, often coaches and athletes will create warm-ups based purely on their own trial and error experiences rather than any scientific research (Bishop, 2003b). Due to the benefits of increased fat metabolism to both recreational and competitive athletes, identifying a warm-up which elicits the highest levels of fat oxidation during subsequent exercise could be of practical use. It would also be useful to determine whether these changes occur purely due to the temperature related effects of warm-up, or whether the activity related effects have an influence, as this would impact the way in which exercise participants chose to pre-warm themselves for subsequent physical activity.

The main aim of this study will therefore be to identify whether a superior method for pre-warming exists for eliciting the highest levels of fat oxidation during submaximal exercise. The study will compare the fat metabolism apparent in a 30 minute bout of exercise at 55% of VO_2 max following active, passive and no warm-up.

CHAPTER 2

LITERATURE REVIEW

There is a need by both the general population and athletes alike to understand and put into practice the methods by which an increased amount of fat can be metabolised during exercise (Schroeder, 2010; Yeo et al., 2011).

Conditions such as overweight and obesity, and the long list of physiological and psychological burdens that they are associated with, are alarmingly high in today's human population. Between 1996 and 2000, the number of individuals in the USA with class 1 obesity (BMI of 30-35kg/m²) doubled, and the increase in those individuals who were morbidly obese (BMI of above 40kg/m²) and super obese (BMI of above 50kg/m²) was four and five-fold respectively (Miller et al., 2012). This issue is not only confined to the USA but has become a global epidemic, affecting both children and adults in the UK, Canada, Australia, and many other countries around the world (McCarthy et al., 2001; Hanley et al., 2000; Ball & Crawford, 2003). Obesity refers to an excess of body fat, and is associated with a number of life-threatening diseases and illnesses (Wadden et al., 2002). At a BMI of 30kg/m², risk of mortality is increased by 30%, and at a BMI of 40kg/m² or more, it increases by 100% (Manson et al., 1995). For those who are unable to lose weight through typical means such as healthier eating and activity habits, there are more drastic measures that can be taken such as pharmacotherapy and bariatric surgery, however these carry with them not only greater expense, but greater risk of side effects. The most common, safe and cost-effective method for losing weight is combining a healthier diet, with physical activity (Wadden et al., 2002). Obesity generally arises from an energy imbalance, whereby energy intake exceeds energy expenditure (Hill, 2004). To avoid becoming overweight, this requires individuals who lead a sedentary lifestyle to consistently consume a very low energy intake, however, human physiology is not suited to a restriction of energy intake, and it is difficult for most people to maintain this (Peters et al., 2002). It has however, been suggested that weight gain could be prevented by reducing positive energy balance by as little as

100kCal a day (Hill et al., 2003). Thereby any means which could increase the rates of fat oxidation and therefore increase energy expenditure during exercise would be a strong incentive for the general population to take part in more physical activity. For those individuals who carry extra weight it is possible that participation in high-intensity exercise may be unsafe, as the cardiovascular response to exercise is influenced by the degree of obesity, and therefore it is low to moderate-intensity exercise that would be more beneficial (Bernard et al., 2012). However, exercise of a lower intensity requires a longer duration to expend the same number of calories as those burned during more intense exercise, and this is influenced by the time available for exercise by the general population (Thompson et al., 1998). A significant issue in the implementation of exercise programmes is motivating an increasingly busy adult population, who often find only an hour or so of free time in their day, to find the time to participate (Davey et al., 2009). Therefore if it were possible to increase the fat burning capacity of moderate-intensity exercise in a shorter period of time, this would again be of great use to the general population looking to lose or control their weight.

For most trained athletes, although weight control and maintenance is important, weight loss is not a primary concern. Diet and nutrition are however an integral part of every athletes training programme, as they influence substrate use during exercise. During prolonged submaximal exercise (<85% of VO_2 max for a period of >2h), fatigue is largely attributed to low muscle glycogen concentrations (Tsintzas & Williams, 1998). Because of this, many nutritional strategies aimed at improving endurance performance have focused on increasing carbohydrate availability through the strategy of exogenous carbohydrate feeding pre and during endurance events (Cermak & Loon, 2013). However, there are issues associated with the ingestion of carbohydrate immediately preceding or during an event in that it increases rates of whole-body carbohydrate oxidation and therefore can increase the rate at which carbohydrate is depleted (Arkininstall et al., 2001). Also, the rate of muscle glycogen utilisation is affected by the initial muscle glycogen concentration and so cannot always be a reliable means of improving performance (Helge, 2000). Therefore an alternative means by which fatigue

can be attenuated and endurance performance improved would be of value to endurance athletes. One such method would be to increase the availability of and capacity to oxidise fat (Yeo et al., 2011). Through endurance training, metabolic adaptations can be gained which increase the rates of fat oxidation during submaximal exercise. These are attributed to an increase in mitochondrial volume, mitochondrial enzymatic adaptations, an increase in capillarisation within the working muscle, an increase in fatty acid binding proteins and a reduction in the signals that activate the major enzymes responsible for metabolising carbohydrate (Turcotte et al., 1999; Yeo et al., 2011). In conjunction with endurance training, athletes can adopt a protocol known as “fat adaptation”, in which a high-fat, low-carbohydrate diet is consumed for up to 2 weeks (Lambert et al., 1994). There is a limited amount of glycogen stored in skeletal muscle and the liver, whereas the absolute amount of fat stored in even the leanest of athletes is more than 60 times the amount of glycogen and is sufficient for hours or even days of continuous exercise (Horowitz & Klein, 2000; Burke & Hawley, 2002). Therefore the ability to increase rates of fat oxidation during prolonged exercise whilst concomitantly reducing the rate of muscle glycogen utilisation will be advantageous to endurance athletes and has been shown to improve performance (Lambert et al., 1994; Venkatraman & Pendergast, 1998).

The main storage site of fat in the human body is adipose tissue, storing about 560MJ (megajoules) in a lean adult man (Horowitz & Klein, 2000). The energy stored here contains fatty acids in the form of triglycerides. These triglyceride stores are acted on by a series of lipases to mobilise lipid from the fat cells into free fatty acids, and this process is known as lipolysis (Shepherd & Bah, 1988). It is these fatty acids that, when bound to plasma albumin, serve as a source of energy for working muscles during exercise (Havel et al., 1963). During exercise, sympathetic nervous system activity is elevated, and this is responsible for increasing the rate of lipolysis occurring in adipose tissue (Shepherd & Bah, 1988). Lipolysis is primarily responsible for supplying free fatty acids to the working muscle during exercise in order for it to be oxidized (Jeppesen & Kiens, 2012). Uptake of these fatty acids for subsequent oxidation occurs via the plasma membrane, where it is esterified

in order to be transported through the inner membrane of the mitochondrion. Energy produced from these free fatty acids is then used to generate adenosine triphosphate (ATP) in the krebs cycle and electron transport chain, within the process of aerobic glycolysis (Rasmussen & Wolfe, 1999). Aerobic glycolysis is the predominant energy system at work during aerobic exercise, i.e. when the intensity of the exercise is low to moderate (<80% of VO_2 max) and/or when the respiratory exchange ratio (RER) is below 1.0. When exercise exceeds this intensity or RER value, a shift in substrate use occurs and it is now carbohydrate providing the energy for ATP to be generated via anaerobic glycolysis. Therefore, if the objective of exercise is to increase the rate or amount of fat oxidation, it is a moderate intensity that should be adopted.

