The Effects of Sago Supplementation for Exercise in a Warm-Humid Environment

A thesis presented in partial fulfilment of the requirements for the degree of Doctor of Philosophy

PhD

In

Health (Sport & Exercise)

at Massey University, Manawatu,

New Zealand.

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2016

ABSTRACT

Whilst carbohydrate (CHO) ingestion during exercise with heat stress theoretically has some benefits for performance there is a lack of evidence on the effects of complex-CHO on exercise and recovery in warm-humid (tropical) conditions. The aims of this thesis were to investigate the effects of sago feeding on exercise performance, some physiological parameters, substrate metabolism, and thermoregulatory responses in the condition of exercise with thermal stress. The initial experimental study investigated the reliability of two novel laboratory-based cycling protocols in the presence of significant thermal stress. These protocols would then be employed in the second part of this thesis. The data indicate that the 15 min time-trial pre-loaded with 45 min fixed-intensity (**Chapter 5**, *Study A*) and 15 min time-trial pre-loaded with 15 min incremental warm-up (**Chapter 5**, *Study B*) were highly reliable when using trained, familiarized males under warm-humid environmental conditions. The second part of this thesis describes experiments which investigated the efficacy of an alternative Malaysian-based CHO, sago, on exercise in conditions which replicate the Malaysian environment (warm and humid). **Chapter 6** describes a study investigating the effect of sago supplementation before and during exercise in a warm-humid environment. The data collected from this study revealed that pre- and during-sago feeding has no differential effects on exercise performance though sago feeding produced a higher glycaemic response during the hour prior to exercise. However, feeding sago before exercise attenuated the rise in core temperature during exercise compared to the control condition, whilst there was a smaller reduction in plasma volume found when consuming sago during steady-state exercise through reduced whole-body sweating, with a concomitant higher plasma sodium concentration. Heart rate was also higher when sago was ingested either before or during exercise compared to control. Then, **Chapter 7** further investigated the utility of sago ingestion as a recovery meal on a

subsequent exercise bout in a warm-humid environment. In terms of performance, sago ingestion during short-term recovery seemed to sustain time-trial performance on the second bout of exercise compared to a control condition (no food) where exercise performance degraded. However, no attenuation of physiological, metabolic and thermoregulatory responses was apparent.

ACKNOWLEDGEMENTS

First and foremost, thanks to the Almighty God for giving me strength, courage and opportunity to complete this thesis. I have to thank Universiti Sains Malaysia (USM) and Ministry of Higher Education Malaysia (MoHE) for the scholarship that provided financial support for my family and myself throughout four amazing years overseas in completing my PhD at Massey University, New Zealand.

I would like to express my sincere gratitude and appreciation to my main supervisor Dr Toby Mündel, and co-supervisors, Prof Steve Stannard and Prof Hugh Morton. Without their guidance, advice, and support it would seem impossible to complete this thesis. Thanks also to the Human Performance Laboratory managers, Hayden, Karl and Blake for the equipment guidance and lessons throughout my data collection process in the laboratory. Many thanks to each of participants who were willing to spend their time to contribute to all my studies and without them, there would be no thesis.

Finally, special thanks to my lovely wife Halida and sons Rifqi Harraz and Raaiq Harraz, and my family for their love, support, and encouragement throughout the course of my studies.

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LIST OF ABBREVIATIONS

A

ANOVA	Analysis of variance

B

Bpm	Beats per minutes

C

CBF	cerebral blood flow
^{o}C	Degrees Celsius
CHO	CHO
CO_2	Carbon dioxide
CNS	Central nervous system
CV	Coefficient of Variation

D

E

EMG	Electromyogram
E_{max}	Maximal evaporative capacity of the environment

G

g	Gram
GE	Gross energy
g/min	Gram per minute
GI	Glycaemic index

H

h	Hour
Hb	Haemoglobin
HR_{max}	Maximum heart rate

I

ICC	Intraclass correlation

K

Kg	Kilogram
kJ	Kilojoule
km	Kilometre
km/h	Kilometre per hour

L

L	Litre
L/min	Litre per minute
LF	Linear factor
LOA	Limit of agreement

M

m	Metre
min	Minute
ml	Millilitre
ml/kg	Millilitre per kilogram
ml/kg/min	Mililitre per kilogram per minute
mmol	Millimole
mmol/L	Millimole per litre
MCA V_{mean}	Middle cerebral artery mean blood velocity

O

O_2	Oxygen

R

r	Correlation coefficient
RPE	Rating of perceived exertion
RPM	Revolutions per minute

S

SD	Standard deviation

T

T_{bicep}	Skin temperature at the bicep
T_{calf}	Skin temperature at the calf
T_{chest}	Skin temperature at the chest
T_{core}	Core temperature
T_{SK}	Mean skin temperature
T_{skin}	Skin temperature
T_{thigh}	Skin temperature at the thigh
TDF	Total dietary fibre

V

VCO_2	Volume of carbon dioxide production
V_E	Minute ventilation
VO_2	Volume of oxygen uptake
VO_2max	Maximal oxygen uptake
VO_2peak	Peak of oxygen uptake
% VO_2peak	Percentage of the peak rate of oxygen uptake

W

W	Watt
WBGT	Wet bulb globe temperature
W_{max}	Watt maximum

X

$\overline{x}$	mean

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CHAPTER ONE

1.0 INTRODUCTION

The relationship between reduced carbohydrate (CHO) availability and the onset of fatigue has been known for some time (Christensen & Hansen, 1939) as the progressive depletion of skeletal muscle's limited glycogen stores and reduction in circulating blood glucose as aerobic/endurance exercise progresses are linked to performance deterioration and volitional fatigue (Cermak & van Loon, 2013). It follows that supplementing CHO can delay the onset of fatigue and improve work output and capacity (Burke & Hawley, 1999), with the combination of an appropriate CHO composition and administration regimen subsequently delivering major benefits to endurance performance (Vandenbogaerde & Hopkins, 2011); hence, for example, the prescriptive use of CHO-containing sports drinks (Sawka, Burke, Eichner, Maughan, Montain & Stachenfeld, 2007).

Many sporting events take place during the hottest season, in warm to hot climates or at the hottest part of a day (Burke, 2001). One of the consequences of exercise heat stress is an alteration in CHO metabolism; Yaspelkis & Ivy (1991) demonstrated that exercise in the heat accelerated fatigue because of an increase in reliance upon CHO as a substrate, whilst Jentjens, Wagenmakers & Jeukendrup (2002) demonstrated that when ambient temperatures increase so does CHO oxidation during exercise largely due to an increased muscle glycogen use. However, total CHO oxidation is often lower as fatigue is reached at an earlier time-point during exercise in the heat when compared to cooler conditions (Galloway & Maughan, 1997). Moreover, Parkin, Carey, Zhao & Febbraio (1999) noted that when endurance-trained subjects cycled to exhaustion at 70% VO_2max in cool, moderate and hot environments, exercise time was shortest in the heat whilst muscle

glycogen levels at fatigue were significantly higher and remained above 300 mmol/kg dry weight leading the authors to conclude that "fatigue during exercise in the heat is related to processes other than CHO availability". Nevertheless, there is evidence that manipulating pre-exercise carbohydrate availability (Pitsiladis & Maughan, 1999) or supplementing CHO during exercise (Carter, Jeukendrup, Mundel & Jones, 2003) can still enhance performance when exercise is completed in the heat.

Where commercially available CHO products are not necessarily affordable or accessible to those competing in sport or exercise, there is a need to investigate local food sources as suitable alternatives. Southeast Asia is a region with over 600 million inhabitants and a year-round tropical (warm-humid) climate, where sago (*Metroxylin sagu*) palms grow all over and their starch is used as an important dietary CHO source (Abd-Aziz, 2002). For example, Malaysia, Indonesia and Papua New Guinea are the world's leading countries in the production of sago (Singhal, Kennedy, Gopalakrishnan & Kaczmarek, 2008) and in Sarawak, Malaysia, sago is widely used to produce sago pearls that can be boiled and consumed directly as a CHO source. Previous research has identified sago as being rapidly digestible, quickly absorbed, therefore it was postulated that sago meals are suitable for consumption before, during and in recovery from exercise (Ahmad, Singh & Ghosh, 2009). Nevertheless, only one study has previously tested this notion; Ghosh, Rahaman & Singh (2010) demonstrated no benefit of feeding 60 g sago at 20-min intervals during cycling at 60% VO_2max on subsequent exhaustion time at 90% VO_2max. The study was conducted in a thermoneutral-warm (25 ± 1^{o}C, 70% ± 5%) environment, however with participants of low aerobic fitness and training status.

A novel aspect of this thesis is to introduce a Malaysian food 'staple' to the field of exercise and sport nutrition. The central part of this thesis is to initiate research work investigating the impact of this local CHO source (sago) on exercise and recovery from exercise in the tropical environmental conditions akin to that experienced in Malaysia. The information developed from the results of the thesis will assist interest as to whether a native starch such as sago can be developed and used as a supplement during exercise. The interest in this is based on fact that sago is consumed as a local Malaysian CHO source (Tek-Ann, Md. Isa & Mohayidin, 1999) and supported by claims that it is a suitable raw material for the chemical industry in developing maltodextrin and sport drinks (Flores, 2007).

The second novel aspect of these studies is the environmental conditions employed which represent the warm-humid Malaysian climate where sago is consumed. These conditions can impair exercise performance because of physiological and metabolic changes which trigger early termination of exercise. Guidelines for acclimatization, cooling, and (re)hydration, are available from well-regarded bodies such as the American College of Sports Medicine (ACSM) (Armstrong, Casa, Millard-Stafford, Moran, Pyne & Roberts, 2007; Sawka *et al.*, 2007; Rodriguez, DiMarco & Langley, 2009b) to help with safety and ensure optimal performance. However, they do not necessarily reflect the Malaysian environment and do not refer to Malaysian foods. Information which can assist those in Malaysia and surrounding countries to tailor recommendations from ACSM (or similar) to local conditions and resources is necessary. The findings of this thesis goes some way to enabling that to occur.

1.1 Overview of Thesis

The concepts briefly introduced in this chapter (**Chapter 1**) will be further explored in the remaining seven chapters.

Chapter 2 entails a focussed review of the literature. This includes a brief overview of the physiological responses to exercise with heat stress including metabolism and performance consequences, carbohydrate supplementation during exercise with heat stress, sago as a nutritional supplement and a brief appraisal of laboratory exercise protocols.

Chapter 3 explicitly states the research aims and hypotheses.

Chapter 4 describes in detail the methods, protocols and equipment that were used in all of the subsequent experimental chapters.

Chapters 5-7 contain the four experimental studies designed to meet the objectives of this thesis. These chapters are written as independent manuscripts and as such include a formal introduction, abbreviated methods, full results and discussion. The content of these chapters ranges from developing and (reliability) testing the cycling protocols to be used with the sago interventions (**Chapter 5**) to investigating whether sago porridge and gel, prepared according to local/traditional Malaysian methods, influence exercise physiology and/or performance when compared to a water-only control condition, and whether supplement timing (before, during, and in recovery from exercise) affected efficacy (**Chapter 6** and **Chapter 7**).

Finally, **Chapter 8** summarizes, critically discusses, proposes directions for future research, and concludes this thesis.

CHAPTER TWO

Publication based on this chapter:

Mohd Rahimi Che Jusoh, Stephen R. Stannard, Toby Mündel. (2016). Sago supplementation for exercise performed in a thermally stressful environment: Rationale, efficacy and opportunity. Temperature, 1-10.

Many major sporting events take place during the hottest season, in warm climates, or at the hottest part of a day (Burke, 2001). During exercise with heat stress, there is consensus that performance is decreased compared with cooler conditions, and there is an increased risk of heat illness, especially with high humidity (Wendt, van Loon & Lichtenbelt, 2007). Therefore, it is of interest that these are the conditions awaiting athletes in the upcoming 2016 Summer Olympics in Rio de Janeiro, Brazil. Additionally, recent major sporting events have been or will be held under thermally stressful climates (e.g. 2020, 2008, 2004 Summer Olympics in Tokyo, Beijing and Athens; 2018, 2010 and 2006 Commonwealth Games in Gold Coast, Delhi and Melbourne; 2022 and 2014 Soccer World Cups in Qatar and Brazil). Thus, athletes and their support teams must take the environmental conditions into consideration for optimal training and performance. The variables which need consideration while training or competing might include ambient temperature and humidity, duration of exercise, time of day, nutrition, clothing, airflow and heat acclimatization status (Casa, Stearns, Lopez & Ganio, 2010).

On a personal level, my country, Malaysia is located in a tropical (warm and humid) zone; this climate is characterized by high monthly temperatures which can exceed 18^{o}C throughout the year and rain or considerable wet (Hue, 2011). Overall, Malaysia has annual temperatures of 27-35^{o}C and 70%-90% relative humidity (Wijayanto, Wakabayashi, Lee, Hashiguchi, Saat & Tochihara, 2011), therefore

making it important for anyone playing sport or exercising to know the risks (of heat illness) and ways in which these can be minimised and performance optimised.

2.0 Review of Literature

This chapter (**Chapter 2**) is devoted to a focussed review of the literature, the purpose of which is to introduce and discuss only the areas pertinent for the ensuing experimental chapters. This rationale for inclusion into the Literature Review is based on the fact that i) the broader topics that precede this thesis include human exercise thermoregulation, human exercise metabolism, carbohydrate as an ergogenic aid, exercise heat stress and reliability of endurance performance protocols, where any one of these topics would itself command a very substantial body of work, ii) there have been a number of comprehensive and thorough reviews published on these topics relatively recently e.g. (Currell & Jeukendrup, 2008; Sawka, Leon, Montain & Sonna, 2011; Brooks, 2012; Cermak & van Loon, 2013; Nybo, Rasmussen & Sawka, 2014) and iii) there is an attempt to minimise unnecessary/redundant repetition throughout this thesis. However, this review will contain a description and critique of the literature that will form the foundation for the thesis from which the specific aims, objectives and hypotheses are formulated.

This chapter will begin by highlighting the effect of ambient heat stress on the performance of prolonged exercise and the physiological consequences thereof. This is followed by a section highlighting the metabolic responses and how supplementation of carbohydrate has been used as an ergogenic aid when exercise is performed in a hot environment. The next section will introduce sago as a starch to be consumed by athletes, with the final section of the literature review briefly

summarizing the common protocols used for cycling endurance performance and their respective reliability. **Chapter 2** concludes with a summary of the findings, and based upon this literature review, the primary foci of this thesis will be formally stated, while the aims, specific objectives and hypotheses outlined in **Chapter 3**.

It is acknowledged that due to the nature of the experimental work within this thesis (**Chapters 5-7**) priority and emphasis within this review of the literature will be given to studies observing physiological and performance responses (thereby unintentionally ignoring psychological and biomechanical literature), measured using cycling protocols of prolonged (i.e. ≥ 30 min) and moderate-high intensity (i.e. 60-85% maximal aerobic capacity) in nature to improve generalizability of results to those sought herein.

Finally, it must be acknowledged that the 'ambient heat' is multi-factorial; the air temperature, air velocity (with cycling usually the speed at which you are travelling), solar radiation (only when exercising outdoors) and air humidity combine in contributing to the stress imposed, and therefore the resulting heat strain. As evaporation from the skin's surface is the predominant route of heat dissipation during exercise, and as most studies are performed with negligible radiant heat (in a laboratory), it is the combination of air temperature and humidity that dictate the sweating requirements to balance the metabolic heat produced through work. In a hot-dry environment sweating accounts for up to 100% heat loss, however when the ambient humidity increases (i.e. tropical conditions) sweat evaporation can account for only 80% heat loss (Casa, 1999). This is depicted in *Figure 2.1* where a Heat Stress Index above 100% denotes a point where body temperature cannot be controlled due to insufficient sweat evaporation to balance the heat load of exercise. Specifically, when the relative humidity exceeds 70%, the water vapour pressure will

reduce the evaporative capacity of the environment (E_{max}) and limit heat dissipation from the skin to environment. Therefore, a temperature-humidity of 25°C-80% is equally as stressful as 35°C-60% (Brotherhood, 2008)

Unfortunately, research into the effects of exercise heat stress has focussed on dry-heat with far less conducted on more humid conditions. As there have been few systematic investigations on the performance and physiological/metabolic effects of similar levels of heat stress through different combinations of temperature-humidity, no distinction will be made throughout this thesis.

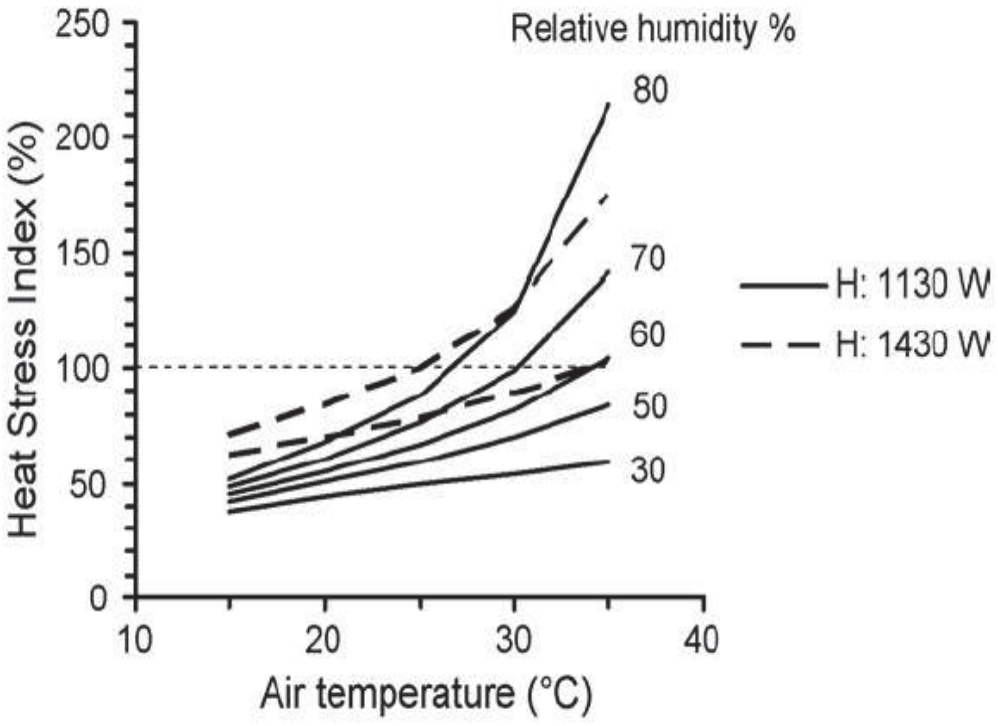

Figure 2. 1: Relationship between ambient temperature and ambient humidity to heat stress index (Brotherhood, 2008).

2.1 AMBIENT HEAT STRESS AND ENDURANCE PERFORMANCE

Continuous, dynamic, whole-body exercise itself often causes a marked rise in body temperatures, usually observed by a rise in core and active muscle temperatures that are thought to have a beneficial effect by increasing the rate of biochemical reactions, such as actin/myosin interaction and glycolytic and oxidative pathways within the body (Q_{10} effect). Early research suggested this to be important/necessary in optimising exercise performance, and that the addition of exogenous (ambient) heat stress did not impair this effect e.g. (Asmussen & Bøje, 1945; Saltin, Gagge, Bergh & Stolwijk, 1972). However, since that time it has been well-established that the additional heat strain placed upon the body whilst exercising for a *prolonged* period in hot conditions exacerbates this rise in body temperature(s) and reduces, rather than improves the capacity for endurance performance (Nybo *et al.*, 2014).

An increased ambient temperature is associated with an increased percentage of non-finishers during prolonged running races (Vihma, 2010; Wegelin & Hoffman, 2011) whilst an inverse relationship is found between ambient temperature and endurance exercise performance within a given competition (Martin & Buoncristiani, 1999; Ely, Cheuvront, Roberts & Montain, 2007; Vihma, 2010; Wegelin & Hoffman, 2011). Laboratory-based exercise performance duration (e.g. time-to-exhaustion) is also reduced by exogenous heat stress. For example, MacDougall, Reddan, Layton & Dempsey, (1974) demonstrated that exercise duration was reduced with hyperthermia relative to when subjects were normothermic or hypothermic. Similarly, Galloway & Maughan, (1997) observed exercise time-to-exhaustion to be shortest in the heat, while Parkin et al., (1999) confirmed these findings by noting that exercise time-to-exhaustion was shortest in the heat, longer in moderate conditions, and longest in cool ambient conditions. However, whilst these traditional

fixed-intensity (constant workload) protocols form the basis of our understanding of the possible mechanisms contributing to hyperthermic fatigue (see *section 2.1.1* below), their face-validity and also reliability are poor (see *section 2.5* below). Notably, self-paced exercise protocols (whether completing a known distance, time or amount of work) allow exercisers to alter their intensity – often according to a pacing strategy – and have greater face-validity and reliability. Similar to the fixed-intensity protocols mentioned above, self-paced performance is also reduced by ambient heat stress (Tatterson, Hahn, Martin & Febbraio, 2000; Marino, 2004; Tucker, Rauch, Harley & Noakes, 2004; Ely *et al.*, 2007; Ely, Cheuvront, Kenefick & Sawka, 2010; Schlader, Raman, Morton, Stannard & Mundel, 2011a; Schlader, Stannard & Mundel, 2011b) through the individual reducing their rate of metabolic heat production (exercise intensity), thus attenuating their rate of core temperature rise and thereby usually reaching lower end-exercise core temperatures than with fixed-intensity exercise (Schlader, Stannard & Mundel, 2011c).

As alluded to in the previous section, exercise capacity is also reduced when humidity is high due to the physical strain imposed. Living (exercising) in an environment above 35^{o}C can be considered as high/hot whilst an environment with humidity in excess of 60% can be considered as 'humid' (Zhao, Zhu & Lu, 2009). Relative humidity is measured by how much moisture is present and compared to how much moisture the air could hold at that temperature. Psychometric charts are used to determine the relative humidity after both the dry and wet bulb temperatures are known (Shelton, 2008). However, there has been little (recent) discussion about the influence of relative humidity on exercise performance and physiological responses in either recreational or trained athletes. According to Liang, Zheng, Zhu, Tian, Lu, and Chen, (2011) body heat is transferred to the environment by convection during low or moderate temperature and humidity. Then, at high

environmental temperatures (e.g. 35^{o}C), the normal core body temperature can only be maintained by evaporating sweat. Therefore, as the relative humidity of the environment is high, the sweat loss from the skin through evaporation is reduced rather compared to in dry environments and as a consequence, core temperature rises (Maughan, Otani & Watson, 2012).

2.1.1 Hyperthermic Fatigue

Historically, an elevation in body temperature(s) has been hypothesized to contribute to performance deterioration. For example, in the abovementioned studies, core temperatures at fixed-intensity exhaustion in the heat were consistently between 39.5°C and 40.0°C (MacDougall *et al.*, 1974; Galloway & Maughan, 1997; Parkin *et al.*, 1999). These findings are supported by the observations that heat acclimation (Nielsen, Hales, Strange, Christensen, Warberg & Saltin, 1993; Cheung & McLellan, 1998), pre-exercise body temperature (González-Alonso, Teller, Andersen, Jensen, Hyldig & Nielsen, 1999), the rate of heat storage (Gonzalez-Alonso, Teller, Andersen, Jensen, Hyldig & Nielsen, 1999), or hydration status (Cheung & McLellan, 1998) do not modify the reliability of a substantially elevated core temperature at fatigue. Therefore, it was proposed that a 'critically' high core temperature (~40°C) caused fatigue (Nielsen *et al.*, 1993), and as this temperature is below that associated with cellular damage (Hales, Hubbard & Gaffin, 1996), this phenomenon would prevent catastrophic hyperthermia (Cheung, 2007), e.g. exertional heat stroke.

However, Brück and Olschewski, (1987) proposed that elevations in body temperatures are not independent but are associated with a cascade of physiological responses (*Figure 2.2*), and therefore a core temperature of ~40°C

could be an artefact of another physiologically limiting process. For example, core temperatures greater than 40°C have been observed during and upon completion of exercise without exertional heat illness symptoms (Robinson, 1963; Pugh, Corbett & Johnson, 1967; Maron, Wagner & Horvath, 1977; Byrne, Lee, Chew, Lim & Tan, 2006; Lee, Nio, Lim, Teo & Byrne, 2010), while core temperatures approaching or exceeding this hypothetical ceiling have not been found to be detrimental to exercise performance during self-paced (variable intensity) running (Ely, Ely, Cheuvront, Kenefick, Degroot & Montain, 2009). Furthermore, 'maximal' core temperature at exhaustion is dependent upon aerobic fitness (Cheung & McLellan, 1998; Selkirk & McLellan, 2001) which demonstrates the plasticity of this apparent hyperthermic threshold.

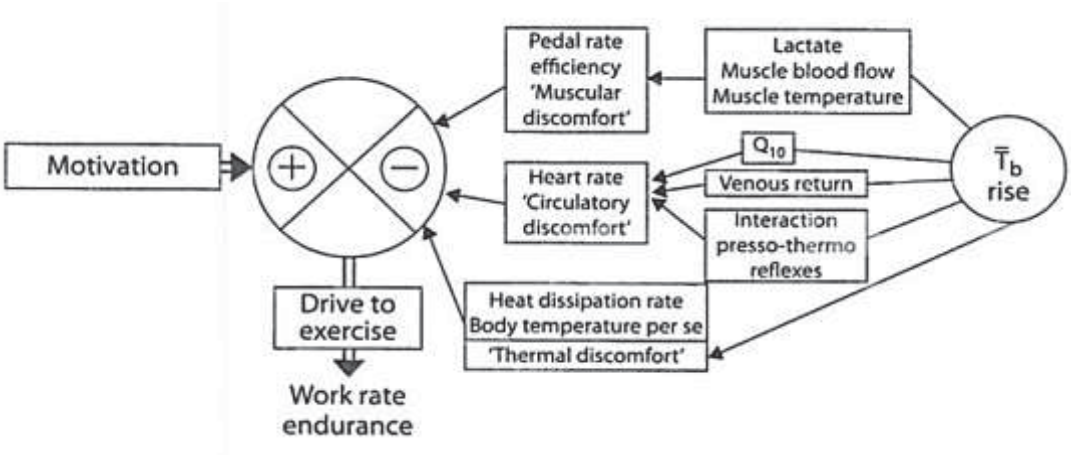

Figure 2. 2: Factors by which body temperatures may exert their influence on exercise endurance (Bruck & Olschewski, 1987).

As the term suggests, an elevated core temperature is a pre-requisite for hyperthermia-induced exhaustion. However, hyperthermia provokes a cascade of physiological responses which range from an altered muscle metabolism (Mundel, 2008), increased cardiovascular strain (Rowell, 1974), a modification of neuromuscular (Cheung, 2008) and cerebral (Nielsen & Nybo, 2003) activity, and endotoxemia (Lambert, 2008). Therefore, it is unlikely that a specific threshold core

temperature determines exercise performance in the heat, rather this (progressive) fatigue is probably mediated by the combined stress placed on the physiological systems maintaining homeostasis. The following section will briefly summarize the physiological responses to prolonged exercise when performed under conditions of heat stress.

2.2 AMBIENT HEAT STRESS AND EXERCISE PHYSIOLOGY

2.2.1 A Skin Blood Flow Challenge

The first serious discussion on the exercise physiological responses in the heat is the effect on human skin blood flow and this response crucial to the maintenance of normal body temperature. In thermal stress condition, the skin blood flow increases to 6-8 L/min during severe hyperthermia due to thermoregulatory vasodilation (Charkoudian, 2003; Hodges, Kosiba, Zhao & Johnson, 2009) whereas resting skin blood flow in thermo neutral condition is approximately 250 ml/min (Charkoudian, 2003) and Johnson, Brengelmann, Hales, et al., (1986) reported 2.3 ml/100 ml/min. The increase in sympathetic vasodilator nerve activity when the higher core and skin temperature during exercise in the heat thus increase skin blood flow for heat dissipation of metabolic heat by convective heat transfer from the core body to the periphery (Roberts, Rivers, Oliveria, Texeira & Raman, 2002; Hodges & Johnson, 2009; Johnson, 2010). Correspondingly, skin blood flow and sweating continue to increase until the heat balance between heat dissipation and heat generation is equal thus body core temperature in normal ranged (Charkoudian, 2003). Identically, during cutaneous vasodilation, heat loss via convective that from internal body to periphery and sweat evaporation from the skin to environment occur outside

the body. Coupled with mass blood flow circulation to the skin during heat stress, Nelson, Haykowsky, Stickland, Altamirano, et al., (2011) reviewed that there also large increase in cardiac output as high 131 ml/min then cause inadequate cerebral perfusion and reduce in cerebral blood flow velocity.

Henceforth, the primary thermoregulatory trigger that affects the skin blood flow is local tissue temperature (Carter & Hodges, 2011) or core body temperature (Johnson, 1986). The sympathetic active vasodilator system is only activated during increases in internal temperature or exposure to heat environment (Charkoudian, 2003). Thus, the cutaneous active vasodilator system is a vital process to release heat from inside the body to avoid heat-stress related illnesses (Kellogg, Zhao, Wu & Johnson, 2010) and core temperature is an indicator to drive sympathetic vasodilator activity (Kamijo, Lee & Mack, 2005). Besides the reflex control of skin blood flow, the local temperature of an area of skin also contributes to control of skin blood flow. The response of the local temperature effect on skin blood flow has been comprehensively explained by Charkoudian (2003). Typically, when a human in thermal stress, the first 3 to 5 minute shows initial rapid increase in blood flow then followed by a moderate decrease and after 25 to 30 minutes, skin blood flow tend to plateau. This response to the local heating on the skin blood flow is known as biphasic (vasodilator response). It has been categorized as an initial rapid increase in blood flow at the beginning of the response to heat stress (Charkoudian, 2003).

Significantly, the increase in blood flow to active muscles are vital to meet the energetic demand or muscular contraction and at the same time, the blood flow to skin also essential for the heat dissipation during exercise in the heat environment. In the first place, low muscle blood flow will cause fatigue then secondly a reduction in skin blood flow will disrupt heat dissipation from the body to the environment and

as a consequence, increase in core temperature. Both effects are commonly seen during cycling exercise in the heat environment that will limit the supply of oxygenated blood to the entire body during exercise (Casa, 1999). There are three factors that contribute to the limit of the blood flow to active muscle during exercise in the heat. Gonzalez- Alonso, Crandall, & Johnson (2008) have listed as an increased sympathetic vasoconstrictor nerve activity with hyperthermia, secondly is for sure limited by thermoregulatory reflexes that associated with increases in skin blood flow. Lastly, they pointed out reduce blood flow to active muscles because of a large difference between the ability of the heart to pump sufficient volume of blood and the potential capacity for vascular conductance in active muscle (Gonzalez-Alonso *et al.*, 2008). The blood flow to the skin during exercise in the heat progressively increased due to the thermoregulatory vasodilation in skin then automatically vasoconstriction in active muscles (Gonzalez-Alonso, Calbet & Nielsen, 1999; Gonzalez-Alonso *et al.*, 2008). It is apparent on the cycling testing protocol when the blood flow to the legs was 13% decreased in dehydration status trial compared to in euhydration trial in the 35^{o}C ambient temperature environment (Gonzalez-Alonso, Calbet & Nielsen, 1998). It seems possible that reducing the blood flow to the active muscles resulted in the degrade exercise performance and appear to be the primary source of fatigue during exercise in the heat stress. The evidence from their study suggested that another combination between heat stress and the restrictions in oxygen supply to the active muscle expose the athletes to reduce aerobic power thus impair exercise performance.

2.2.2 A Thermoregulatory Challenge

During physical activity, metabolic heat production increases considerably (~10-20 fold), and because the human body is not entirely efficient, about 70-80% of the

energy expended gets converted to heat (Powers & Howley, 2009). It is this increase in heat production within the body, in combination with competition between organs for cardiovascular adjustments, which can create problems for regulating body temperature, and subsequently impact on performance. This higher metabolic heat production during exercise inevitably causes an increase in core temperature to some extent, but this is not indicative of a 'loss' in thermoregulation as often there is a plateau in the rise of core temperature that occurs within ~20 min (Nielsen & Nielsen, 1962, 1965; Saltin & Hermansen, 1966). The resulting core temperature plateau is achieved throughout a range of ambient temperatures (5°C - 30°C); (Nielsen & Nielsen, 1962), and is predominantly a function of relative exercise intensity (Saltin & Hermansen, 1966) and the thermal environment (Lind, 1963).

It is this characteristic plateau that illustrates that the body is in thermal balance (heat loss = heat gain), and thermal balance is seen to be disrupted if core temperature continues to rise without a plateau, as typically seen during exercise in hot environments that can lead to hyperthermia (see *section 2.1*). This is characteristic of an 'uncompensable' environment with exercise continuation inevitably leading to a further increase in core temperature. *Figure 2.3* illustrates that as ambient temperature increases, the contribution from convection and radiation to heat loss rapidly decreases until evaporative heat loss (via increased sweating) is the only means of heat removal from the body. The increase in evaporative heat loss at these temperatures can compensate for this change at low exercise intensities, but as exercise intensity increases metabolic heat production will be too high and heat removal insufficient to maintain a thermal steady state, leading to an increase in core temperature. This concept is illustrated in *Figure 2.4*, as when

exercise intensity increases, in combination with high air temperatures, the less chance there is of being able to maintain a steady-state core temperature.