There are numerous methods that exist to elicit or maximise the desired benefits or adaptations of exercise; training, nutrition, warm-up etc. The benefits of warm-up on subsequent exercise have been investigated for decades (Robergs et al., 1991). In 1954, Malareck investigated the physiological justification of so called “warming up”. Since then there have been numerous studies exploring the effects that warm up has on the human body and there is now conclusive evidence as to the physiological, biochemical and metabolic changes that pre-warming brings about (Robergs et al., 1991). Increased muscle temperature resulting from warm up decreases the viscous resistance of muscles and joints as well as decreasing the stiffness of muscle fibres during contraction, resulting in lower risk of injury during subsequent exercise (Soligard et al., 2008). Increased oxygen delivery to the working muscles is also attributed to pre-warming via a rightward shift in the oxyhaemoglobin dissociation curve, vasodilation of muscle blood vessels and increased muscle blood flow (McCutcheon et al., 1999). The elevated oxygen consumption by isolated mitochondria is also attributed to an increase in muscle temperature and this enhances aerobic energy production by accelerating rate-limiting oxidative reactions (Koga et al., 1997). Muscle glycogenolysis, glycolysis and high-energy phosphate degradation increase during exercise when muscle temperature is increased (Parkin et al., 1999). Improvements in central nervous system function and an increase in the

transmission speed of nerve impulses have been demonstrated when muscle temperature is increased (Ross & Leveritt, 2001). There is also evidence to show that a warm up will increase the baseline VO_2 level that subsequent exercise begins at, allowing for less anaerobic work to be involved, so that there is a higher capacity for it later in the activity should it be needed, and this will increase time to exhaustion (Bishop et al., 2002). During exercise alterations occur to the metabolic response of the working muscles, these can be dependent on a number of factors and although not solely responsible, elevation in muscle temperature has a significant effect (Robergs et al., 1991). Conducting a warm-up is one of the most commonly used and effective methods of increasing muscle temperature prior to a subsequent bout of exercise in order for the metabolic changes to be elicited. Increased temperature of skeletal muscle allows for increased blood flow to the working muscles. This is caused by vasodilation of the blood vessels, which is triggered by increased oxygen consumption and nitric oxide synthase (Harris et al., 2003; Heinonen et al., 2011). This increased blood flow is responsible for increasing the contribution of fat as a fuel source at the onset of exercise subsequent to warm up, presumably because delivery of free fatty acids to the working muscle to be oxidized is facilitated, rather than them being transported back to the liver to be re-esterified (Horowitz & Klein, 2000; Gray & Nimmo, 2001). Through this vasodilation of the vessels and increased blood flow, warm-ups also allow athletes to reach a steady state of metabolism faster than if they were to begin exercising with no prior warming (Brunner-Ziegler et al., 2011). A steady state in oxygen consumption is also achieved more quickly, and this speeding up of VO_2 kinetics is related to accelerating metabolic reactions, particularly aerobic metabolism, that increase oxygen delivery to the capillaries and mitochondria (Grassi et al., 1995). Without a warm up, muscle metabolism would require longer to adapt to the new requirements of the exercise, and therefore an oxygen debt would arise due to the demand of oxygen being too great for the supply (Brunner-Ziegler et al., 2011). Warm up can generally be split into two categories; active warm up and passive warm up (Brown et al., 2008). Active warm-ups aim to dynamically warm the body through exercise, this can be achieved through a number of methods and is usually sport specific, for example in the present

study, the main exercise bout will be completed on a cycle ergometer, and therefore the active warm-up will also be done on a cycle ergometer. Passive warm-ups aim to increase temperature through external stimuli for example heat pads, saunas, warm water submersion etc. and therefore conserve energy whilst eliciting the same thermoregulatory effects. By distinguishing between these two methods it is possible to establish whether the adaptations and benefits of warm-up are caused purely by its thermoregulatory properties, or are influenced by the activity related effects.

When considering the impact that warm up has on the metabolic response to exercise, Robergs et al. (1991) focused on muscle glycogenolysis during intense exercise. This study revealed that warm up resulted in an increase in VO_2 and a decrease in blood lactate accumulation following warm up, yet despite these benefits, muscle glycogen degeneration was not reduced and in fact the rates of glycogenolysis were relatively low. These results indicated that warm up can increase oxidative energy metabolism at the onset of subsequent exercise. McCutcheon et al. (1999) examined the effects of prior exercise on muscle metabolism during sprint exercise in horses. They conducted three trials of no warm up, low intensity warm up and high intensity warm up and observed that although sprint performance was similar between the three trials, there was a lower rate of glycogen utilisation during the sprint following a low intensity warm up compared to the high intensity warm up or no warm up. They also found that when prior exercise was completed, regardless of intensity, compared to no warm up, there was a reduction in the rate of muscle lactate accumulation, a lower O_2 deficit, a higher peak VO_2 , a reduction in the contribution of anaerobically derived ATP and an increased time to exhaustion. There was no significant difference between a high intensity warm compared to a warm up of lower intensity. Using water perfused cuffs (a method of passive warm up), Starkie et al. (1999) investigated the effect of temperature on muscle metabolism during submaximal exercise in humans. They observed an increase in muscle glycogen utilisation during submaximal exercise and suggested that the increased muscle temperature may be partly responsible for this. However, this change was not fully accredited to temperature as ATP and

phosphocreatine (PCr) stores were unaffected. Gray et al. (2002) considered the effects that warm up have on metabolism prior to and during intense dynamic exercise. They particularly focused on whether pre warming has any effect on reducing the reliance on non-oxidative ATP production. Their main finding was that there was a reduction in both blood and muscle lactate accumulation following a warm up, suggesting there may be a decreased reliance on energy derived from anaerobic sources, however they did not attribute this purely to muscle temperature elevation, but instead suggested that there was an increase of readily available fuel for oxidative ATP regeneration.

This knowledge of the effects of warm up has meant that researchers, sports scientists and healthcare professionals alike are able to focus on finding an appropriate warm up for an array of different physical activities using specifically tailored combinations of variables including type, duration and intensity of exercise. However, as there is such a vast array of options, there must first be evidence to suggest in the broadest of terms which type of warm up is most beneficial or appropriate for the parameter being measured, and whether these changes are brought about by temperature increases alone, or are effected by the activity related properties of warm-up.

Previous studies considering the differences between active and passive warm up have focused on a number of different variables, including performance outcomes, metabolic adaptations, biochemical changes etc., and these have been observed over different intensities and types of exercise. Gray and Nimmo (2001) considered the changes in metabolism and performance during high-intensity exercise of short duration following active, passive and no warm up. They concluded that although the mechanism by which muscle temperature is elevated has influence on certain metabolic changes including VO_2 and blood lactate response, it is not muscle temperature alone that is solely responsible for these changes. They also observed that although different metabolic and physiological changes were apparent following the different types of warm up, there were no significant differences in performance parameters between active, passive and no warm

up. Gregson et al. (2002) conducted a study to determine the effects of pre-warming, using both active and passive techniques, on the metabolic and thermoregulatory responses to prolonged, exhaustive submaximal exercise. It was concluded from this study that pre-exercise warming, whether it be through active or passive means had a negative effect on prolonged exercise and reduced the participant's ability to perform. This was thought to be due to a decreased capacity for heat storage and an increase in thermoregulatory strain which resulted in a premature onset of high internal temperature, which led to termination of the exercise. Brown et al. (2008) compared the effects of active and passive warming on high-intensity, intermittent running. Despite different metabolic and physiological responses observed between the active and passive trials, no significant differences were seen in performance. They concluded that although an improvement in intermittent running speed was seen when preceded by a warm up compared to with no warm up, there was no significant difference between active or passive warming on this parameter. They also found no difference in the decrement of performance fatigue between the two protocols. Brunner-Ziegler et al. (2011) conducted a comparison of the metabolic and biomechanic responses between active and passive warm ups. They were concerned with the energy supply and muscle strength performance during a six minute spiroergometer test following each of the three conditions (active, passive and control). They concluded that conditions which may promote an improved performance were more apparent after an active warm-up compared to a passive or no warm-up, and that athletes were more likely to reach the metabolic steady state faster, following an active warm-up.