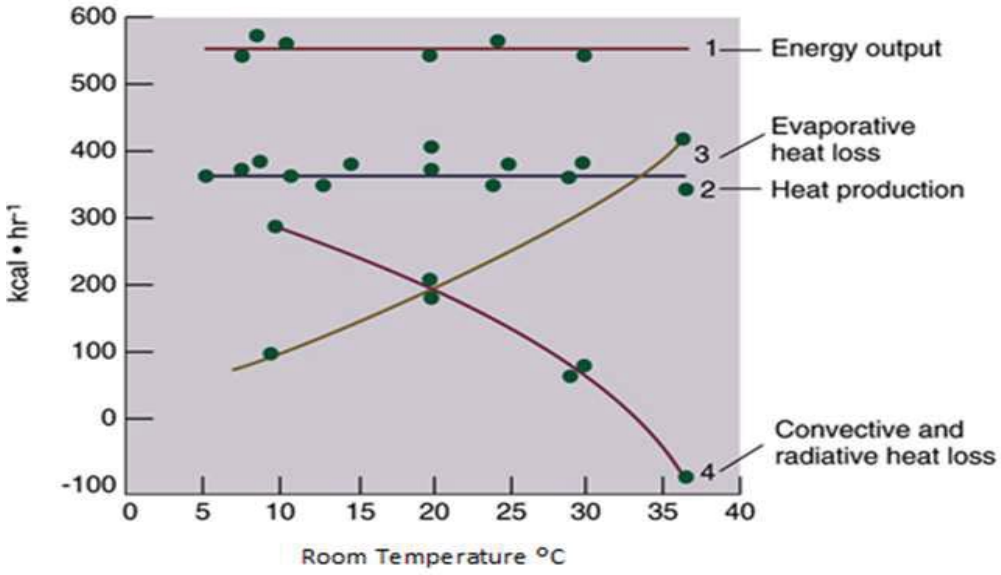

Figure 2. 3: Heat production and contributions of evaporative, convective and radiative heat loss during exercise at a range of environmental temperatures (Powers & Howley, 2009).

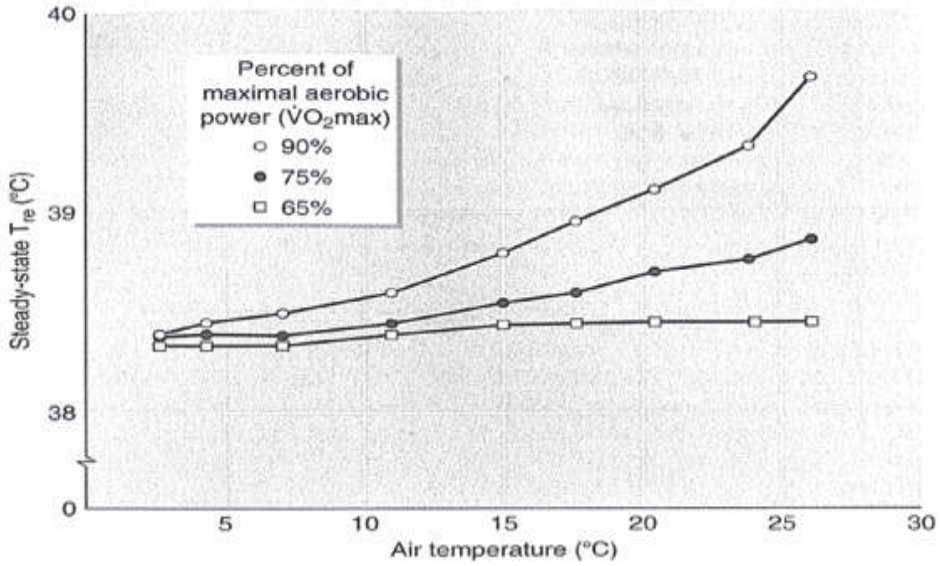

Figure 2. 4: Core temperature over a range of air temperatures at three different exercise intensities (Armstrong, 2000).

2.2.3 A Cardiovascular Challenge

In order for evaporation to increase during times of heat stress, blood flow to the skin must be increased. This can lead to an exacerbated competition between the skin and the muscle for contribution of the cardiac output with reduced blood flow to either of these tissue beds inevitably leading to performance decrements during exercise; reduced muscle blood flow limiting the duration/intensity of exercise, with reduced cutaneous blood flow potentially causing hyperthermia over time (Gonzalez-Alonso *et al.*, 2008). Accordingly, prolonged exercise in the heat provides a significant cardiovascular challenge that is characterized by a reduced stroke volume, central blood volume, aortic pressure and cardiac output, and the attainment of near maximal heart rates (Rowell, Marx, Bruce, Conn & Kusumi, 1966). Rowell (1986) commented that "…the greatest stress ever imposed on the human cardiovascular system (except for severe hemorrhage) is the combination of exercise and hyperthermia". These changes are illustrated in *Figure 2.5.*

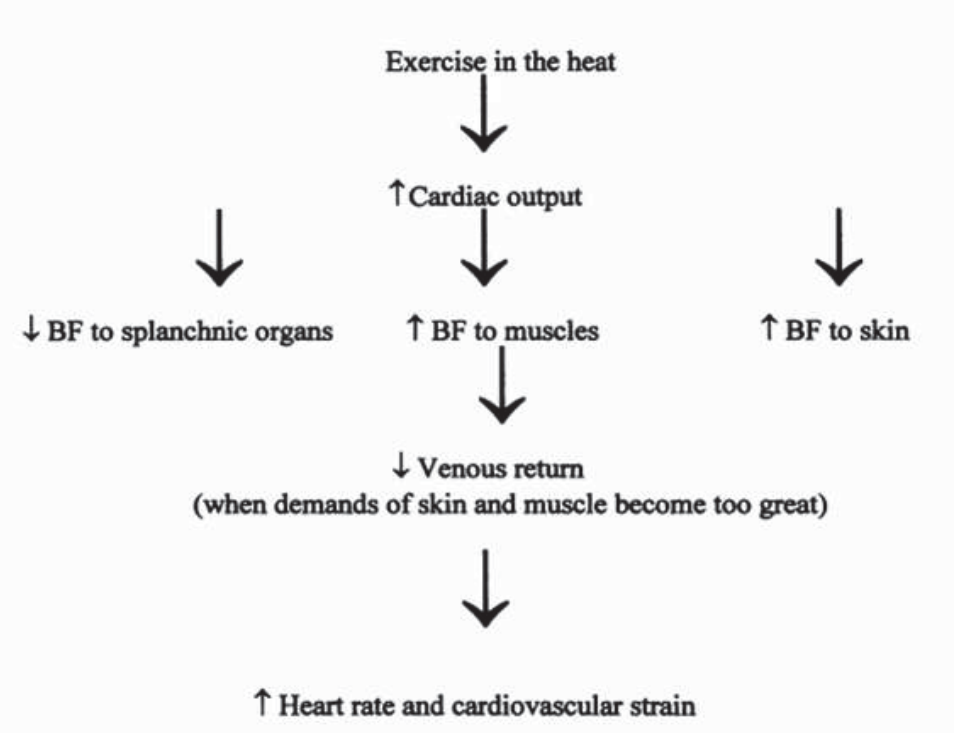

Figure 2. 5: Cardiovascular changes during exercise in the heat (Casa, 1999).

Further evidence of a role for the cardiovascular system to limit exercise in the heat is found with a decreased splanchnic blood flow possibly compromising the intestinal barrier, increasing permeability, and initiating a cascade of events perhaps mediating endotoxemia (Lambert, 2004; Lambert, 2008). The increased gastrointestinal permeability is likely due to increased exercise intensity or hyperthermia but Shing, Peake, Lim, et al., (2014) suggested rehydration during exercise among well trained athletes minimizes gastrointestinal stress in hot conditions.

2.2.4 A Central Nervous System Challenge

The brain and central nervous system have received far less investigation during exercise heat stress until relatively recently. Nybo & Nielsen (2001b) found that during exercise in the heat middle cerebral artery mean blood velocity (MCA V_{mean}) was reduced, indicating reduced blood supply to the brain. Additionally, Nybo, Moller, Volianitis, Nielsen & Secher, (2002) observed global cerebral blood flow (CBF) to be reduced during the hot trial compared to the control, and that whole-brain blood flow was 18% lower at the end of exercise in the heat. Although a reduced CBF and MCA V_{mean} may be detrimental when exercising in the heat, the actual consequences of these reductions are not entirely known. Despite the reduced blood flow to the brain, the cerebral metabolic consumption of O_2 is maintained indicating that O_2 delivery does not appear to be compromised (Nielsen & Nybo, 2003). As a result of a reduced CBF during heat stress, heat removal from the brain via the jugular venous blood is reduced (Nielsen & Nybo, 2003), with Nielsen & Nybo (2003) concluding that during exercise in the heat (and with hyperthermia), some degree of cerebral heat storage is inevitable and may contribute towards the concept of ‘central fatigue’ during exercise in the heat.

Despite the progressive development of hyperthermia, neuromuscular activity, as measured via electromyogram (EMG), is similar during fixed-intensity bouts of cycling in both hot and moderate conditions (Hunter, Gibson, Mbambo, Lambert & Noakes, 2002). By contrast EMG activity, and thus skeletal muscle recruitment, is lower in the heat during prolonged self-paced cycling exercise compared to that in a cooler environment (Kay, Marino, Cannon, St Clair Gibson, Lambert & Noakes, 2001; Tucker *et al.*, 2004; Tucker, Marle, Lambert & Noakes, 2006; Abbiss, Burnett, Nosaka, Green, Foster & Laursen, 2010). However, as exercise intensity decreased concurrently with EMG activity in all instances, it is unclear as to whether neuromuscular skeletal muscle recruitment decreased exercise intensity or was a consequence of this intensity reduction.

Similar findings have been observed immediately following prolonged exercise in the heat. EMG activity of the exercised muscle group is reduced following exercise in the heat (Ftaiti, Grelot, Coudreuse & Nicol, 2001; Nybo & Nielsen, 2001a; Martin, Marino, Rattey, Kay & Cannon, 2005). However, Saboisky, Marino, Kay, & Cannon, (2003) and Abbiss, Levin, McGuigan & Laursen, (2008) found force production and power output to be attenuated despite maintenance of EMG activity. Of particular interest is that in all of the abovementioned studies the observed reductions in voluntary force production were mainly due to reductions in voluntary (central) activation and not the inability of the muscle itself to produce an equivalent force output (Nybo & Nielsen, 2001a; Saboisky *et al.*, 2003; Martin *et al.*, 2005; Abbiss *et al.*, 2008). It remains to be determined whether the observed changes in central nervous system (CNS) functioning (from the brain through to the innervation of muscle) associated with hyperthermia represent a failure or a regulated response (Racinais & Oksa, 2010).

As the intervention within this thesis (sago ingestion) targets metabolism, specifically that of carbohydrate, the following section is dedicated to substrate utilisation and carbohydrate supplementation during exercise in the heat separate to other physiological responses.

2.3 CARBOHYDRATE METABOLISM DURING AND SUPPLEMENTATION FOR EXERCISE WITH AMBIENT HEAT STRESS

2.3.1 Substrate Utilisation during Exercise and Heat Stress

During continuous exercise, the maximal duration (endurance) for which a submaximal workload can be maintained has an inverse relationship to the exercise intensity (Sahlin, 1992); this relationship is curvilinear in appearance (*Figure 2.6*).

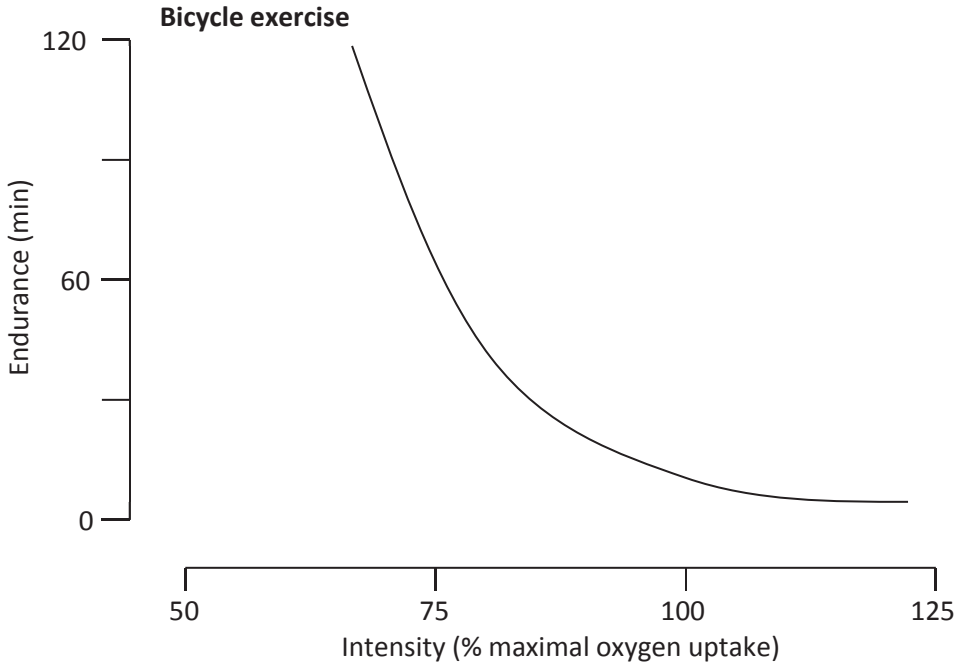

Figure 2. 6: Estimated endurance time during cycle ergometry in relation to work intensity (Sahlin, 1992).

At moderate-high intensities (60-90% VO_2max), such as the exercise completed within this thesis and most-oft reported during competitive endurance exercise, muscle glycogen stores and levels of blood glucose are generally thought to be the limiting factors to exercise endurance in moderate ambient conditions, with depletion of these stores or hypoglycaemia being associated with earlier fatigue or a decreased performance (Cermak & van Loon, 2013).

There have been consistent observations of greater CHO and reduced fat oxidation in terms of substrate utilisation during exercise in the heat when compared to exercise at cooler ambient temperatures. For example, Fink, Costill & Van Handel, (1975) compared 60 min of intermittent exercise in 41^{o}C and 9^{o}C and observed muscle glycogen utilization to be higher and triglyceride lower in the heat, in addition to greater hepatic glucose production and a higher RER. Febbraio, Snow, Stathis, Hargreaves, & Carey (1994b) found muscle glycogen utilization to be elevated by 20-80% as a result of non-exhaustive bouts of exercise in 40^{o}C versus 20^{o}C, with Yaspelkis & Ivy (1991) suggesting that fatigue was accelerated in the heat because of an increase in reliance upon CHO as a substrate.

Not all studies report an increased RER and total CHO oxidation is often lower as fatigue is reached at an earlier time-point during exercise in the heat when compared to cooler conditions (Galloway & Maughan, 1997; Parkin *et al.*, 1999). However, estimates of whole-body substrate oxidation represent the sum of metabolism of all the body's tissues, so may not reflect actual substrate utilization in the exercising muscle, especially at low intensities. Similarly, Young, Sawka, Levine, Cadarette & Pandolf, (1985) and Maxwell, Gardner & Nimmo (1999) observed no differences for muscle glycogen utilization during exercise in heat stress or when heat acclimated. An explanation here might be found as in the study by Young et al.,

(1985) participants began their 30 min of cycling at 70% of VO_2max in heat with a low pre-exercise muscle glycogen content, and Chesley, Hultman, & Spriet (1995) had previously noted that the rate of glycogenolysis during submaximal exercise was mainly influenced by pre-exercise glycogen levels.

The most detailed investigation of muscle metabolism during exercise heat stress has come from Febbraio and colleagues. During 40 minutes of cycling at 70% VO_2max an increased muscle lactate and glycogenolysis was observed at 40°C when compared to the same protocol at 20°C (Febbraio *et al.*, 1994b). Following 7 days of heat acclimation, they demonstrated that muscle glycogenolysis and lactate production were attenuated, these changes were accompanied by a reduction in core and muscle temperatures and catecholamine response (King, Costill, Fink, Hargreaves & Fielding, 1985; Febbraio, Snow, Hargreaves, Stathis, Martin & Carey, 1994a). Therefore, they blunted the rise in core temperature by cycling for 40 minutes at 70% VO_2max in an environmental chamber at 3°C and 50% RH as opposed to 20°C and 20% RH and found a reduced muscle glycogenolysis was accompanied by a lower muscle temperature and catecholamine response (Febbraio, Snow, Stathis, Hargreaves & Carey, 1996c). Direct infusion of adrenaline to mimic levels observed during exercise at 40°C (Febbraio, Lambert, Starkie, Proietto & Hargreaves, 1998) and water-perfused cuffs used to manipulate muscle temperature independently of core temperature (Starkie, Hargreaves, Lambert, Proietto & Febbraio, 1999), were able to identify, in part (and possibly not limited to) a higher muscle temperature and adrenergic response secondary to a greater rise in core temperature as the mechanisms of an increased muscle lactate production, glycogenolysis and CHO oxidation during exercise in the heat (40°C) when compared to the cool (20°C).

Therefore, from the available evidence it can be concluded that during exercise with heat stress there is a greater reliance on CHO as a substrate and that the greater depletion of muscle glycogen stores may limit exercise when compared to more temperate environments. However, the available information (above) was conducted on fixed-intensity exercise and to the candidate's knowledge this remains unproven with self-paced exercise.

2.3.2 Carbohydrate Supplementation during Exercise with Heat Stress

If an increased CHO oxidation can influence/limit exercise in hot conditions, as argued in the previous section, then it should be possible to delay fatigue during such exercise through feeding of CHO before, during, and in recovery before a subsequent bout. There appears to be several investigations into the physiological and performance effects of CHO supplementation during exercise heat stress, however, this is far more limited when concerning feeding before or in recovery from such exercise.

To the candidate's knowledge only one study has addressed the issue of whether pre-exercise CHO supplementation improves performance in the heat. Pitsiladis & Maughan (1999) provided participants with either a low (10%) or high (80%) CHO diet but with similar caloric content for 3 days following glycogen depletion and then cycled them to exhaustion at 30°C. Following the high CHO diet participants improved their endurance time by 8-73% (53 vs 44 min) and their RER, rate of and total CHO oxidation, and lactate concentration was higher (with the converse true for fat). The high CHO diet also reduced perceived exertion. Following the high CHO diet regime, the individual's endurance time was improved by 8-73% (53 vs 44 min) and their RER, rate of and total CHO oxidation, and lactate concentration was

higher (with the converse true for fat) in the hot-humid (30^{o}C and 70% RH) trial. The high CHO diet also reduced RPE in both exercise in cold and in the heat (Pitsiladis & Maughan, 1999).

There have been consistent reports of CHO supplementation during exercise heat stress proving ergogenic (Below, Mora-Rodriguez, Gonzalez-Alonso & Coyle, 1995; Carter *et al.*, 2003), however the mechanism(s) responsible remain poorly understood and not all studies have observed performance effects (Febbraio, Murton, Selig, Clark, Lambert, Angus & Carey, 1996a). However, of particular note should be that most often the medium with which CHO is administered takes the form of a fluid i.e. with/-out CHO (placebo-matched) and often this is consumed *ad libitum*. Therefore, on first appearance it is difficult to appraise whether it is the separate level of hydration having an effect, as more fluid is often consumed during a CHO trial e.g. Carter et al., (2003). Correspondingly, Horswill, Stofan, Lovett & Hannasch (2008) provided iso-volumetric electrolyte-beverages to participants during 1-h of fixed-intensity cycling at 30°C distinguished only by their CHO content (~94g vs 0g) and observed no physiological differences between drinks. Similarly, Below et al., (1995) replicated this observation (of no physiological differences) during 50 min of fixed-intensity cycling at 31°C when fluid was matched but CHO content differed; however, interestingly in the immediately preceding work-dependent time-trial both fluid and CHO independently (6%) improved performance compared to a placebo, and the combined effects were additive (12%). Notably, along with the above study there is evidence from self-paced cycling protocols that CHO supplementation during exercise improves performance (Abbiss *et al.*, 2008).

However, the observation that performance is improved despite no changes in whole-body fuel selection could once again reflect dissonance with specific tissue

metabolism or because of an imbalance between hepatic glucose production and glucose uptake by the muscle and/or other tissues (Hargreaves, Angus, Howlett, Conus & Febbraio, 1996; Angus, Febbraio, Lasini & Hargreaves, 2001). It is also now acknowledged that, particularly in shorter (<1h), more intense (~80% VO_2max) bouts of exercise an improved CHO status may have a central ergogenic effect that is not related to or detectable by whole body (indirect) calorimetry (Cermak & van Loon, 2013).

Much like the evidence for pre-exercise CHO supplementation, there is scant confirmation that concerns the ingestion of CHO in recovery from and for subsequent exercise in the heat. However, indirect evidence has been reported by Davis, Burgess, Slentz, Bartoli & Pate (1988) who noted that a second (work-dependent) cycle bout in conditions of heat stress completed following a 30 min recovery period was performed quicker when 6% CHO was consumed vs. a fluid-matched placebo. This is further supported by a recent investigation (Fernández-Elías, Ortega, Nelson & Mora-Rodriguez, 2015) demonstrating that following exercise heat stress the resynthesis of muscle glycogen (within 3h) is affected by the CHO consumed and not by rehydration. Therefore, these results above point to CHO supplementation in recovery from exercise heat stress being beneficial and ergogenic. In most post-exercise CHO ingestion studies, the duration of short-term recovery ranged from 3-6 h after the first bout of exhaustive exercise (Betts & Williams, 2010) and was followed by a second bout of exercise to establish whether recovery (performance) was complete (maintained) or not.

The 20th century saw many CHOs developed and marketed as nutritional sporting supplements that enhance performance, such as glucose, fructose, maltose, sucrose, maltodextrin, and also galactose (see *Table 2.1*). However, CHOs can be

classified as simple or complex (Burke, 2000; Geissler & Powers, 2010) and the purpose of the following section is to provide the limited published evidence that exists on the effect of complex-CHO (starch) on exercise performance, and introduce sago as a nutritional supplement with potential for an ergogenic effect.

Table 2. 1: The types of CHO sources (Burke, 2000).

Type	Examples
Monosaccharides (1 unit)	Glucose
	Fructose
	Galactose
Disaccharides (2 units)	Sucrose
	Lactose
	Maltose
Oligosaccharides (3–20 units)	Raffinose (3 units)
	Stachyose (4 units)
	Verbascose (5 units)
	Fructo-oligosaccharides
	Commercially derived glucose polymers/maltodextrins (5–15 units)
Polysaccharides (20–1000 units)	
Starch	Amylose
	Amylopectin
Non-starch polysaccharides	Cellulose
	Hemicellulose
	Pectins
	β-glucans
	Fructans
	Gums
	Mucilages
	Algal polysaccharides

2.4 STARCH, SAGO AND EXERCISE SUPPLEMENTATION

2.4.1 Starch for Exercise

Starch has a variety of applications especially within the food industry. It is categorized as an essential source of CHO for the human diet and is the richest natural CHO available from agricultural raw materials (Huijbrechts, Sudhölter, Boeriu & Franssen, 2008; BeMiller & Whistler, 2009). A primary concern for starch is digestibility which is characterized by the rate and the duration of the glycaemic response (Singh, Dartois & Kaur, 2010). In industry, common starches are derived from corn, wheat, rice, potato and sago (Karim, Tie, Manan & Zaidul, 2008).

Starch comes in two molecular forms: linear and branched glucose polymers. Thus, starch is a mixture of two polysaccharides, the linear molecule of amylose, and highly branched molecule of amylopectin (Zobel & Stephen, 2006; Murphy, 2009). In terms of its physical forms, starch can be found as raw or swollen granules, granule pieces, entangled polymer masses of amylose and/or amylopectin, or as individual molecules of amylose and amylopectin (Jackson, 2003).

Although extensive research has been carried out on CHO supplementation during exercise, data concerning the effect of specific starches on exercise performance is scarce. However, the limited studies investigating starch on exercise performance can be seen in *Table 2.2*. The majority of these studies have used waxy starch (Goodpaster, Costill, Fink, Trappe, Jozsi, Starling & Trappe, 1996; Jozsi, Trappe, Starlling, Goodpaster, Trappe, Fink & Costill, 1996; Roberts, Lockwood, Dalbo, Volek & Kerksick, 2011) and corn starch (Guezennec, Satabin, Duforez, Koziet & Antoine, 1993; Johannsen & Sharp, 2007; Stephens, Roig, Armstrong & Greenhaff,

2008). Irrespective of the type of starch, their basic units contain the glucose chains amylose and amylopectin that classify the CHO as complex. The efficacy of these CHOs, in terms of slow or quick digestion, is dependent on their amylopectin: amylose ratio as this then influences absorption (as glucose) and thence oxidation rates during exercise (Cermak & van Loon, 2013). Some starches appear to be a suitable energy source for exercise as a performance improvement has been observed (Goodpaster *et al.*, 1996; Stephens *et al.*, 2008). Starch meals such as waxy starch (Goodpaster *et al.*, 1996) and daily starchy foods (Folch, Peronnet, Massicotte, Charpentier & Lavoie, 2003), have been investigated before or during exercise. Johannsen & Sharp (2007) also investigated pre-exercise ingestion of modified corn starch during endurance exercise, whilst Roberts et al., (2011) investigated the exercise response to high-molecular weight hydrothermally modified waxy maize starch in trained cyclists.

Table 2. 2: Studies investigating the effect of complex-CHO on exercise (Ormsbee, Bach & Baur, 2014).

Study	Starch type	Timing of ingestion	Protocol	Performance
Roberts et al., (2011)	Waxy (95% amylopectin), hydrothermally modified	30 min before exercise	150 min cycling at 70% VO_2max, TTE at 100% VO_2max	No effect
Goodpaster et al.,(1996)	Waxy (100% amylopectin), or resistant starch (100% amylose)	30 min before exercise	60 min cycling at 75% VO_2max, 30 min TT	6.3% improved performance with waxy corn
Jozsi et al., (1996)	Waxy (100% amylopectin) or resistant starch (100% amylose)	Post-exercise consumption over 12 h	60 min cycling at 75% VO_2max, 6 x 1 min at 125% VO_2max, 24 h rest, 30 min TT	No effect
Stephens et al., (2008)	Low and high molecular weight and modified starches	Post-exercise feeding 2 h prior to second bout	TTE cycling at 73% VO_2max, 2 h rest, 15 min TT	2.3% improved performance with high molecular modified starches
Guezennec et al., (1993)	Complex CHO foods; bread, potato, rice, spaghetti Corn starch (100% amylopectin & 70:30% of amylose and amylopectin ratio)	An hour before each exercise trial	2 h cycling at 60% of VO_2max	Not measured
Johannsen & Sharp, (2007)	Corn-derived dextrose, unmodified high-amylose corn starch, modified high-amylose corn starch	30 min before exercise	2 h cycling at 60% of VO_2peak	Not measured

Notes: TTE, time to exhaustion; TT, time trial; VO_2max, maximal O_2 consumption.

2.4.2 Sago for Exercise

Although sago starch is a major CHO source, rice is preferred as the main staple food in Malaysia (Abd-Aziz, 2002). Sago, *Metroxylon Sagu*, is one of the oldest tropical plants in Southeast Asia including in Sarawak, Malaysia (Pei-Lang, Mohamed & Karim, 2005; Mohamed, B. Jamilah, Abbas & Roselina, 2008). The environment of Malaysia being warm and humid in the tropical lowlands is favourable for growing sago palms as temperatures above 25^{o}C and relative air humidity of ~70% are preferred (Singhal *et al.*, 2008). In fact, since the 1970's Sarawak has been one of the world's biggest exporters of sago (Tek-Ann *et al.*, 1999) and contributes to the country's economy. Nornadiha, Fazilah, Bhat, et al., (2010) identified that a large amount of starch can been found in the palm's trunk. Sago starch is a versatile food ingredient and widely used in numerous food and industrials applications either in its native form or modified as a texturizer, gelling agent, and thickener (Karim *et al.*, 2008) or commonly used for food production such as vermicelli, bread, crackers and biscuits (Abd-Aziz, 2002; Mohamed *et al.*, 2008). Recent developments in the food industry include use as a raw material for maltodextrins and cyclodextrins in infant formulas, sport drinks, and carriers in pharmaceuticals (Flores, 2007).

Native sago starch contains ~25% (Wong, 2009) and 20-23% (Tie, Karim & Manan, 2008) amylose and this compares with 18-23% for potatoes, 17-29% for wheat and 8-37% for rice BeMiller & Whistler (2009). Goodpaster et al., (1996) demonstrated that certain forms of CHO, such as starch, produce a different metabolic profile during exercise because of their more complex structure; this should be similar for sago. On the other hand, Mohamed et al., (2008) reviewed the literature and as sago starch contains 27% amylose and 73% amylopectin, it was suggested that due to the high(er) amylopectin content sago may be digested quicker when compared

to other starches high in amylose i.e. a higher-GI (Thorne, Thompson & Jenkins, 1983); this is due to amylopectin being easier to hydrolyse in the intestine compared to amylose, and therefore digested quicker (Singh *et al.*, 2010; Hamzah, 2011). Ahmad et al., (2009) demonstrated that sago porridge provides a robust glycaemic response but with a lower insulinaemic response compared to sago gel and paste at rest, and suggested it would be suitable before, during and after endurance exercise. The high-GI reported by Ahmad et al., (2009) is further supported by Hassan, Elobeid, Kerkadi, & Suheil (2010) who calculated blood glucose responses (AUC) of CHO-based foods, including sago. They reported a GI of ~80 for sago, using glucose as the standard reference food (GI of ~97) and compared to white bread (Hassan *et al.*, 2010).

Nevertheless, only one study has previously supplemented any form of sago during exercise. Ghosh et al., (2010) demonstrated no benefit of feeding 60g sago at 20-min intervals during cycling at 60% VO_2max on subsequent exhaustion time at 90% VO_2max. However, the study was conducted in a thermoneutral environment and with participants of low aerobic fitness and training status, making results difficult to interpret and generalise to an athletic population exercising in tropical conditions.

2.5 LABORATORY TESTS OF ENDURANCE CYCLING PERFORMANCE

In order to assess the efficacy of any treatment or intervention, it is important to determine which variable(s) is most important: is identifying physiological responses the primary goal, or is it whether or not performance is altered? The answer to this question will (*should*) determine what type of exercise protocol is adopted. The next logical question is whether the exercise protocol used can reliably detect differences and how sensitive it is. Without this knowledge one might wrongfully conclude no difference due to high test variability or participant variation. Knowledge of the typical variance associated with a protocol used on a certain sample under those (often laboratory) conditions allows for a more informed decision on the magnitude of a treatment effect. The advantage of using laboratory protocols and equipment, especially displaying low variation (high reliability), is that "real" differences can be determined with realistically small sample sizes, especially when concurrent with lifestyle standardization (e.g. diet, exercise, time of day etc.) and a within-subject design. Cycle ergometers are by far the preferred mode of exercise because work-rate is easily set and altered, the participant remains largely stationary (other than leg movement) making physiological measurement easier, and they take up less room (therefore are more portable) than, for example, a treadmill.

Before appraising the various protocols used within the literature, it is necessary to understand the term "reliability" more deeply, hence the next section. It must be acknowledged that it is beyond the scope of the current review to comprehensively examine validity, reliability and sensitivity within a sporting context e.g. (Currell & Jeukendrup, 2008).

2.5.1 Reliability

The reliability of measures is not comprehensively understood which is surprising given that a difference in performance of one minute can drastically impact competition outcome (Schabort, Hawley, Hopkins & Blum, 1999). Jeukendrup & Martin (2001) highlighted this concept as they determined that at an elite level a 1% performance improvement would represent a 15 second difference over a 10 km cycling race. According to Pyne, Trewin & Hopkins (2004) for an athlete to substantially increase their chance of success for medal contention at the Olympic Games they have to improve their performance by approximately 0.5 the typical race-race variation. This statement demonstrates that possessing knowledge of the "fixed" variance is essential for performance improvement. Furthermore, Saris, Antoine, Brouns, Fogelholm, Gleeson, et al., (2003) suggest that any studies evaluating the effects of nutritional supplementation on exercise performance must be reliably proven in that population to detect a small difference in performance and other physiological parameters.

The reliability of a protocol refers to its consistency or reproducibility when performed repeatedly (Hopkins, Schabort & Hawley, 2001), with a test displaying poor reliability being unsuitable for tracking changes due, for example, to a treatment or intervention. Several factors affect reliability such as the type of test, type of measure, athletic status and test duration, however the factor with the most effect is the type of test (Hopkins *et al.*, 2001), hence the focus of the proceeding section. There are also different methods of (statistically) assessing reliability, as displayed in *Table 2.3* below.

Table 2. 3: Statistics used in reliability analysis (Currell & Jeukendrup, 2008).

Statistic	Formula	Definition	Advantages	Disadvantages
Pearsons r	$r = \frac{\sum Z_x Z_y}{N}$	Extent to which two variables are related	Get a significant value	Cannot detect changes in the mean Influenced by inter-subject variation
ICC	$ICC = \frac{F - 1}{F + (k - 1)}$	Measures the relative homogeneity within groups in relation to the total variation	Used for more than one retest	Can be sensitive to systematic bias Affected by sample heterogeneity
CV	$CV = \frac{X}{SD} \times 100$	Expresses error as a percentage of the mean	Easy to compare between methods Dimensionless Provides magnitude of what the day-to-day differences are	Only accounts for 68% of the variability
LOA	$LOA = x_{diff} \pm (1.96 \times SD_{diff})$	Reference interval for the test-retest differences expected for 95% of the population	Assumes population of test retest difference	Affected when the measurement error becomes larger as the magnitude of the test score increases (heteroscedasticity)

CV = coefficient of variation; F = F ratio from ANOVA analysis; ICC = intraclass correlation coefficient; k = (observations – test) / (subjects – 1); LOA = limits of agreement; N = number of pairs of scores; SD = standard deviation; Z = Z scores for each subject on the X and Y variables; $\overline{x}$ = mean.

The most common reliability testing involves a test-retest; when repeated testing is undertaken three components of reliability are important which are the changes in mean performance, intra-subject variation and retest correlation (Hopkins, 2000). Hopkins et al., (2001) argue that the typical percent error (the standard error of measurement expressed as a coefficient of variation, [CV] is most appropriate and most studies report this as their measure of reliability of a test). The CV is equivalent to the standard deviation (SD) of an individual's repeated measurements, expressed as a percent of the individual's mean test score. It is simple to derive, dimensionless

which allows for direct comparisons of reliability measures between data sets irrespective of exercise mode or calibration/scaling, with a smaller CV demonstrating better reliability (Hopkins *et al.*, 2001).