Although it is widely evidenced that a warm up, be it active or passive, has beneficial effects on the performance of subsequent exercise, either through metabolic, physiological or biomechanical adaptations, there is still dispute as to the precise changes it brings about, and particularly whether these are due to temperature elevations or other mechanisms. The research regarding muscle metabolism in particular has delivered inconsistent results. It is widely accepted that VO_2 is elevated and blood and muscle lactate is reduced, however there is conflicting evidence into the aerobic and anaerobic

contributions that arise following a warm up. Considering the limited previous research into the effect that warm up has on fat metabolism during subsequent exercise, this will be the main focus of the present study. It will also attempt to distinguish between the activity related benefits and the temperature-related benefits of warm-up by comparing the effects of an active, passive and no warm-up. Although previous research has generally focused on exercise that is high in intensity and short in duration, for the purposes of this study, due to its emphasis on fat oxidation as a tool for the general population and athletes alike, submaximal, medium duration exercise will be used to determine the effects of the warm up protocols.

Given the design of the proposed study, and the previous literature suggesting that the use of a warm-up will elevate metabolic reactions during subsequent exercise, it is reasonable to hypothesise that a higher rate of fat metabolism will occur during protocols that are preceded by a warm-up, compared to no warm-up, and that the active trial will have more of an effect on metabolism than the passive trial. However, due to the lack of consistency in the design of previous studies, there will be differences in some of the procedures used; where some variables will be similar to previous studies, others will differ. Examples of procedures that may vary include the duration, intensity and type of exercise used during the active warm-up, the method of pre-heating used during the passive warm-up, the recovery period duration, the mode of activity during the exercise bout, the method for measuring temperature and the method by which substrate use is determined. Because of these differences in procedures, it is possible that conflicting results will be observed, and it is important to recognise this when discussing the results.

CHAPTER 3

METHODS

Subjects. Eight healthy, sports students of Cardiff Metropolitan University, both male and female (M=3, F=5) participated in the study which received approval from Cardiff Metropolitan University Ethics Committee. All participants were provided with information on the purpose of the study (Appendix B), and were required to sign a letter of informed consent (Appendix C), as well as complete a Par-Q form before testing (Appendix D), and a current health questionnaire before each subsequent trial (Appendix E). Their contribution and involvement in the study was entirely voluntary and could be terminated at any time. The characteristics of the subjects are presented in Table 1.

Table 1. Subject Characteristics

Variable	Combined Group (N=8)	Males (N=3)	Females (N=5)
Age (years)	21 ±0.7	21 ±0.6	20 ±0.5
Body Mass (kg)	70 ±15.4	72 ±9.5	69 ±19.1
Stature (cm)	172 ±6.9	175 ±6.7	170 ±6.7
VO ₂ max (ml/kg/min)	37.5 ±8.0	44.4 ±7.5	33.4 ±5.2

Values: Means ±SD

Experimental Design. Each participant was required to visit the laboratory on four separate occasions over a period of 4-5 weeks. On their first laboratory visit, participants completed a VO₂ max test. On each subsequent visit, a 30 minute submaximal exercise bout was completed, preceded by either an active warm-up, a passive warm-up, or no warm-up as demonstrated in Figure 1. Participants were asked to abstain from alcohol consumption and strenuous exercise 24 hours prior to testing. They were also asked not to consume any food 2 hours before testing, and to replicate their diet as closely as possible on the day of each trial.

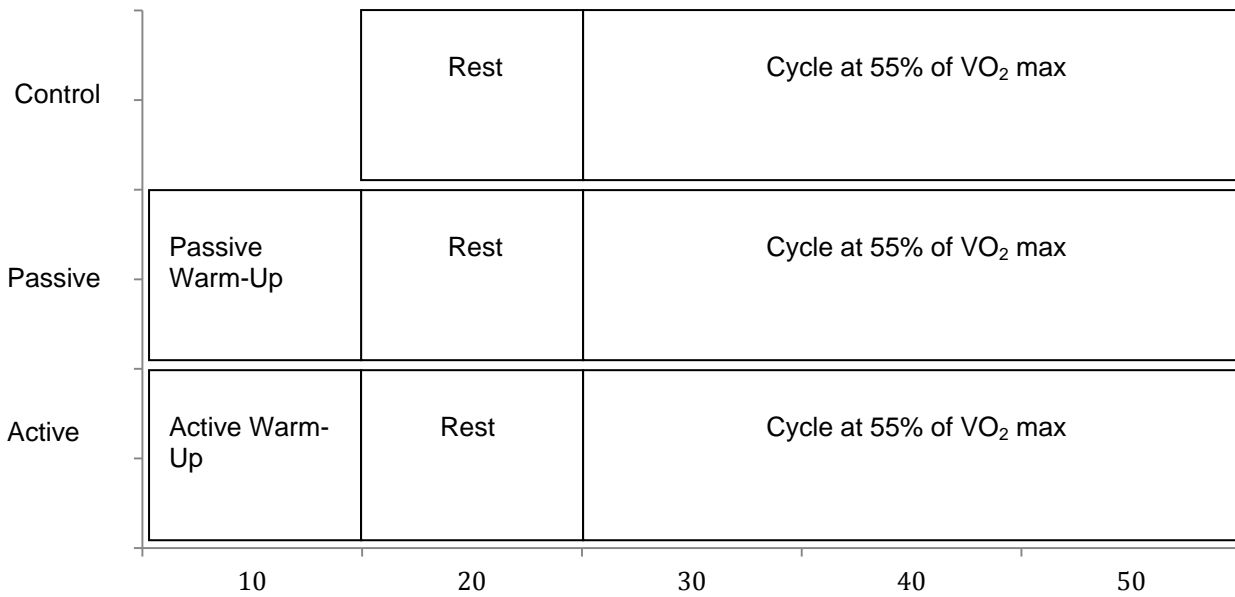


Figure 1. A timeline of the three protocols.

Determining VO₂ max and maximal power output. Each participant performed a VO₂ max test on a cycle ergometer (Corival, LODE, Gronigen, Netherlands) in order to determine their maximal power output and from this establish the intensity they would work at during subsequent submaximal exercise. These VO₂ max values are presented in Table 1. Participants were asked to choose a cadence which felt comfortable during a short warm-up, and then told to stay within ± 5 RPM of this cadence throughout the test. The test was initiated at 30W and increased by 30W every 3 minutes until the participant reached exhaustion. The workload at this point was then taken to be their maximal power output at VO₂ max, i.e. 100% VO₂ max. Individual data points were then used to determine the power output which corresponded to the desired intensity e.g. 40%, 55% of VO₂ max using the equation:

$$y = mx + c$$

Expired air was collected and analysed throughout using an automated respiratory gas analysis system (CPX, Oxycon, Warwick, UK). During this visit, the height and weight of each participant was also measured and recorded.