Other factors that improve the reliability of a measure include the participants being trained, a shorter duration protocol, controlling or standardising participant training and diet and reducing a practice effect through use of a familiarisation (Hopkins *et al.*, 2001). Therefore, these factors will be considered and implemented for the experimental chapters.

2.5.2 Reliability of Common Cycling Protocols

Taking a quick look at some studies investigating nutritional (carbohydrate) interventions on exercise, reveals the use of cycling to exhaustion at a fixed intensity of 60% and 73% of VO_2max (Carter *et al.*, 2003; Carter, Jeukendrup & Jones, 2005), cycling time-trials of 16km (Jeukendrup, Hopkins, Aragon-Vargas & Hulston, 2008) and 1h (Carter, Jeukendrup & Jones, 2004), a 16.1km time-trial pre-loaded with 90 min cycling at 60% of VO_2max and a 1h time-trial pre-loaded with 120 min cycling at 55% (Currell & Jeukendrup, 2008).

Traditionally, submaximal exercise capacity tests have been used to cycle at a fixed percentage of maximal workload or O_2 uptakes to volitional exhaustion (or a pre-determined marker thereof). Such tests have largely been used to give basic/mechanistic (physiological) data during a 'physiological steady-state' as it can confidently be said that variable *x* (e.g. CHO intake) exerts an effect on variable *y* (e.g. RER) when other factors have been controlled. However, their face-validity is poor as there are few instance where there is a competition to see how far someone

could cycle at the same speed. Further, early investigations by Krebs & Powers (1989) and McLellan, Cheung & Jacobs (1995) reported high within-individual variation (CV) of 27% and 17%, respectively when cyclists exercised at a constant power to exhaustion. This was supported by Jeukendrup, Saris, Brouns & Kester (1996) who observed a test-retest CV of 27% using trained cyclists/triathletes when they cycled to exhaustion at 75% W_{max} who argued that these "open-ended" tests are influenced more heavily by psychological factors such as motivation and boredom.

In contrast to these fixed-intensity capacity tests, protocols that have a known end-point (time-trial) and allow participants to alter their intensity - often according to a pacing strategy - not only have greater face-validity (more accurate physiological simulation of real-life race and performance conditions) but also display a greater test-retest reliability. In the same study, Jeukendrup et al., (1996) observed a CV of 3.4% when participants were allowed to complete a set amount of work (based on 1h at 75% W_{max}) that was self-paced. Meanwhile Zavorsky, Murlas, Gow, Kim, Poulin-Harnois, Kubow & Lands (2007) reported the CV of a 20 km cycling time-trial to be 1.2% in trained and 4.8% in recreational cyclists (Zavorsky *et al.*, 2007). Additionally, longer time-trials such as a 100 km protocol display high reliability with 1.7% of CV (Schabort, Hawley, Hopkins, Mujika & Noakes, 1998).

Of course, the variable-intensity nature of these protocols makes it difficult to accurately assert the effect of any intervention on physiological parameters. Therefore, variations on the time-trial protocol have included sprints within a protocol (Marino, Kay, Cannon, Serwach & Hilder, 2002) to mimic the actual stochastic nature of cycle racing and a "pre-load" of fixed-intensity cycling preceding the time-trial (Jeukendrup *et al.*, 1996). The latter, in particular, allows data (e.g.

physiological) to be collected to further determine the efficacy of an intervention to complement a performance measure, with Jeukendrup et al., (1996) having observed a similarly low CV (3.5%) when participants cycled for 45 min at 70 %W_{max} followed by as much work completed as possible within the 15 min time-trial. Similarly, Doyle & Martinez (1998) investigated the reliability of 90 min of ergometer cycling at 70% of VO_2max followed by 30 min time-trial and observed the same CV of 3.5%, whilst (Sewell & McGregor, 2008) reported a CV of 3.4% in recreationally active participants cycling for 60 min at 65% VO_2peak followed by a 20 min time-trial.

However, as seen in *sections 2.1* and *2.2* of this chapter, ambient heat stress alters performance and physiological responses to exercise with only one study having previously investigated the reliability of a time-trial protocol in the heat, either with or without a pre-load (Marino *et al.*, 2002), therefore in **Chapter 5** a suitable protocol had to first be developed and tested that allowed the collection of both performance and physiological data that was reliable for use in conditions of ambient heat stress.

2.6 SUMMARY

The purpose of this chapter was to focus on introducing only the literature pertinent for the ensuing experimental chapters; more specific background is given within the *Introduction* of each experimental chapter (**Chapters 5-7**), therefore an attempt at minimising repetition has been made.

In reviewing this literature it was noted that there is consensus that both fixed-intensity endurance and self-paced performance is impaired when performed in the

heat as compared to cooler conditions, and that certainly a limiting factor appears to be a marked hyperthermia. Concurrent with this higher body temperature(s), further strain is placed on the body's cardio vascular, neuromuscular and central nervous systems such that conceivably anyone could be the cause of this performance deterioration. There is also considerable evidence demonstrating a greater reliance on carbohydrate as a substrate and the majority of studies have demonstrated an ergogenic effect of supplementing with carbohydrate, however the exact mechanism(s) responsible for this performance improvement remain unclear. Though several studies are available on carbohydrate supplementation *during* exercise in conditions of heat much less is known of feeding *before* or *in recovery* from exercise heat stress. Furthermore, few investigations have used whole-foods but the evidence for starches, such as sago, to be appropriate for supplementation appears strong. Finally, in order to accurately and correctly determine whether a nutritional intervention, such as sago, improves exercise performance the typical variance of a population using a specific test (and equipment) is necessary. However, it is apparent that there have been few investigations determining the reliability of cycling protocols that allow the collection of both steady-state physiological and self-paced performance, and none with the addition of ambient heat stress. Accordingly, the above 'gaps' in the literature form the basis of the research aims and hypotheses, as detailed in **Chapter 3**.

CHAPTER THREE

3.0 RESEARCH AIMS & HYPOTHESES

The experimental studies in this thesis (**Chapters 5, 6 and 7**) were planned subsequent to the review of literature (*see* **Chapter 2**), which identified the limitations with the current (rather broad) research literature. Although numerous research avenues could have been established, it became apparent that there is inadequate research into exercise in tropical conditions (warm-humid) and that the provision of carbohydrate supplements, especially whole-foods, has not adequately been tested under these conditions. Therefore, the overall objective of this thesis was established accordingly.

The purpose of this thesis is to investigate an ingredient, sago starch, found and used across parts of Southeast Asia (a tropical region), and whether it's use confers a performance and/or physiological benefit whilst cycling (General Aim I). Secondarily, the available literature suggests that preparation of sago foods (porridge and gel) may be of benefit at different times, such as a "top-up" before, a supplement during or recovery from exercise and, therefore, the timing of supplementation was investigated (General Aim II).

3.1 Aims

General Aim I was first investigated by determining the typical error beyond which performance needed to change in response to any intervention, in order for it to be worthwhile i.e. signal: noise. Therefore, in **Chapter 5** two exercise protocols were developed and tested for specific use in the proceeding chapters with the sago intervention(s). This information would then be able to determine whether sago

supplementation in **Chapters 6** and **7** was indeed a 'real' benefit or not. General Aim II was investigated by preparing the sago interventions differently (porridge and gel) for ease-of-use and, knowing the magnitude of change needed to make any change "real" (**Chapter 5**) comparing the timing of ingestion on subsequent exercise physiology and performance (**Chapters 6** and **7**).

General Aims I and II can be split into more specific objectives, presented below.

3.1.1 General Aim I:

1) Establish the reliability and sensitivity of a cycling protocol that includes both a fixed-intensity (for physiological data) and self-paced (for performance) component, when standardising diet and exercise for >24 hours, using trained males and in conditions of humid-heat (**Chapter 5**).
2) Investigate whether sago supplementation affects physiology and/or performance when compared to a control condition (**Chapters 6 and 7**) when using the same cohort under the same conditions as 1) above.

3.1.2 General Aim II:

1) Investigate whether, using the reliable and sensitive protocol, sample and conditions from **Chapter 5** (*Study A*), sago supplementation before or during exercise affects physiology and/or performance when compared to a control condition (**Chapter 6**).
2) Investigate whether, using the reliable and sensitive protocol, sample and conditions from **Chapter 5** (*Study B*), sago supplementation during recovery from exercise enhances subsequent physiology and/or performance when compared to a control condition (**Chapter 7**).

It is hoped and intended that the results of this thesis, in respect to these general aims and specific objectives, provides a foundation for future research concerning more sustainable, affordable and non-commercial supplementation for performance enhancement within the Southeast Asian region although this development can be collaborative and with commercialization in mind.

3.2 Hypotheses

The review of literature (*see* **Chapter 2**) identified and generated numerous experimental hypotheses specific to those objectives described within both General Aims I and II. The specific hypotheses that were tested in the experimental studies of this thesis are presented below.

3.2.1 Specific Hypotheses:

1) The amount of work completed (kJ) within the 15-min time-trial will be reliable and sensitive (i.e. a coefficient of variation <5%) when performing a test-retest (**Chapter 5**).
2) The metabolic response (blood glucose) to sago porridge at rest will be higher than a control (**Chapters 6** and **7**).
3) Sago supplementation will improve work completed during the 15-min time-trial above the typical error and when compared to a control (**Chapters 6** and **7**).
4) The timing of sago supplementation will influence the ergogenic effect (**Chapters 6** and **7**).
5) Sago supplementation will influence the physiological responses to exercise when compared to a control (**Chapters 6** and **7**).

CHAPTER FOUR

4.0 GENERAL METHODOLOGY

This chapter will outline the methodology common to all experimental chapters (**Chapters 5, 6, 7**). Details specific to each particular study are outlined in the appropriate experimental chapter. All data collection and sample analysis took place within the Human Performance Laboratory, School of Sport and Exercise in Palmerston North. Ethical approval for the series of studies was obtained from the Massey University Human Ethics Committee: Southern A (11/82) and conducted in accordance with the latest *Declaration of Helsinki*.

4.1 PARTICIPANTS

The participants recruited were male and over 18 years of age. All participants were local to the Manawatu region and regularly participating in club-level cycling/triathlon races. Specifically, beyond this inclusion criteria was cycling >100 km per week and exclusion criteria was where a general health questionnaire was failed or a known allergy to sago. Before agreeing to take part, participants received an information sheet and provided written consent having been fully informed of the risk and benefits. Participants retained the right to withdraw at any time without prejudice.

Descriptive data of the participants' physical characteristics for the series of studies is presented in *Table 4.1.*

Table 4. 1: Participants characteristics

Subject	Age (years)	Height (m)	Weight (kg)	VO_2peak (ml/kg/min)	VO_2peak (L/min)	HRpeak (bpm)	Peak Power Output (W)
1	45	1.72	72.0	83.3	6.33	175	507
2	51	1.77	72.5	67.0	4.86	170	330
3	40	1.87	96.4	68.8	5.94	169	458
4	47	1.86	73.0	63.1	4.85	171	446
5	40	1.69	67.8	74.1	5.13	182	382
6	49	1.72	69.3	56.9	4.14	169	302
7	25	1.86	76.7	70.3	5.52	189	372
8	27	1.75	86.4	67.7	5.70	168	333
9	42	1.86	88.2	58.6	5.20	189	406
10	42	1.73	77.6	50.8	3.94	179	342
11	24	1.93	92.0	69.5	5.10	188	411
12	33	1.66	62.2	66.9	4.09	189	281
13	39	1.92	106.0	55.5	5.88	183	516
14	21	1.74	63.9	79.7	5.35	188	429
Mean	**38**	**1.79**	**79**	**67**	**5.1**	**179**	**394**
SD	**10**	**9**	**13**	**9**	**1.0**	**9**	**73**

4.2 PRELIMINARY TRIALS

All participants had been given an information sheet at least a week prior, completed the general health questionnaire and signed a consent form. For each study (**Chapters 5, 6, 7**) the participants visited the laboratory for preliminary submaximal and peak cycling tests, and then again for an experimental familiarization.

4.2.1 Submaximal and Peak Oxygen Uptake (VO_2peak Test)

A submaximal test required the participants to cycle on an electronically braked cycle ergometer (Lode Excalibur, The Netherlands) for 6 min at each of four consecutive submaximal power outputs which were 100 W, 150 W, 200 W, and 250 W with a fan (Fantech Pty Ltd., China) located in front of the participants with an airflow of 20 km/h. Following a 10 min rest, VO_2peak was determined by a ramp protocol (45 $W.min^{-1}$) until volitional fatigue. Expired gases (VacuMed Vista Turbofit, USA) and heart rate (HR, Polar Vantage NV, Finland) were collected continuously

throughout both tests. This session was conducted in a thermoneutral ambient environment (18 - 22^{o}C).

A linear relationship between the mean rate of VO_2 during the last 2 min of each submaximal stage and power output was determined and used to calculate a power output which would elicit 55 and 75% of VO_2peak workload during the pre-loaded cycling and time-trial for each participant for the remaining experimental trials.

4.2.2 Familiarization Trial

Following at least 24h rest, a familiarization trial was undertaken to ensure the participants were accustomed to the procedures employed during the investigation and to minimise any potential learning or anxiety effects. The familiarization trials followed exactly the same protocol and measurements as the main experimental trials except for the blood sampling which was only undertaken during actual experimental trials. This session was performed in an environmental chamber that simulated a warm-humid climate of 29 ± 1.0^{o}C and relative humidity of 78 ± 1.4%.

4.3 PARTICIPANT'S DIETARY AND EXERCISE CONTROL

Participants completed experimental trials with seven days separation to minimise any effect of heat acclimation and ensure sufficient recovery (e.g. substrate, cardiovascular etc.) and at the same time of day (±1h) to minimise any circadian variation. This period was also marked by abstinence from alcohol and only habitual caffeine use (as abstinence would in itself confound from withdrawal effects). As the intervention was dietary in nature, strict exercise and dietary control was in place from >24h prior to each experimental trial. On the day before any experimental trial,

participants' only exercise was when they attended the laboratory to complete a standardized training ride 60 min in duration at a fixed power output that elicited ~65% of their maximum heart rate in moderate environment (18 - 22^{o}C). Following this, they were provided with a standardized snack (1x Sanitarium UP & GO, New Zealand: 823 kJ providing 30.3 g carbohydrate, 8.3 g protein and 3.8 g fat) to be consumed immediately, dinner (2x Watties Snack Meals, New Zealand: 2100 kJ providing 42.0 g carbohydrate, 31.6 g protein and 22 g fat, and 1x One Square Meal, New Zealand: 1450 kJ providing 45.1 g carbohydrate, 8.4 g protein and 11.7 g fat) and breakfast for the day of the trial (1x Sanitarium UP & GO, New Zealand: 823 g providing 30.3 g carbohydrate, 8.3 g protein and 3.8 g fat, and 1x One Square Meal, New Zealand: 1450 kJ providing 45.1 g carbohydrate, 8.4 g protein and 11.7 g fat). This dietary and exercise control minimised any variation in pre-trial metabolic state and muscle glycogen concentration. Fluid was encouraged and available to ensure adequate hydration. A euhydrated state was further ensured by instructing the participants to drink a pre-measured bolus of water (5 ml/kg bodyweight) two hours prior to each trial.

In addition to the dietary and exercise control above, for **Chapters 6** and **7** (sago supplementation) the intervention(s) and control trials were randomised and where possible balanced, to minimize order effects.

4.4 EXPERIMENTAL TESTS AND PROCEDURES

The studies employed two protocols, both using a pre-loaded cycling time-trial. For the first protocol (**Chapters 5** and **6**) participants cycled for 45 min (preload) at a fixed workload that elicited 55% VO_2peak followed immediately by a 15 min time-

trial (~75% VO_2peak) where they completed as much work as possible. For the second protocol (**Chapters 5** and **7**) participants cycled for 5 min at each of three consecutive fixed workloads (preload/warm-up), which were 100 W, 150 W and 200 W followed immediately by a 15 min time-trial (~75% VO_2peak) where they completed as much work as possible. For the preload in both protocols, the cycle ergometer (Lode Excalibur, The Netherlands) was set to cadence-independent (hyperbolic) mode and then switched to cadence-dependent (linear) mode for the time-trial. The time-trial was based on the formula of Jeukendrup et al., (1996):

$$W = Lf\ (rpm)^2$$

where W = workload; L = linear factor; rpm = pedal revolutions per minute.

For all trials, participants were able to customize the ergometer (handlebar and saddle height, seat position etc.) and this was replicated for each visit. They wore only lycra cycling shorts, socks and shoes and tap water was provided to drink in aliquots of 3 ml/kg body weight either at 15 min intervals or when requested to minimise dehydration. Following completion of the time-trial, participants performed a low-intensity cool-down for at least 5 min where recovery (physiological variables) was monitored to ensure participant safety, reduce risk of heat illness and follow best practice for recovery.

4.4.1 Experimental Trial Equipment & Measurement

4.4.1.1 Anthropometric Measurement

For all experimental trials, the participant's height was determined by a stadiometer (Seca, Bonn, Germany). The measurement was taken in upright, barefoot posture and accurate to 0.1 cm. Nude body weight was measured using scales (Jandever, Taiwan) accurate to 0.1 kg, with weight being recorded just after participants arrived

in the laboratory, having voided, and additionally immediately after each experimental trial.