For each protocol, skin temperature sensors were secured to participants using Micropore™ 3M tape, at seven sites on the body; forehead, bicep, hand, trunk, thigh, shank and foot, as according to the weighting coefficients equation used by Hardy, DuBois and Soderstrom (1937). Measurements from these sensors were recorded on a data logger (SQ2010, Squirrel, Shepreth, UK) and noted every 5 minutes throughout the protocol.

Control Trial. Participants were required to sit at rest for 10 minutes before the exercise bout, replicating the recovery period that would be used during the warm-up protocols. Following this period of inactivity they were transferred to the cycle ergometer and completed the submaximal exercise bout.

Active Warm-Up. Participants completed a 10 minute repeated light to heavy interval warm up consisting of 90 seconds at 40% of their individual VO₂ max and 30 seconds at 100% VO₂ max on a cycle ergometer, shown in more detail in Figure 2. They were then instructed to sit at rest with limited movement for 10 minutes before being transferred back on to the ergometer to complete the submaximal exercise bout.

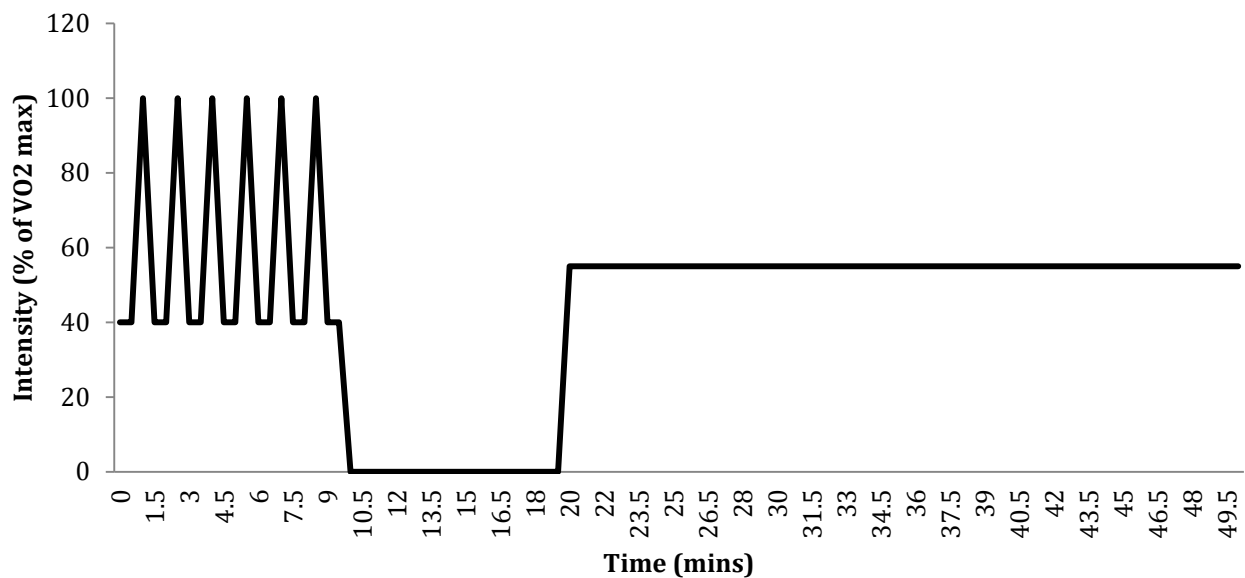


Figure 2. A detailed timeline showing the intensity of exercise throughout the active protocol.

Passive Warm-Up. Participants had both lower limbs covered by denim sleeves lined with silicone tubes, which were attached to a heated water tank (Julabo F12, Labortechnik GmbH, 77960 Seelbach, Germany) that perfused water through the tubes maintaining it at a constant set temperature of 50 degrees Celsius, similar to the method used by Starkie et al. (1999). This passive warming continued for 10 minutes to replicate the duration of the active warm up. The participants were then instructed to sit at rest with limited movement for 10 minutes before being transferred back on to the ergometer to complete the submaximal exercise bout.

Exercise Bout. The submaximal exercise bout in each protocol was a continuous cycle for 30 minutes at a cadence of 80RPM and a power output corresponding to 55% of each individual's VO_2 max. Expired air was collected and analysed throughout using an automated respiratory gas analysis system (CPX, Oxycon, Warwick, UK). Heart rate was also recorded using non-invasive telemetry (RS4000, Polar Electro, Kempele, Finland).

Data Processing. From the VO_2 and respiratory exchange ratio (RER) values that were provided from the gas analysis system, it was possible to calculate the amount of fat metabolised during the 30 minute exercise bout. This was done by taking an average of both values over the bout. The RER value could then be used to determine the fat usage in g/litre O_2 . This number was multiplied by the average VO_2 value in L/min, and the product of this was multiplied by 30 to account for the bout duration. A similar method was used to calculate energy expenditure however RER values were used to determine energy/litre O_2 rather than g/litre O_2 . Heart rate and skin temperature data were all calculated by taking an average value from all data points.

Data Analysis. All data analysis was carried out using SPSS. Two-way analysis of variance (ANOVA) was used to determine differences between trials for VO_2 , energy expenditure, heart rate, skin temperature and the amount of fat metabolised. Significance was set at $P < 0.05$ and where relevant, post-hoc comparisons were carried out.

CHAPTER 4

RESULTS

VO_2 . The average VO_2 max value of all eight participants was calculated to be 38ml/kg/min. At the onset of the exercise bout, no significant difference was found in the participant's VO_2 between each of the three trials (Figure 3). During the 30 minute exercise bout in each trial, no significant difference was found between the average VO_2 of participants (Figure 4).

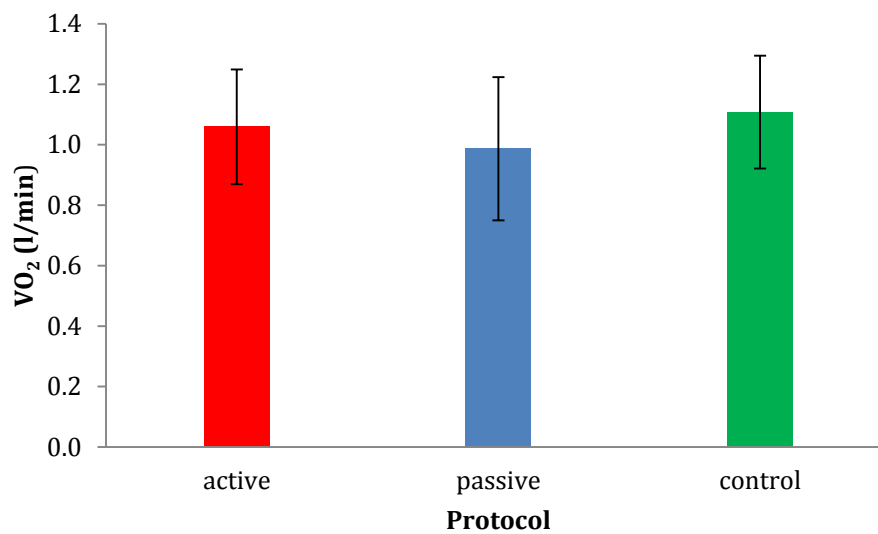


Figure 3. VO_2 at the onset of exercise bout in each trial.