4.4.1.2 Environmental Chamber

All the experimental trials were performed in an environmental chamber where the temperature was set at ~28°C and a water bath (Laboratory Supplies Ltd., New Zealand) was used to maintain relative humidity ≥70%. A dry-/wet-bulb (Mason Hygrometer, UK) and black globe thermometer (Campbell Scientific Inc., USA) was placed in the environmental chamber and environmental conditions were monitored every 5 minutes and maintained constant throughout the experiment trials by closing the water bath or adjusting the chamber's temperature control. The resulting heat exposure measured: wet-bulb temperature of 25.7 ± 1.4°C, wet bulb globe temperature (WBGT) of 26.7 ± 1.2°C or equivalent to an approximate dry-bulb temperature and relative humidity combination of 40°C/35%, 34°C/55% or 29°C/90% with the latter being closest to the actual conditions (30 ± 2°C, 76 ± 4%). A fan (Fantech Pty Ltd., China) was located in the heat chamber, in front of the participant and in the same location for each trial, to stimulate airflow of 20 $km.h^{-1}$ during a ride.

4.4.1.3 Core Temperature Measurement

Rectal temperature was chosen as an index of core body temperature, as ingestion of fluid and sago would not interfere with measurement (cf. oesophageal) and to reduce cost/budget (cf. GI pill). For each trial, participants self-inserted the factory-calibrated rectal thermistor (Covidien Mon-a-Therm, USA) 10 cm beyond the anal sphincter. The thermistor was connected to a USB-Based Temperature Measurement Device and displayed on TracerDAQ® software.

4.4.1.4 Skin Temperature Measurement

For continuous measurement of skin temperatures during trials, four factory-calibrated surface thermistors (Grant Instruments Ltd., UK) were attached to the chest, bicep, thigh, and calf on the left side of the participant's body using surgical tape. The skin temperature data was displayed on TracerDAQ® software, and to determine mean skin temperature, the following equation (Ramanathan, 1964) was used:

$$T_{SK} = (0.3 \times T_{chest}) + (0.3 \times T_{bicep}) + (0.2 \times T_{thigh}) + (0.2 \times T_{calf})$$

4.4.1.5 Expired Gas Analysis

Expired gases were collected and recorded via Turbofit (VacuMed Vista Turbofit, USA) metabolic software for determination of minute ventilation (V_E), oxygen uptake (VO_2) and carbon dioxide production (VCO_2) and hence the respiratory exchange ratio (RER); all values as STPD. During gas collection, collection was via custom tubing (Hytrel Tube 60'', USA) and a one-way valve mouthpiece (Silicone Mouthpieces, USA) that connected directly to a flow sensor at the entrance of the mixing chamber. A nose clip was placed to prevent any expired air being lost to the environment. Prior to each experimental trial, the instrument received a 2-point calibration using a zero and a known gas mixture (beta-standard: O_2 15.01%, CO_2 5.02%) and volume (VacuMed 3L Calibration Syringe, USA). Substrate oxidation rates ($g.min^{-1}$) were calculated from indirect calorimetry measurements using the following stoichiometric equation (Jeukendrup & Wallis, 2005), and assuming a nonprotein contribution:

$$\text{CHO Oxidation} = 4.210\ VCO_2 - 2.962\ VO_2$$

$$\text{Fat Oxidation} = 1.695\ VO_2 - 1.701\ VCO_2$$

4.4.1.6 Rating of Perceived Exertion (RPE)

Borg's rating of perceived exertion scale (Borg, 1982) was used; the scale ranges from 6 (no exertion) to 20 (maximal exertion). Participants were familiarised with the scale during the submaximal and peak exercise tests, with measurement every 15 min during experimental trials.

4.4.2 Blood Sampling

Following their arrival to the laboratory and other measurements, participants rested in a semi-reclining position whilst an indwelling cannula with a tap (BD Venflon™ I.V Cannula) was inserted into an antecubital vein and connected to an extension line (SmartSite® Extension Set, Switzerland) to allow repeated blood sampling. The cannula was kept patent by regular flushing with 3 ml of sterile saline (sodium chloride 0.9% IV-IM; Multichem NZ Ltd., New Zealand). At each time-point, the initial 2 ml drawn was discarded and then 4 ml blood was collected into lithium heparin containing vacutainers (Becton-Dickinson, Plymouth, UK).

Whole blood was used to measured haemoglobin (Hb) concentration (HemoCue® Hb+ 201 System, Sweden) and a capillary tube (Heparinized Capillary, USA) (in duplicate) was filled for determination of haematocrit by micro-centrifugation. From the changes in haematocrit and Hb concentrations from rest to the end of exercise, percentage change in plasma volume were estimated using the formula described by Dill & Costill (1974). The remaining whole blood was then centrifuged at 4^{o}C and 3500 rpm for 15 min. Following this, aliquots of plasma were transferred into pre-labelled 1.5 ml Eppendorf tubes (Genuine Axygen Quality, USA) and stored at -80^{o}C until further analysis. Plasma glucose, lactate, sodium and potassium concentrations were measured using an automated analyser (ABL FLEX, Radiometer, Denmark) with a repeatability of ≤0.1 mmol/L.

4.5 SAGO SUPPLEMENT FORMULATION

The volume of sago provided was calculated as 0.8 g per kilo body weight for each participant. A dose of 0.8 g/kg bodyweight was chosen because it fits nicely within what is suggested by the ACSM Position Stand for CHO ingestion during exercise (Rodriguez *et al.*, 2009b). For example, sago is ~86% CHO w/w, therefore ingestion of sago at a rate of 0.8 g/kg bodyweight for a 75 kg person, equates to 52 grams per hour of CHO. The sago was soaked in 790 ml distilled water and left to stand for 10 min. Thereafter, the mixture was prepared using a local traditional double-boil cooking method (Morris & Hsiung, 1999) for 25 min. Stirring of this mixture was done for about 2 min after 20 min of cooking. At the end of cooking, 7 ml artificial flavour and 0.8 g natural sweetener (Hansells Food Group Ltd, New Zealand) were added and left to cool to room temperature (Ahmad *et al.*, 2009). This sago formulation was used for supplementation before (**Chapter 6**) and after (**Chapter 7**) exercise, whilst for supplementation during exercise (**Chapter 6**) the sago was first ground before soaking (as above) – this provided a more malleable gel that easily fit into tubes for feeding directly into the mouth (squeezing) whilst on the bike.

Proximate analysis was performed on a sample of 100 g cooked sago by Massey University's Nutrition Laboratory (*Table 4.2*).

Table 4. 2: Basic nutrient composition in 100 g of cooked sago

Sago (100 g)	**% CHO**	**% Starch**	**% Fat**	**% Protein**	**Calculated Energy (kJ)/ 100 g**
	11.3	10.5	0.1	0.2	199
	% Ash	**% Moisture**	**GE kJ/g**	**% TDF**	**Sugars g/100 g**
	< 0.1	88.3	2.0	0.1	0.03

GE: Gross Energy; TDF: total dietary fibre

4.6 STATISTICAL ANALYSIS

All statistical analyses were performed with SPSS software for windows (IBM SPSS Statistics 20, NY, USA). Descriptive values were obtained and reported as means and standard deviation (SD) unless stated otherwise. A Shapiro-Wilk test was used to ensure data did not differ substantially from a Gaussian distribution. The specific statistical analyses are explained further in each experimental chapter. However, in general all performance data (work completed) was analysed with either a one- or two-way ANOVA. Similarly, all physiological and perceptual data were analysed with a two-way ANOVA. Sphericity was assessed and where the assumption of sphericity could not be assumed, adjustments to the degrees of freedom were made ($\varepsilon > 0.75$ = Huynh-Feldt; $\varepsilon < 0.75$ = Greenhouse-Geisser). Following a significant main or interaction effect, *post-hoc* pairwise analyses were performed using a paired samples *t*-test with Bonferroni correction if appropriate.

CHAPTER FIVE

5.0 Reliability of a Pre-Loaded Cycling Time-Trial in a Warm-Humid Environment

Publication based on this chapter:

Che Jusoh, M. R., Morton, R. H., Stannard, S. R., & Mündel, T. (2015). A reliable preloaded cycling time trial for use in conditions of significant thermal stress. Scandinavian journal of medicine & science in sports, 25(S1), 296-301.

Abstract

The purpose of this study was to assess the reliability of a 15-min time-trial pre-loaded with 45 min of fixed-intensity cycling under laboratory conditions of thermal stress. Twelve healthy male trained cyclists/triathletes (41 ± 10 y, VO_2peak: 69 ± 8 ml/kg/min, peak aerobic power: 391 ± 72 W) completed three trials (the first a familiarization) where they cycled at ~55% VO_2peak for 45 min and 15 min warm-up followed by a 15 min time-trial (~75% VO_2peak) under conditions of significant thermal stress (WBGT: 26.7 ± 0.8°C, frontal convective airflow: 20 $km.h^{-1}$). Seven days separated trials, which were conducted at the same time of day following 24 h of exercise and dietary control. Reliability increased when a familiarization trial was performed, with the resulting coefficient of variation and intra-class correlation coefficient of the work completed during the 15 min time-trial 3.6% and 0.96 (Study A) and 2.3% and 1.00 (Study B), respectively. Therefore, these results demonstrate a high level of reliability for a 15 min cycling time-trial following a 45 min pre-load when performed under laboratory conditions of significant thermal stress using trained cyclists/ triathletes.

5.1 INTRODUCTION

Performance is one of the most common outcome measures within the exercise sciences and often used to assess the efficacy of treatment effects, such as training programs and a number of possible ergogenic aids (nutritional, pharmacological, physiological etc.). When performance is measured it is necessary to know the reliability of such a test, as lack of this knowledge might result in wrongfully concluding no difference due to high test variability or intra-/inter-subject variation. Therefore, knowledge of the typical variance associated with a performance test used on a certain sample under those (often laboratory) conditions allows for a more informed decision on the magnitude of a treatment effect. Another of the advantages of using laboratory protocols and equipment that display low variation (high reliability) is that "real" differences can be determined with realistically small sample sizes, especially when concurrent with lifestyle standardization (e.g. diet, exercise, time of day etc.) and a within-subject design.

Traditionally, submaximal exercise capacity tests using an ergometer have been used to cycle at a fixed percentage of maximal workload (W_{max})/O_2 uptake (VO_2max) to volitional exhaustion (or a pre-determined marker thereof). Such tests have largely been used to give basic/mechanistic data during a physiological steady-state; however, their face-validity is poor. Furthermore, such tests have usually yielded a high level of variability even when using trained participants. For example, Jeukendrup et al., (1996) observed a test-retest coefficient of variation (CV, a common measure reporting the within-subject variation expressed as a percentage of the mean) of ~27% using trained cyclists/triathletes when they cycled to exhaustion at 75% W_{max}; they argued that "open-ended" tests are influenced more heavily by psychological factors such as motivation and boredom. In contrast to

these fixed-intensity capacity tests, protocols that have a known end-point (time-trial) and allow participants to alter their intensity - often according to a pacing strategy - not only have greater face-validity but also display a greater test-retest reliability. In the same study, Jeukendrup et al., (1996) observed a CV of 3.4% when participants were allowed to complete a set amount of work (based on 1h at 75 % W_{max}) that was self-paced. Variations on the time-trial protocol have included sprints within a protocol (Marino *et al.*, 2002) and a "pre-load" of fixed-intensity cycling preceding the time-trial (Jeukendrup *et al.*, 1996). The latter, in particular, allows data (perceptual/physiological) to be collected to further determine the efficacy of an intervention to complement a performance measure, with Jeukendrup et al., (1996) having observed a similarly reliable CV (3.5%) when participants cycled for 45 min at 70% W_{max} followed by as much work completed as possible within the 15 min time-trial.

Many competitive sporting events take place during the warmer summer months or in climates that considerably exceed the typical laboratory ambient thermal profile (20°C and 50% relative humidity) used whilst assessing performance reliability. As it has been demonstrated that exercise capacity (Galloway & Maughan, 1997) and performance (Tatterson *et al.*, 2000) are negatively affected with increased ambient thermal stress and that at moderate-to high-intensity exercise in the heat the onset of fatigue occurs much earlier due to a high thermal strain (Schlader *et al.*, 2011a) there remains a question as to whether the aforementioned protocols (Jeukendrup *et al.*, 1996) designed for moderate laboratory conditions are suitable for use under more thermally stressful conditions. To the candidate's knowledge, only one study has investigated the effect of elevated thermal stress on the reliability of a similar ~1 h protocol as used by Jeukendrup et al., (1996). Marino et al., (2002) reported a CV of 1.3% for a 1 h cycling time-trial including six "all-out" sprints every 10 min when

laboratory conditions were 33°C with 63% relative humidity. A pre-loaded time-trial under warm conditions (30°C with 53% relative humidity) has been reported using treadmill running, where Tyler & Sunderland., (2008) observed a CV of 2.7% following 75 min at 60% VO_2max proceeded by a 15 min self-paced time-trial. However, no studies have directly assessed the reliability of a pre- loaded cycling-based time-trial.

Therefore, the purpose of the present chapter was to assess the reproducibility of a 15 min time-trial preloaded with fixed- intensity cycling under conditions of significant thermal stress (warm-humid), as this protocol offers the dual benefit of steady-state data and a performance outcome. As the subsequent experimental chapters differ in their timing of (sago) intervention, two different protocols were designed to each meet the need of that chapter: **Chapter 6** (*Study A*: 15 min time-trial pre-loaded with 45 min fixed- intensity) and **Chapter 7** (*Study B*: 15 min time-trial pre-loaded with 15 min incremental warm-up). The former was designed with a view to collecting sufficient data before the time-trial in response to sago feeding before and during the trial, whereas the latter was designed primarily to be a repeat- test where sago was fed in the 2 h recovery between exercise bouts.

5.2 METHODS

5.2.1 Participants

Twelve healthy male cyclists and/or triathletes agreed to participate in these studies. Their mean ± SD physical/maximal characteristics for Study A (*n* = 8) was 41 ± 10 years, 1.78 ± 0.07 m, 77 ± 10 kg, 69 ± 8 ml/kg/min, 174 ± 8 bpm and 391 ± 72 W. The mean ± SD age, height, weight, VO_2peak, maximal heart rate, and peak aerobic power of the participants for Study B (*n* = 8) were 35 ± 8 years, 1.80 ± 0.11 m, 81 ± 15 kg, 68 ± 10 ml/kg/min, 185 ± 5 bpm, and 411 ± 81 W, respectively.

5.2.2 Experimental Procedures

All the participants visited the laboratory on four separate occasions: 1) preliminary submaximal and maximal tests, 2) experimental familiarization, 3 and 4) experimental trials. Full methodological details can be found in **Chapter 4**; however, a brief description follows with any specific details pertinent to this chapter only expanded upon. All trials were completed on an electronically-braked cycle ergometer, used either in the cadence-independent mode (hyperbolic mode, for steady-state) or a cadence-dependent mode (linear mode, for time-trial). Participants' set-up (e.g. seat/handle bar height and horizontal position etc.) was customised and replicated for each subsequent visit.

5.2.2.1 Preliminary Trials

Following weight and height measurements, this session was conducted in a moderate laboratory environment (18-22^{o}C) with a fan located in front of the participants with airflow of 20 km/h. A submaximal and maximal exercise test was carried out to determine a linear relationship between the mean rate of VO_2 during the last 2 min of each submaximal stage and power output was determined and

used to calculate a power output which would estimate to elicit the steady-state/warm-up and ~75% (time-trial) of VO_2peak for each participant for the remaining trials (see **Chapter 4** under *section 4.2.1*).

5.2.2.2 Experimental Trial Development

It was initially intended to adopt the protocol used by Jeukendrup et al., (1996) whereby participants would cycle for 45 min at 70% of VO_2peak followed by as much work completed as possible within the 15 min time-trial. However, following pilot testing it soon became clear that this combination of exercise intensity and ambient heat stress was uncompensable and it was unrealistic for participants to even complete the full 45 min steady-state exercise. This is supported by previous work in this laboratory in similarly trained cyclists that resulted in volitional fatigue after only 20 min when cycling at 70% of VO_2max where rectal temperatures had already reached 39.4°C under a similarly stressful environment (Schlader *et al.*, 2011a). Watson, Hasegawa, Roelands, Piacentini, Looverie and Meeusen (2005) employed a protocol that allowed participants to successfully complete 60 min at 55% of W_{max} followed by a time-trial estimated to take 30 min when cycling at 75% of W_{max} in conditions of 30°C and 50-60% relative humidity, and subsequent pilot testing identified this workload (a pre-load of ~55% VO_2peak) to be appropriate.

5.2.2.3 Familiarization Trial

The familiarization trial was undertaken to ensure participants were accustomed to the procedures employed during the investigation and to minimise any potential learning effects during the experimental trials. These trials replicated entirely the experimental trials outlined below.

5.2.2.4 Diets and Exercise Control

Twenty-four hours prior to each visit, participants completed a standardized training ride and were then provided with a standardized snack, dinner and breakfast as well as euhydration encouraged (see **Chapter 4** under section *4.3*).

5.2.2.5 Experimental Trials

On arrival to the laboratory participants voided and they then self-inserted a rectal thermistor 10 cm beyond the anal sphincter and entered the environmental chamber wearing only cycling shorts, shoes and socks. Once seated on the ergometer, the heart rate monitor was positioned across the chest and four skin surface thermistors were attached to the chest, arm, thigh, and calf on the right side of the body and connected to a USB-based Temperature Measurement Device.

5.2.2.5.1 Experimental Study A

Participants then cycled for 45 min at the pre-determined power output that was estimated to elicit 55% of VO_2peak with the ergometer set in the cadence-independent mode. Every 10 min an expired gas sample was collected for 3 min (VacuMed Vista Turbofit, USA), every 5 min heart rate and every 15 min Borg's rating of perceived exertion (Borg, 1982) were recorded. Rectal and skin temperature readings were taken every 5 min throughout the trial. Tap water was provided to drink in aliquots of 3 ml/kg body weight either at 15 min intervals or when requested to minimise dehydration. Immediately on completion of the 45 min steady-state period, the ergometer was set to linear mode, based on the formula (see **Chapter 4** under section *4.4)* of Jeukendrup et al., (1996). During this time, they were asked to complete as much work as possible in the 15 min with the only information received being when every 3 min had elapsed. Following completion of

the time-trial, participants performed a low-intensity cool-down for at least 5 min where recovery was monitored.

5.2.2.5.2 Experimental Study B

Participants completed a warm-up consisting of 5 min fixed-intensity cycling at each of three consecutive workloads: 100, 150 and 200 W. Expired gas samples were collected during the final 2 min of every stage with heart rate, core and skin temperatures also recorded every 5 min throughout the trial. Tap water was provided to drink of 3 ml/kg body weight either at pre-exercise or when requested during exercise to minimise dehydration. Similarly to Study A, following the 15 min warm-up, the ergometer was set to linear mode to complete as much work as possible in the 15 min time-trial and the only information they received being when every 3 min had elapsed. Following completion of the time-trial, participants performed a low-intensity cool-down for at least 5 min where recovery was monitored.

5.2.3 Statistical Analysis

In addition to the analyses outlined in **Chapter 4** under section *4.6*, in order to assess test-retest reliability for time-trial performance (work completed), several measures were calculated according to Hopkins (2000); these were the mean difference (change in mean), intra-class correlation coefficient (ICC), and the typical error of measurement as a coefficient of variation (CV) between trials. As Portney and Watkins (2009) have suggested that to ensure reasonable validity for most clinical measurements the ICC should exceed 0.90, this cut-off was adopted for the current data.

5.3 RESULTS

5.3.1 Experimental Study A

5.3.1.1 Time Trial Performance

As can be seen in *Table 5.1 (A),* the amount of work completed for the time-trial during the familiarization trial was lower ($p < 0.05$) than during Trial 1 and Trial 2, which were not different to each other ($p > 0.05$). From *Table 5.1 (B),* it can be seen that the reliability of the 15 min time-trial was improved when a familiarization was performed. Finally, these data indicate an acceptable reliability especially when a familiarization is performed, and put in the context of the reliability of the physiological variables between trials i.e. a CV and ICC of 2.4% and 0.95, and 4.1% and 0.96 for the exercise responses of heart rate and VO_2, respectively.

Table 5. 1: Individual performances (A) and measures of test-retest reliability (B) for work completed (kJ) during the 15-min cycling time trial for Study A.

(A)

Participant	Familiarization	Trial 1	Trial 2
1	278.4	288.9	271.4
2	230.0	232.4	244.9
3	215.4	209.6	212.3
4	231.2	247.8	251.8
5	231.4	210.0	210.7
6	191.2	197.0	187.2
7	263.6	302.1	292.2
8	201.1	230.0	249.8
Mean ± SD	**230 ± 29**	**240 ± 38**	**240 ± 35**

(B)

Measure of Reliability	Familiarization – Trial 1	Trial 1 – Trial 2
Intra-class Correlation Coefficient	0.89	0.96
Lower 95% confidence limit	0.56	0.84
Upper 95% confidence limit	0.98	0.99
Change in Mean (%)	3.7	0.3
Lower 95% confidence limit	-2.9	-3.9
Upper 95% confidence limit	10.8	4.5
Typical Error as a CV (%)	5.7	3.6
Lower 95% confidence limit	3.7	2.4
Upper 95% confidence limit	12	7.5

5.3.1.2 Physiological & Thermoregulatory Measures

Based on their mean VO_2 and heart rate responses, participants were exercising at an intensity eliciting 59 ± 7% VO_2peak and 75 ± 9% HR_{max} during the 45 min steady-state cycling. The cardio-respiratory and temperature responses can be seen in *Figure 5.1.*

Main effects of time ($p < 0.001$) but not trial or interaction (both $p > 0.05$) were observed for rectal temperature, which increased from 37.1 ± 0.4 and 37.1 ± 0.3^{o}C at rest to 38.4 ± 0.3 and 38.4 ± 0.3^{o}C at 45 min before increasing further to 39.0 ± 0.4 and 39.1 ± 0.5^{o}C at the end of the time-trial for the first and second experimental trials, respectively. No effects of time, trial or interaction (all $p > 0.05$) were observed for mean weighted skin temperature with average values of 33.2 ± 0.8 and 33.1 ± 0.7^{o}C for the first and second experimental trials, respectively. Main effects of time ($p < 0.001$) and trial ($p < 0.05$) but no interaction ($p > 0.05$) were observed for heart rate, which increased from 121 ± 11 and 117 ± 12 bpm after 5 min to 141 ± 16 and 137 ± 20 bpm at 45 min before increasing further to 170 ± 7 and 169 ± 10 bpm at the end of the time-trial for the first and second experimental trials, respectively.

Main effects of time ($p < 0.001$) but not trial or interaction (both $p > 0.05$) were observed for minute ventilation, which increased from 59 ± 8 and 63 ± 8 L/min at 5 min to 71 ± 8 and 73 ± 9 L/min at 45 min. Similarly, VO_2 displayed a main effect of time ($p < 0.001$) but not trial or interaction (both $p > 0.05$), with values increasing from 2.9 ± 0.5 L/min at 5 min to 3.3 ± 0.5 L/min at 45 min for both trials. Finally, ratings of perceived exertion averaged 12 ± 1 for both trials during the 45 min steady-state before increasing ($p < 0.001$) to 18 ± 1 at the end of the time-trial.

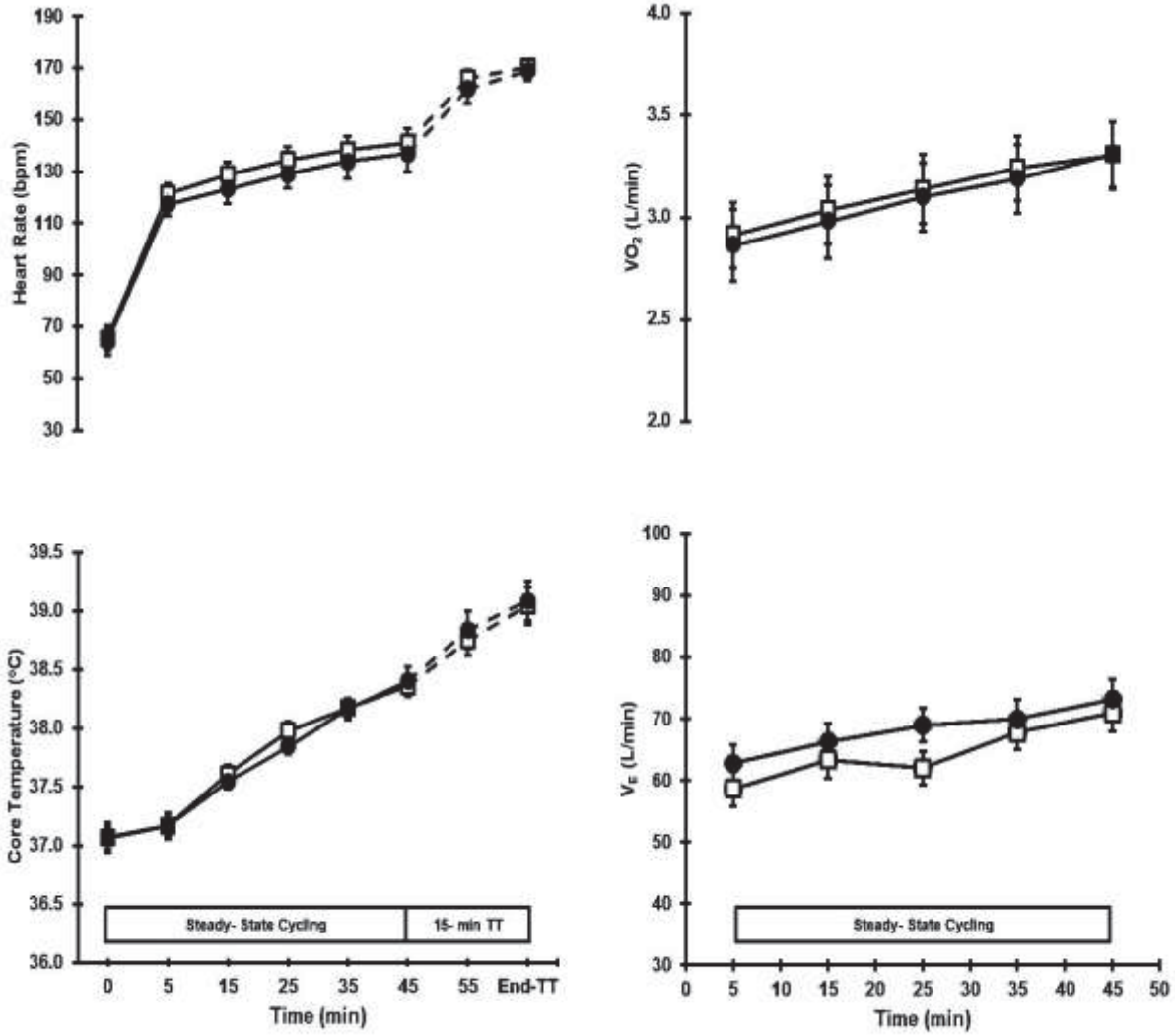

Figure 5. 1: Study A; Heart rate, core temperature, O_2 uptake and ventilation during 45 min steady-state cycling (—) followed by 15-min time trial (----) for Trial 1 (□) and Trial 2 (●). Values are mean ± SEM.

5.3.2 Experimental Study B

5.3.2.1 Time Trial Performance

As can be seen in *Table 5.2 (A),* the amount of work completed for the time-trial during the familiarization, Trial 1 and Trial 2 was not different ($p > 0.05$). However, from *Table 5.2 (B)* it can be seen that the reliability of the 15-min time-trial was still improved when a familiarization was performed. These data also indicate an acceptable reliability both with and without a familiarization being performed, and put in the context of the reliability of the physiological variables between trials i.e. a CV and ICC of 2.9% and 0.89, and 5.2% and 0.79 for the exercise responses of heart rate and VO_2, respectively.

Table 5. 2: Individual performances (A) and measures of test-retest reliability (B) for work completed (kJ) during the 15 min cycling time trial for Study B.

(A)

Participant	Familiarization	Trial 1	Trial 2
1		296.9	286.0
2	278.2	278.1	287.5
3	244.1	245.6	241.9
4	335.1	347.7	321.9
5	202.9	177.0	181.6
6	308.5	308.8	302.1
7	217.0	207.2	208.7
8	200.5	195.8	196.0
Mean ± SD	**255.2 ± 53.3**	**257.1 ± 60.6**	**253.2 ± 53.3**

(B)

Measure of Reliability	Familiarization – Trial 1	Trial 1 – Trial 2
Intra-class Correlation Coefficient	0.98	1.00
Lower 95% confidence limit	0.88	0.99
Upper 95% confidence limit	1.00	1.00
Change in Mean (%)	-1.8	-1.9
Lower 95% confidence limit	-7.1	-4.4
Upper 95% confidence limit	3.7	0.8
Typical Error as a CV (%)	4.3	2.3
Lower 95% confidence limit	2.8	1.5
Upper 95% confidence limit	9.8	4.7

5.3.2.2 Physiological & Thermoregulatory Measures

Based on their VO_2 and heart rate responses, participants were exercising at an intensity eliciting 41 ± 8, 52 ± 8 and 63 ± 8% VO_2peak and 56 ± 8, 66 ± 7 and 77 ± 8% HR_{max} during the 15 min fixed-intensity warm-up. The cardio-respiratory and temperature responses can be seen in *Figure 5.2.*

Main effects of time ($p < 0.001$) but not trial or interaction (both $p > 0.05$) were observed for rectal temperature, which increased from 37.1 ± 0.4 and 37.0 ± 0.5^{o}C at rest to 37.5 ± 0.4 at 15 min before increasing further to 38.3 ± 0.4 at the end of the time-trial for the first and second (or both) experimental trials, respectively. No effects of time ($p > 0.05$) but trial and interaction effects (both $p < 0.05$) were observed for mean weighted skin temperature with average values of 32.8 ± 0.8 and 32.9 ± 1.1^{o}C for the first and second experimental trials, respectively. Main effects of time ($p < 0.001$) and trial ($p < 0.05$) but no interaction ($p > 0.05$) were observed for heart rate, which increased from 108 ± 12 and 101 ± 19 bpm after 5 min to 145 ± 13 and 141 ± 18 bpm at 15 min before increasing further to 174 ± 11 and 171 ± 14 bpm at the end of the time-trial for the first and second experimental trials, respectively.

Main effects of time ($p < 0.001$) but not trial or interaction (both $p > 0.05$) were observed for minute ventilation, which increased from 38 ± 4 at 5 min to 57 ± 9 and 60 ± 6 L/min at 15 min. Similarly, VO_2 displayed a main effect of time ($p < 0.001$) but not trial or interaction (both $p > 0.05$), with values increasing from 2.1 ± 0.3 L/min at 5 min to 3.3 ± 0.3 L/min at 15 min for both trials.

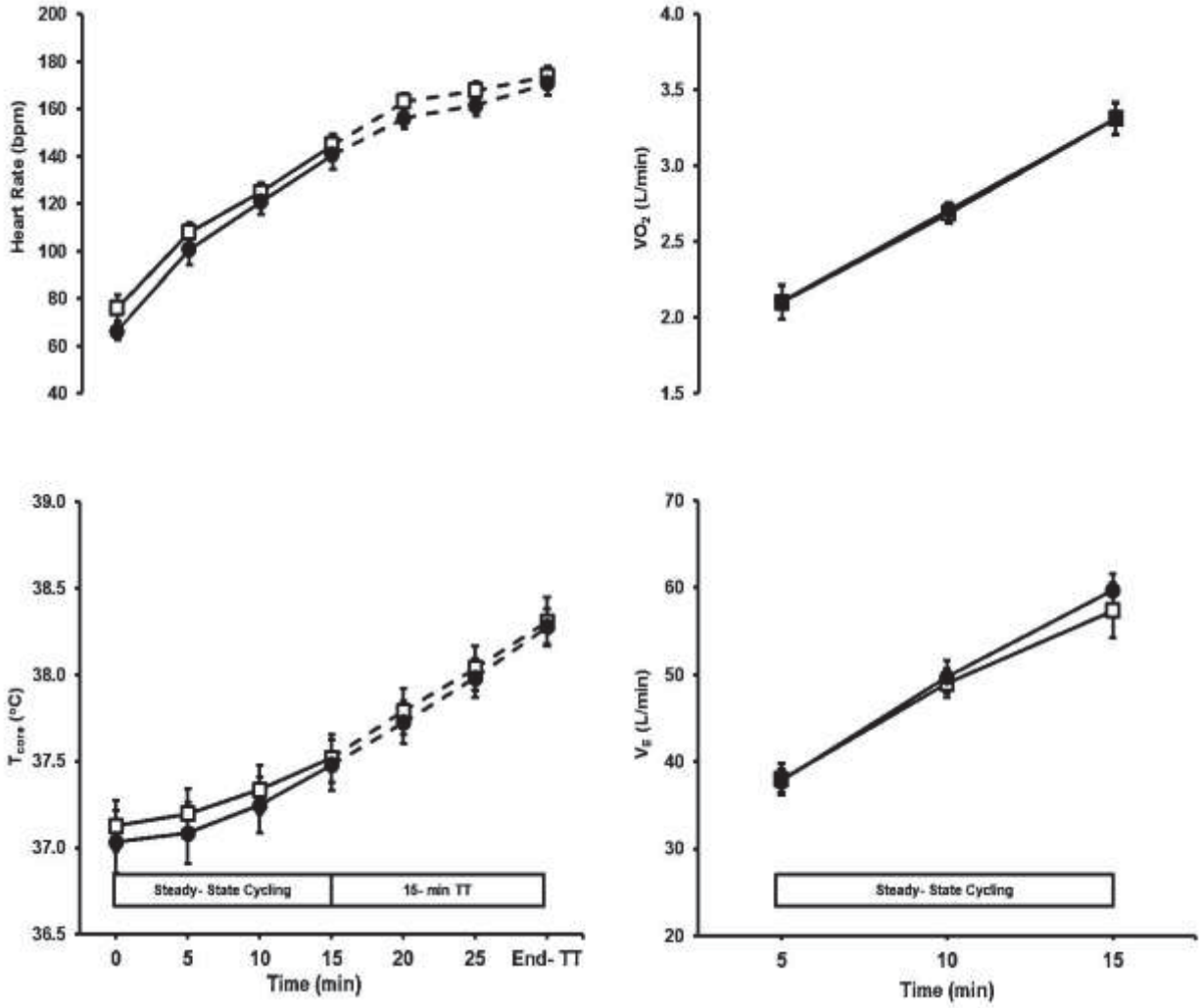

Figure 5. 2: Study B; Heart rate, core temperature, O_2 uptake and ventilation during 15-min steady-state cycling (—) followed by 15-min time-trial (----) for Trial 1 (□) and Trial 2 (●). Values are mean ± SEM.