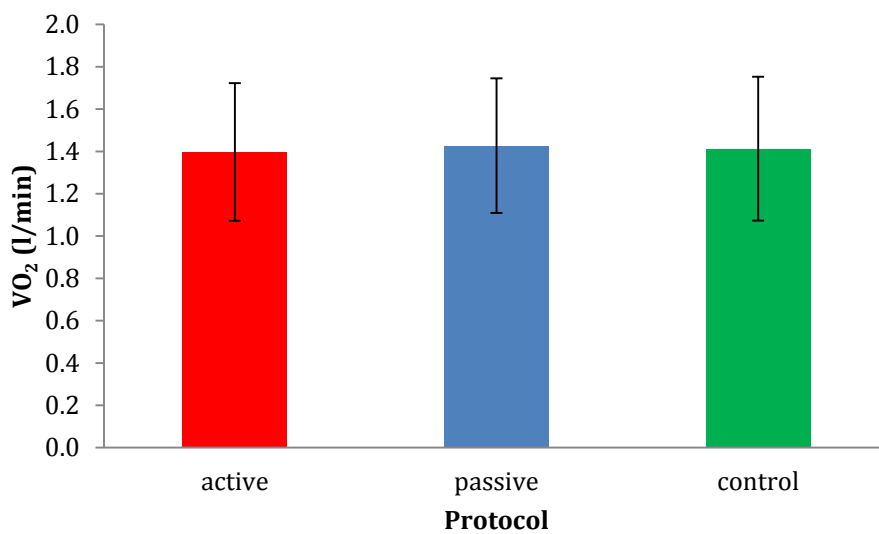


Figure 4. Average VO_2 during exercise bout in each trial.

Energy Expenditure. The highest total energy expenditure during the 30 minute exercise bout was in the passive trial (878kJ), however there was no significant difference between the energy expended in each of the three trials (Figure 5).

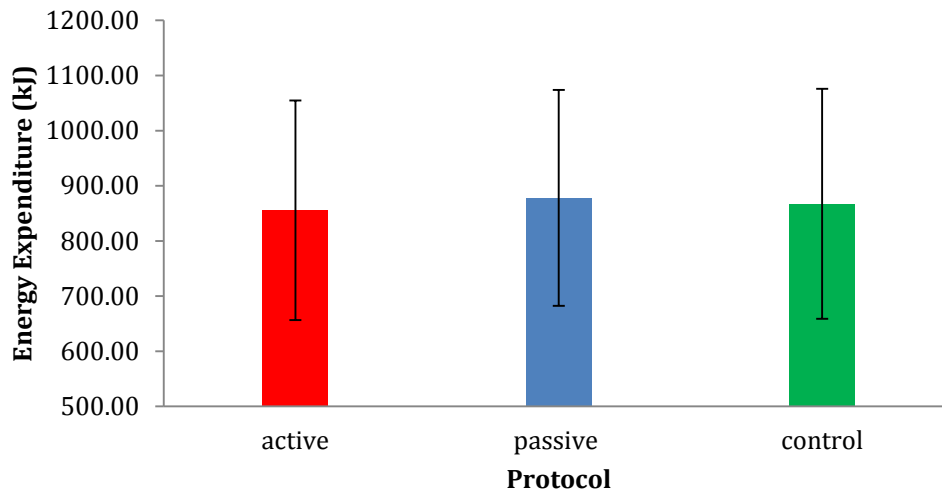


Figure 5. Energy expended during exercise bout in each trial.

Heart Rate. A typical heart rate response throughout each trial is presented in Figure 6. During the warm-up, average heart rate was significantly higher ($p < 0.05$) in the active trial than in the passive. Throughout the ten minute rest period in all trials, the average heart rate was significantly higher ($p < 0.05$) in the active trial than in the passive trial. However there was no significant difference between the active and control trials, or the passive and control trials. During the exercise bout there was no significant difference in the average heart rate between any of the three trials (Figure 7).

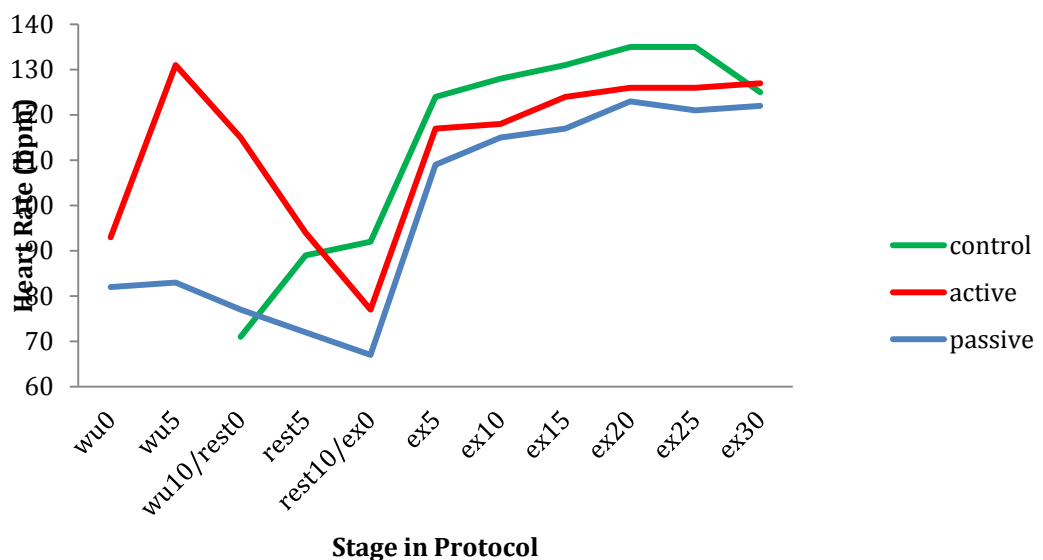


Figure 6. Typical heart rate response to each trial.

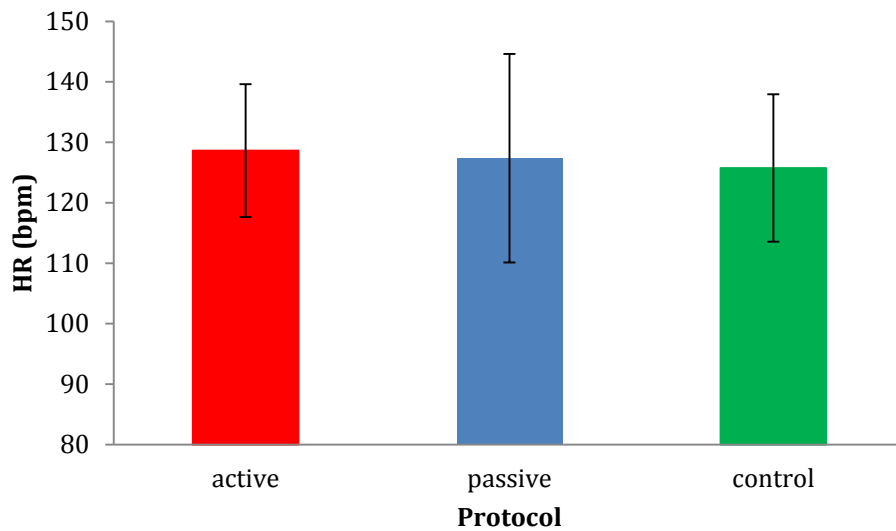


Figure 7. Average heart rate during exercise bout in each trial.