5.4 DISCUSSION

The main finding of the current study is that a 15-min time-trial performed following a fixed-intensity pre-load of 45 (steady-state, Study A) and 15 (warm-up, Study B) min on a cycle ergometer is reproducible for trained, familiarized males under laboratory conditions of significant thermal (warm-humid) stress. Therefore, knowing the typical variance of these tests under these conditions one can determine the "real" magnitude of any treatment i.e. defining the signal above the noise for the subsequent chapters of this thesis where an intervention (sago) will be introduced.

These results (a CV of 3.6 and 2.3%) compare favourably with the original results of Jeukendrup et al., (1996) who observed a CV of 3.5% when participants cycled for 45 min at 70% W_{max} followed by as much work completed as possible within the 15 min time-trial but without heat stress. When taken together with the results of Marino et al., (2002) who reported a CV of 1.3% for a 1 h cycling time-trial including six "all-out" sprints every 10 min, and Tyler and Sunderland (2008) who observed a CV of 2.7% following 75 min treadmill running at 60% VO_2max proceeded by a 15 min self-paced time-trial, it becomes clear that the addition of ambient heat stress does not necessarily affect the reproducibility of such endurance performance tests. Nevertheless, there are several issues that warrant comment.

Firstly, the current results support previous observations (Jeukendrup *et al.*, 1996; Marino *et al.*, 2002; Tyler & Sunderland, 2008) that a familiarisation trial is important in minimising any learning and thereby possible confound to the overall treatment effect(s), although they differ from Currell, Jentjens & Jeukendrup, (2006) and Currell & Jeukendrup, (2008) who suggested the familiarization session was not necessarily needed among well-trained cyclists because they were accustomed to

the laboratory testing procedures and also time-trial protocol. This was the case in study B as participants performed better in the familiarization trial compared to Trial 1 and 2, thus suggesting no further learning effect. Interestingly, although most measured variables (performance, body temperatures, ventilation, O_2 uptake and perceived exertion) responded consistently between both experimental trials, heart rate was consistently lower by ~4-5 bpm during the steady-state/warm-up cycling in the second experimental trial in both studies A and B. This has been observed previously (Marino *et al.*, 2002) and has been argued to reflect either a greater efficiency or reduced level of anxiety (Schabort *et al.*, 1998). It could be argued that this might be an indication that some adaptation to the thermal stress had occurred; however, as Barnett & Maughan (1993) observed no attenuation (acclimation) in physiological variables when 1 h of cycling at 55% VO_2max was performed at weekly intervals in the heat (35°C and 60% relative humidity) and in the present study no attenuation was seen for the other physiological and perceptual variables, acclimation to the heat seems unlikely to have occurred.

Next, it must be emphasized that care was taken to avoid further confound due to the use of inexperienced/untrained participants, diurnal variation and altered metabolic state, which have all been shown to influence endurance performance (McLellan *et al.*, 1995; Atkinson, Todd, Reilly & Waterhouse, 2005; Rauch, St Clair Gibson, Lambert & Noakes, 2005). The latter in particular is of note for this thesis (starch intervention) and agree with, for example, Doyle & Martinez (1998), who noted that control of diet and training are of significant importance to achieve better reliability with a consequence of lack of such control being inconsistent muscle glycogen levels due to fluctuating CHO intake. Another factor that likely contributed to the high test reliability seen here was that feedback was provided. Previous studies have provided feedback through heart rate and elapsed time/distance/work

e.g. (Jeukendrup *et al.*, 1996; Marino *et al.*, 2002; Tyler & Sunderland, 2008), and other than being a more face-valid approach this allows the use of a pacing strategy due to a known endpoint.

Finally, the use of a protocol with both fixed-intensity and self-paced components has strengths and challenges. An advantage is the ability to collect steady-state data (perceptual, physiological) that can often complement a performance measure, whereas with self-paced protocols the variation in exercise intensity and resulting perceptual and physiological responses make it difficult to assert that independent variable *x* (e.g. fluid intake) exerts an effect on variable *y* (e.g. performance) as there may be confound (e.g. a higher power output due to self-pacing would presumably raise core temperature and augment sweat rate etc.). A disadvantage of pre-loading a time-trial in this way could be that by the time they start the time-trial participants are too close to their physiological limit(s); this might particularly be the case where the ambient thermal profile is high enough that the participant suffers sufficient thermoregulatory strain to destabilize performance and increase the risk of exhaustion and thermal injury. For example, where the rate of heat production (exercise intensity) is fixed and greater than the evaporative capacity of the environment (vapour pressure) this would lead to a continued rise in core body temperature that has been proposed to limit exercise endurance above a certain point (Schlader *et al.*, 2011a). However, as our pilot testing identified this as a significant limiting factor, it was decided to reduce the exercise intensity for the steady-state (Study A) in order to attenuate this hyperthermia, which resulted in participants beginning the time-trial having considerable room for an increase i.e. from ~38.4 to 39.1^{o}C. For the shorter protocol (Study B), this effect was even greater as rectal temperature had risen by only ~0.4^{o}C during the warm-up to ~ 37.5 ^{o}C at the start of the time-trial. In a similar vein, Pitchford, Fell, Leveritt, Desbrow &

Shing (2013) reduced their participants' target amount of work by 20% to ensure they could complete a 1 h time-trial at 75% VO_2peak in hot conditions.

In conclusion, a 15 min cycling time-trial performed following a fixed-intensity pre-load of 45 min (Study A) and 15 min warm-up (Study B) is highly reliable when using trained, familiarized males under laboratory conditions of (humid) heat stress. Notably, this protocol provides an attractive alternative to the two most commonly used laboratory endurance tests, fixed-intensity exhaustion and self-paced time-trial.

CHAPTER SIX

6.0 The Effects of Sago Supplementation before and during Exercise in a Warm-Humid Environment on Physiology and Performance

Publication based on this chapter:

Che Jusoh, M. R., Stannard, S. R., & Mündel, T. (2016). Physiologic and performance effects of sago supplementation before and during cycling in a warm-humid environment, Temperature, 3:2, 318-327.

Abstract

The present study determined whether 0.8 g per kilo body weight sago ingested before (Pre-Sago) or during (Dur-Sago) exercise under warm-humid conditions (30 ± 2°C, 78 ± 3 % RH; 20 $km.h^{-1}$ frontal airflow) conferred a performance and/or physiological benefit compared to a control (Control) condition. Eight trained, male cyclists/triathletes (45 ± 4 y, VO_2peak: 65 ± 10 ml/kg/min, peak aerobic power: 397 ± 71 W) completed three 15-min time-trials (~75% VO_2peak) pre-loaded with 45 min of steady-state (~55% VO_2peak) cycling following >24h standardization of training and diet. Measures of work completed, rectal and mean skin temperatures, heart rate, expiratory gases and venous blood samples were taken. Compared to Control, Pre-Sago resulted in a smaller rise in rectal temperature (0.3 ± 0.5°C) whilst heart rate increased to a greater extent (6 ± 13 bpm) during exercise (both $P < 0.05$), however, compared to Control time-trial performance remained unaffected (Pre-Sago: -0.5 ± 4.0%, $P > 0.05$). During exercise, plasma glucose concentrations were maintained higher for Dur-Sago than Control ($P < 0.05$), however substrate oxidation rates remained similar ($P > 0.05$). Dur-Sago also resulted in a higher plasma sodium concentration (2 ± 2 $mmol.l^{-1}$) and lower whole-body sweat loss (544 ± 636 g) and, therefore, reduced plasma volume contraction (all $P < 0.05$). Heart rate increased to

a greater extent (5 ± 13 bpm) during Dur-Sago, yet compared to Control time-trial performance remained unaffected (+0.9 ± 2.3%, $P > 0.05$). Uniquely, these results indicate that during exercise heat stress feeding sago can result in some 'beneficial' physiological responses, however these do not translate to changes in exercise performance when performed in a post-prandial state.

6.1 INTRODUCTION

Consuming carbohydrate (CHO) before and/or during prolonged exercise can delay the onset of fatigue and improve work output and capacity (Burke & Hawley, 1999). The main goals for CHO supplementation are to fill skeletal muscle and liver glycogen stores prior to exercise and to provide exogenous glucose during prolonged exercise; the latter to partly offset skeletal muscle and central nervous system CHO requirements when glycogen stores run low. The combination of an appropriate CHO composition and administration regimen can subsequently deliver major benefits to endurance sport performance (Vandenbogaerde & Hopkins, 2011); hence the prescriptive use of CHO-containing sports drinks (Sawka *et al.*, 2007).

Glycogen takes some hours to form following CHO ingestion, and cannot be manufactured and stored whilst a muscle fibre is contracting. Thus, CHO ingestion in the hour before exercise practically provides the only opportunity to "top up" hepatic glycogen stores and maximize exogenous carbohydrate availability as exercise begins. The performance effects of CHO ingestion in the hour prior to exercise are varied but are generally positive despite an oft-seen transient hypoglycaemia as exercise begins (Hawley, Burke, Angus, Fallon, Martin & Febbraio, 2000).

Many major sporting events take place during the summer, in warm environments or at the hottest part of a day (Burke, 2001). During exercise with heat stress, there is consensus that performance is decreased and there is an increased risk of heat illness, especially with high humidity through reducing E_{max} thereby increasing core temperature (Maughan *et al.*, 2012; Moyen, Ellis, Ciccone, Thurston, Cochrane, Brown, Coburn & Judelson, 2014). Heat stress during exercise also results in

alterations in CHO metabolism. Febbraio (2001) concluded that heat stress increases CHO utilization and decreases fat utilization, whilst Jeukendrup (2003) concurs that the ambient environmental conditions can affect substrate utilization at rest or during exercise. For example, Yaspelkis & Ivy (1991) demonstrated that exercise in the heat accelerated fatigue because of an increase in reliance upon CHO as a substrate, whilst Jentjens et al., (2002) demonstrated that when ambient temperatures increase so does CHO oxidation during exercise largely due to an increased muscle glycogen use. There have been consistent reports of CHO supplementation proving ergogenic during exercise heat stress, even for shorter (<1h), more intense (~80% VO_2max) bouts (Below *et al.*, 1995; Carter *et al.*, 2003); however, the mechanism(s) responsible remain poorly understood and others have found no such effect (Febbraio, Murton, Selig, Clark, Lambert, Angus & Carey, 1996b).

Where commercially available CHO products are not necessarily affordable or accessible to those competing in sport or exercise, there is a need to investigate local food sources as suitable alternatives. Sago (*Metroxylin sagu*) palms grow all over Southeast Asia, a region with over 600 million inhabitants and a year-round tropical climate. Where there is insufficient rain to grow wet rice, sago palms are used as staple foods. For example, in Malaysia sago starch is an important dietary CHO source (Abd-Aziz, 2002) with Malaysia, Indonesia and Papua New Guinea being the world's leading countries in the production of sago (Singhal *et al.*, 2008). In Sarawak, Malaysia, sago is widely used to produce sago pearls that can be boiled and consumed directly as a CHO source.

To date, there has been no investigation of sago meals ingested before or during exercise although some studies have tested starch meals such as waxy and corn

starch (Saris, Goodpaster, Jeukendrup, Brouns, Halliday & Wagenmakers, 1993; Goodpaster *et al.*, 1996). Sago starch contains 27% amylose and 73% amylopectin (Mohamed *et al.*, 2008) and CHO supplementation consisting of a high amylopectin proportion before exercise has been shown to be equally beneficial as glucose, with less carbohydrate available to the active musculature when the starch is higher in amylose content due to a lower exogenous carbohydrate oxidation (Saris *et al.*, 1993; Goodpaster *et al.*, 1996). Starch can be separated into three categories based on its digestibility (Sands, Leidy, Hamaker, Maguire & Campbell, 2009) and in this context sago is known as being rapidly digestible and quickly absorbed (Ahmad *et al.*, 2009), again suggesting it should be suitable for consumption before/during exercise.

Therefore, the purpose of the present chapter was to determine whether sago ingestion before or during exercise under conditions of heat stress conferred a performance and/or physiological benefit(s) compared to a control condition. In order to collect both meaningful physiological data during a controlled steady-state period and include a measure of performance, in combination lasting greater than 45 min, the protocol developed and tested in **Chapter 5** (*Study A)* was used knowing that it is highly reliable (CV=3.6%, ICC=0.96) when using the same cohort and experimental control.

6.2 METHODS

6.2.1 Participants

Eight healthy, male cyclists/triathletes agreed to participate in this study (Age, 45 ± 4 years; Height, 1.77 ± 0.74 m; Weight, 77 ± 10 kg; VO_2peak, 65 ± 10 ml/kg/min HR_{max}, 176 ± 7 bpm; Peak Power Output, 397 ± 71 W).

6.2.2 Experimental Procedures

All the participants visited the laboratory on five separate occasions: 1) preliminary submaximal and maximal tests, 2) experimental familiarization, 3-5) experimental trials. Full methodological details can be found in **Chapter 4**, however, a brief description follows with any specific details pertinent to this chapter only expanded upon. All trials were completed on an electronically-braked cycle ergometer, used either in the cadence-independent mode (hyperbolic mode, for steady-state) or a cadence-dependent mode (linear mode, for time-trial). Participants' set-up (e.g. seat/handle bar height and horizontal position etc.) was customised and replicated for each subsequent visit.

6.2.3 Preliminary Testing and Familiarisation

Following weight and height measurements, this session was conducted in a moderate laboratory environment (18-22^{o}C) with a fan located in front of the participants with airflow of 20 km/h. A submaximal and maximal exercise test was carried out to determine a linear relationship between the mean rate of VO_2 during the last 2 min of each submaximal stage and power output (see **Chapter 4** under section *4.2.1*). The familiarization trial was undertaken to ensure participants were accustomed to the procedures employed during the investigation and to minimise

any potential learning effects during the experimental trials. These trials replicated entirely the experimental trials outlined below.

6.2.4 Diets and Exercise Control

Twenty-four hours prior to each visit, participants completed a standardized training ride and were then provided with a standardized snack, dinner and breakfast as well as euhydration encouraged (see **Chapter 4** under *section 4.3)*.

6.2.5 Experimental Protocol and Measurement

A week after the familiarization, the participants completed a randomised crossover design of three experimental trials separated by at least 7 days; these trials were Control (nothing), Pre-Sago (Sago consumed before exercise) and Dur-Sago (Sago consumed during exercise); A schematic diagram accompanying the following section can be seen in *Figure 6.1*. For further details on sago supplementation see **Chapter 4** *section 4.5,* however, briefly for Pre-Sago 0.8 g per kilo body weight Sago was consumed as a bolus an hour before exercise whereas for Dur-Sago this same amount (0.8 g per kilo body weight) was divided into four equal amounts and consumed at 0, 15, 30 and 45 min during exercise.

On arrival to the laboratory participants voided and they then self-inserted a rectal thermistor 10 cm beyond the anal sphincter. A cannula was inserted into a forearm vein and a baseline venous blood sample (5 ml) taken (-60 min). Following measurement of weight participants were given their sago-porridge (Pre-Sago) or nothing (Dur-Sago and Control) and rested seated for a further hour, during which time blood samples were collected at -45, -30, and -15 min for the Pre-Sago and Control trials.

Then participants entered the environmental chamber wearing only cycling shorts, shoes and socks. Once seated on the ergometer, the heart rate monitor was positioned across the chest and four skin surface thermistors were attached to the chest, arm, thigh, and calf on the right side of the body and connected to a USB-based Temperature Measurement Device. Resting values for all measurements were recorded.

Participants cycled for 45 min at the pre-determined power output that was estimated to elicit 55 %VO_2peak with the ergometer set in the cadence-independent mode. Every 15 min a venous blood sample was obtained, every 10 min an expired gas sample was collected for 3 min, every 5 min heart rate and every 15 min Borg's rating of perceived exertion were recorded. Rectal and skin temperature readings were taken every 5 min throughout the trial. Tap water was provided to drink of 3 ml/kg body weight either at 15 min intervals or when requested to minimise dehydration. Immediately on completion of the 45 min steady-state period, the ergometer was set to linear mode (see **Chapter 4** under *section 4.4*). During this time, they were asked to complete as much work as possible in the 15 min with the only information received being when every 3 min had elapsed. Following completion of the time-trial, participants performed a low-intensity cool-down for at least 5 min where recovery