Skin temperature. There was a significant difference ($p < 0.05$) between the average skin temperature reached following the warm-up in the passive trial (32.22°C) compared to the active (29.87°C). There was no significant difference in the temperature between all three trials at the onset of the exercise bout (Figure 8) or during the exercise bout (Figure 9).

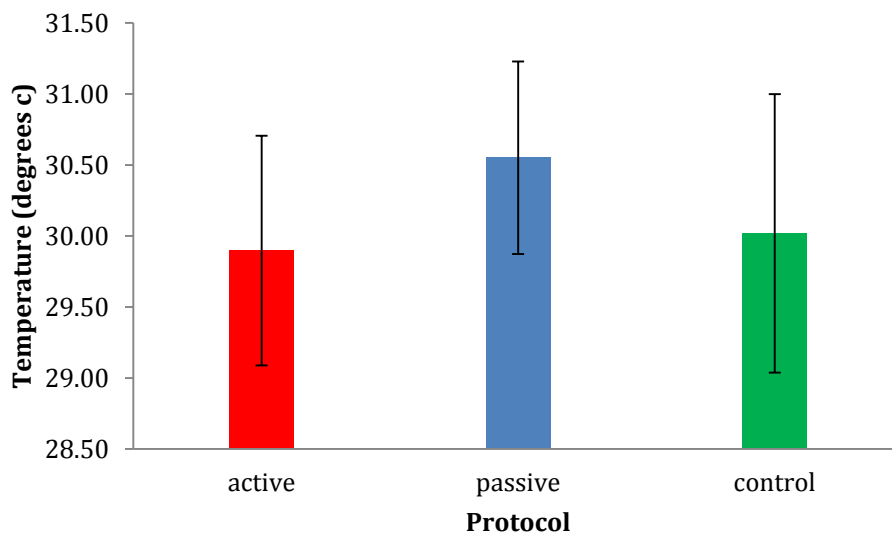


Figure 8. Skin temperature at the onset of exercise bout in each trial.

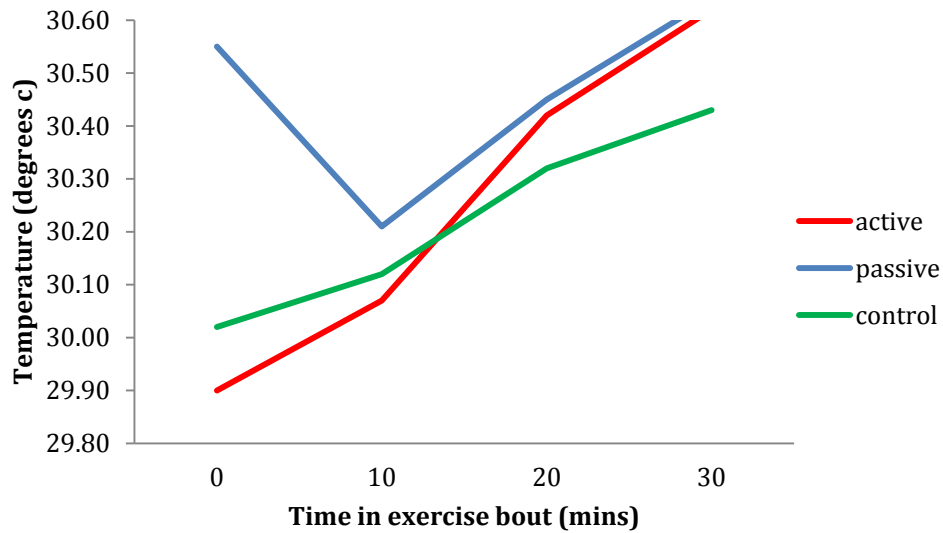


Figure 9. Skin temperature response during exercise bout in each trial.

Fat Metabolism. There was a non-significant trend towards greater fat metabolism in trials preceded by a warm-up compared to no warm-up, and a non-significant increase in the active trial compared to the passive ($10.26 \pm 2.88\text{g}$, $9.18 \pm 3.17\text{g}$, and $8.76 \pm 3.27\text{g}$ in the active, passive and control trials respectively) as demonstrated in Figure 10.

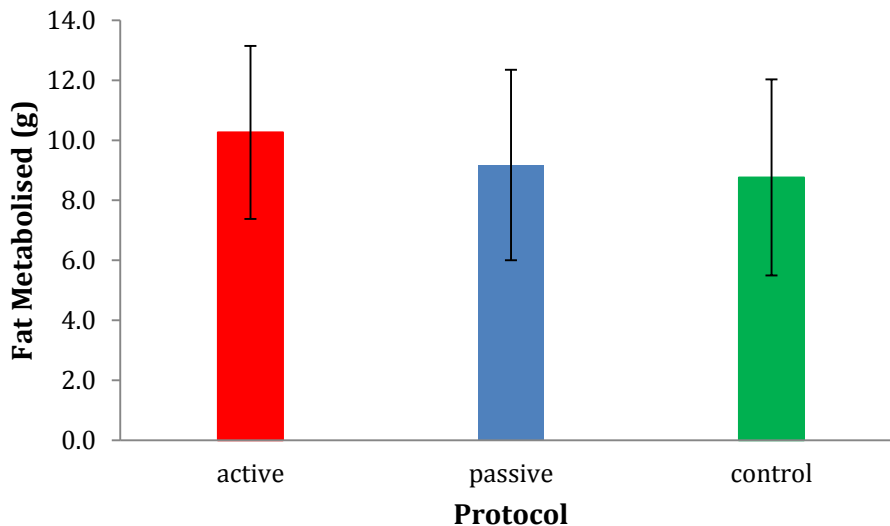


Figure 10. Amount of fat metabolised during exercise bout in each trial.

CHAPTER 5

DISCUSSION

The aim of this study was to identify whether the method of pre-warming had any influence on the metabolism, in particular fat oxidation, of participants during subsequent exercise. Although a trend was seen towards pre-warming eliciting more fat oxidation than the control trial, and an active warm-up having a greater effect on metabolism than a passive warm-up, there was no significant difference found between the three trials. Therefore the results of this study suggest that there are no beneficial effects of using a warm-up, whether it is active or passive, over no warm-up, on the fat metabolising properties of subsequent submaximal exercise. VO_2 , heart rate, skin temperature and energy expenditure measurements were taken throughout warm-up, recovery and the exercise bout in order to better understand what had caused the difference in metabolism between trials, should any have occurred.

In the current study, there was no significant difference observed in the VO_2 measurements of participants at the onset of exercise following active, passive or no warm-up or in the average oxygen uptake during the 30 minute exercise bout. These results are similar to the findings of both Gregson et al. (2002) and Brunner-Ziegler et al. (2011) who found no significant difference in VO_2 values between active, passive and control trials. Similarly Koga et al. (1997) found no significant difference in VO_2 kinetics as a consequence of elevated muscle temperature. However, Gray and Nimmo (2010) and Brown et al. (2008), although not finding a significant difference between active and passive trials, did observe an increase in VO_2 values when pre-warming was used compared to the control trial. There is existing literature to suggest that elevated VO_2 allows athletes to reach the steady state of metabolic pathways more rapidly through increased blood flow to working muscles due to lowered vascular resistance, increased enzyme activity, and an increase in total oxygen consumption and delivery to the capillaries and mitochondria (Koga et al., 1997; Bishop, 2003; Gerbino et al., 1996). This is thought to be achieved

more readily through an active warm-up as opposed to a passive or no warm-up; however the results of the current study and those of similar design do not show evidence to support this (Gregson et al., 2002; Brunner-Ziegler et al., 2011). Even where significant difference was found between pre-warming and control (Gray & Nimmo, 2010; Brown et al., 2008), no difference was found between the methods of pre-warming (i.e. either active or passive) and this would suggest that it is the temperature related effects of warm up rather than the activity based effects that influence VO_2 kinetics.

No significant difference was observed between the heart rate responses of participants during the 30 minute exercise bout in each of the three trials (129bpm, 127bpm and 126bpm in the active, passive and control trials respectively) in the current study. Starkie et al. (1999) observed a similar heart rate response, even though exercise intensity was slightly higher at 70% of VO_2 max, compared to 55%. Although an increase was seen with the onset of exercise, a plateau was reached after 10 minutes and no significant difference was seen between all three trials. Brunner-Ziegler et al. (2011) also found no significant difference in heart rate response between any of the three trials. These results differ however, to those of Koga et al. (1997) and Gray et al. (2002) who observed that elevation in muscle temperature resulted in significantly higher heart rates during subsequent exercise. Likewise Gregson et al. (2002) and Brown et al. (2008) saw a significant increase in heart rate when preceded by a warm-up compared to control trials, but found no significant difference in the heart rate response between active and passive heating. Gray and Nimmo (2010) however found a significant difference in heart rate between all three trials, with active being higher than passive, and passive higher than control. It is obvious that during an active warm-up, heart rate would be elevated compared to a passive or no warm-up. The results of the current study are no exception, with the heart rate during the active warm-up reaching 127bpm compared to a heart rate of 80bpm in the passive warm-up and control trial. However, following the ten minute recovery period, at the onset of exercise, the heart rates were 77bpm, 67bpm and 92bpm for the active, passive and control trials respectively. This could be explained by the length of the recovery period, as heart rate has been seen to drop by almost

half in only five minutes of recovery after exercise (Bosquet et al., 2007). The increase in the heart rate during the control trial could be attributed to anticipatory rise, however as this rise was not seen in either of the other two protocols, it is more likely that the high resting heart rate (92bpm and 96bpm) of two of the participants affected the average heart rate results which were otherwise generally low (68bpm-85bpm). As the heart rates of participants were similar at the onset of exercise, it is not surprising that during the 30 minute exercise bout, no significant difference was observed in the heart rate response.

Following the passive warm-up, skin temperature was significantly higher than that achieved in the active warm-up; however this significance disappeared at the onset of the exercise bout and was not seen throughout the exercise. These results are comparable to those of Gregson et al. (2002) who also found no significant difference in skin temperature between any of the three trials at the onset of exercise or within the exercise bout. Gray and Nimmo (2010) observed a similar skin temperature response following the passive trial compared to the active, however this significantly higher temperature was maintained through to the onset of exercise. Koga et al. (1997) found that pre-warming using local heating of the quadriceps led to significantly higher skin temperatures in the lower limbs compared to the control, but showed no significant difference in the upper body. Using passive heating methods it is likely that a greater skin temperature response will be seen than in an active warm-up. This is due to the weighting coefficients used to calculate the mean skin temperature. It is common to use local heating of the quadriceps during a passive warm-up, and as this relatively large area of the body has a large weighting coefficient, the overall mean skin temperature is significantly increased. When observing muscle temperature however, Gray and Nimmo (2010) and Gregson et al. (2002) saw a significantly higher temperature in both active and passive trials compared to control, but at no time was a difference seen in muscle temperature between active and passive trials. This demonstrates the variability that can be seen within results when using different measures. Muscle temperature as opposed to skin temperature is perhaps a better means of measuring the thermoregulatory response to

exercise, however due to ethical implications it was not possible to use this method in the current study.

Energy expenditure is not a variable that is commonly measured in studies of similar design, however due to the focus on substrate use and its impact on health in the current study, it was taken into account. There was no significant difference seen in the amount of energy expended during the exercise bout in all three trials (856 \pm 199kJ, 878 \pm 196kJ and 867 \pm 209kJ in the active, passive and control trials respectively). It is common for energy expenditure to increase with higher body temperatures due to the processes initiated in order to maintain homeostasis, for example peripheral vasodilation and sweating (Dean et al., 2014). However, as no significant difference was seen in the basal measurements at the onset of exercise in each trial, it is not surprising that the amount of energy expended during the 30 minute bout of exercise in the current study was similar following all three conditions.

The main variable measured in this study was the amount of fat metabolised during the 30 minute submaximal exercise bout following each of the three conditions. Although a trend was seen towards pre-warming eliciting more fat oxidation than the control trial, and specifically an active warm-up having a greater effect than a passive warm-up, this trend was not significant and therefore it cannot be concluded that a difference exists between the three protocols. These findings are comparable to those of Gregson et al. (2002) who observed similar concentrations of FFA's during exercise following active, passive and no warm-up. They proposed that subsequent exercise had no effect on substrate availability as blood lactate levels, which are an indicator of carbohydrate availability, also showed no significant difference between trials. Starkie et al. (1999) however observed that an increase in muscle temperature, achieved through pre-warming, augments net muscle glycogen utilisation during submaximal exercise, suggesting that an increased amount of carbohydrate was utilised. Although carbohydrate use is not a direct measure of fat use, it does give some suggestion as to which fuel source was more dominant during exercise. In the case of Starkie et al (1999), the significant increase in muscle temperature at the onset of exercise in the pre-

warming trial compared to the control was thought to be the cause of the increase in glycogenolytic rate. They proposed that the elevated muscle temperature may have directly affected the key enzymes involved in the regulation of glycogen utilisation, which may have resulted in a substrate shift towards greater carbohydrate use, and less fat oxidation. However, due to the difficulties in measuring human skeletal muscle samples, they were unable to measure intramuscular lipid utilisation and therefore it is possible that the increase in glycogen utilisation may be related to other factors for example mitochondrial function. Contrary to these findings, Gray et al. (2002) found evidence to suggest that exercise preceded by an active warm-up may have a decreased reliance on anaerobically derived energy sources due to the decreased accumulation of blood and muscle lactate. Due to the lack of significant difference in muscle temperature observed between trials, their results also strongly suggest that the metabolic alterations are attributable to factors other than temperature alone. Brunner-Ziegler et al. (2011) also observed lower lactate levels; however these were seen following the passive warm-up rather than the active warm-up. They suggested that the increase in body temperature after the passive warm-up caused less anaerobic energy expenditure during the subsequent exercise. However these results conflicted with the oxygen uptake measurements, which showed no significant difference in VO_2 values between trials. The absence of blood sampling and therefore lactate measurement was a limitation of the current study. Due to ethical implications it was not possible to include this measurement and therefore the potential for further insight into the substrate utilisation within the exercise bout was lost. Although indirect calorimetry is the standard method for determining energy transfer and fuel utilisation during exercise, it is only effective under steady-state conditions and cannot account for the contribution of substrate use in the early transition to steady state (Mole & Hoffman, 1999).

A further limitation of the present study was the sample of participants who took part in the study. Due to time constraints, only eight participants were involved in the study. They were also all active, university sports students. Therefore, the results cannot be generalised to a larger population. It would

be invalid to apply these findings to a different population, for example children or the elderly. Although the participants were all of a similar age and fitness level, they were all from a variety of different sporting backgrounds and therefore had different training; where some were more aerobically trained, others were more anaerobically trained. This meant that there could be differences in their metabolic reactions to the prescribed exercise as there is evidence to suggest that using a work rate corresponding to a percentage of VO_2 max may be inappropriate as it could be closer to the lactate threshold in some participants than others (Baldwin et al., 2000).

CHAPTER 6

CONCLUSION

In conclusion, the results of the current study suggest that the use of a warm-up, whether it is active or passive, compared to no warm-up makes no significant difference to the fat metabolising properties of subsequent submaximal exercise and therefore there appear to be no beneficial effects of using a warm-up when endeavouring to increase fat use during exercise either for weight control or training adaptations.

The equivocal results arising from studies focused on the alterations to metabolism following different modes of warm-up mean that there is a need for further research into the area, with particular focus on substrate use as this is the variable where most discrepancy is apparent.

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APPENDICES

APPENDIX A

ETHICS STATUS



Cardiff
Metropolitan
University

Prifysgol
Metropolitan
Caerdydd

Date: 18th March 2014

To: Miss Jennifer Bell

Project reference number: 14/3/18U

Your project was recommended for approval by myself as supervisor and formally approved at the Cardiff School of Sport Research Ethics Committee meeting of 27th November 2013.

Yours sincerely,

A handwritten signature in black ink, appearing to read "M Hughes".

Michael G Hughes

Supervisor

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APPENDIX B

PARTICIPANT INFORMATION

Project title: Comparison of fat metabolism during submaximal exercise following active, passive and no warm-up.

Researcher: Jennifer Bell

Supervisor: Mike Hughes

Please take time to read the following information in order to understand the aim of the research and what would be required of you should you chose to participate.

Background: Warm up has long been recognised as a key contributing factor to athletic performance. There is an abundance of evidence to support its use as an ergogenic aid. As the name suggests, the main intention of a warm up is to elevate body temperature, this can be done either through active warm up (dynamic warming of the body via exercise) or passive warm up (increasing core and muscle temperature through external stimuli). However there is little research into the comparison of metabolic changes in the form of substrate use that these two methods elicit. Fat loss, particularly for the general population, is a main motivator of exercise participation. For this reason, the aim of this study is to compare the metabolism of fat during submaximal exercise following different warm up protocols.

What the study involves: Participants will be required to attend 4 laboratory sessions:

- Session 1- A VO_2 max test. Participants will be required to cycle until exhaustion on an ergometer. Expired air will be collected and analysed in order to establish individual levels of intensity for subsequent exercise.

- Session 2- A control. Participants will be required to cycle on an ergometer for 30 minutes at 55% of their VO_2 max power output, without a warm up. Temperature and heart rate will be monitored. Expired air will be collected and analysed.
- Session 3- A cycling warm up. Participants will be required to complete a warm up on a cycling ergometer. The warm up will last for 10 minutes. The first 4 minutes will be at an intensity of 40% VO_2 max, followed by 6 minutes of sprint intervals, comprising of 60 seconds at 90% VO_2 max and 90 seconds recovery at 40% VO_2 max. There will then be a recovery period of 10 minutes, followed by another 30 minute bout of submaximal exercise. Temperature and heart rate will be monitored throughout. Expired air will be collected and analysed.
- Session 4- A passive warm up. Participants will have denim sleeves lined with silicone tubes through which warm water will be perfused, wrapped around both legs until body temperature reaches the same level achieved during the active warm-up. There will then be a recovery period of 10 minutes, followed by another 30 minute bout of submaximal exercise. Temperature and heart rate will be monitored throughout. Expired air will be collected and analysed.

Participant Requirements:

- Participants must abstain from strenuous exercise and alcohol consumption 24 hours prior to testing.
- On the day of testing, participants should not consume any food of nutritional value 2 hours prior to testing. Dietary intake previous to this should be replicated as closely as possible between each trial.
- Participants must complete a Par-Q form prior to all testing to ensure their suitability. A pre-test questionnaire will also be administered before each trial to ensure they are fit to take part.

Are there any risks? The risks associated with this study are very small. As with any exercise there is always a minor risk of injury however no more so than would be experienced in an ordinary training session. The control trial in session 1 may carry with it a slightly higher risk of injury due to the lack of a warm up however the low intensity means this is highly unlikely. If it at any point during any of the sessions the participants feel unwell or are unable to continue they have the right to stop. Health questionnaires will be administered before each session to ensure the participant is in a fit state to take part.

Are there any benefits? As a participant in this study you will gain information about your own thermoregulatory, cardiovascular and metabolic responses to exercise as well as an insight into the effectiveness of warm up manipulation, which may help with your training or competition.

Confidentiality and the right to withdraw: All data generated from this study will remain strictly confidential. You have the right not to take part or to withdraw from participation at any time.

APPENDIX C
INFORMED CONSENT

Title of Project: Comparison of fat metabolism during submaximal exercise following active, passive and no warm-up.

Name of Researcher: Jennifer Bell

Participant to complete this section. Please initial each box.

1. I confirm that I have read and understand the information sheet for this study and have had the opportunity to ask any questions I may have.

2. I understand that my participation is entirely voluntary and I have the right to withdraw myself from the study at any time.

3. I understand that while the data provided by my involvement may be reported, I will not be named and my participation will remain confidential.

4. I agree to take part in this study.

Name of participant: _____

Signature of participant: _____

Date: _____

APPENDIX D

PAR-Q FORM

Name:

Date of Birth:

Male / Female (please circle)

Height: Weight:

Contact Number:

Please read the following carefully and answer as accurately as possible. The questions are designed solely to determine whether the proposed exercise is appropriate for you. Your answers will be treated as strictly confidential. If you have any doubts or difficulties with any of the questions please contact the person responsible for the study.

1. Has your doctor ever said to you that you have a heart condition and that you should only do physical activity recommended by a doctor?
2. Do you feel pain in your chest when you do physical activity?
3. In the past month have you had chest pain when you were not doing physical activity?
4. Do you lose your balance because of dizziness or do you ever lose consciousness?
5. Do you have a bone or joint problem (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 any other reason why you should not do physical activity?

YES	NO
YES	NO
YES	NO
YES	NO
YES	NO
YES	NO
YES	NO

I have completed the questionnaire to the best of my knowledge and any questions that I have raised have been answered to my full satisfaction.

Signed:

Date:

APPENDIX E

CURRENT HEALTH QUESTIONNAIRE

This form is to be used in conjunction with the General Health Questionnaire. It is to be completed in the laboratory prior to the commencement of the exercise test.

		YES	NO
1.	Have you suffered from a viral illness in the last two weeks?		
2.	Have you eaten within the last 2 hours?		
3.	Have you consumed alcohol within the last 24 hours?		
4.	Have you performed strenuous exercise within the last 24 hours?		
5.	Is there anything to your knowledge that may prevent you from successfully completing the tests that have been outlined to you?		

I have completed the questionnaire to the best of my knowledge and any questions that I have raised have been answered to my full satisfaction.

Signed:

Date: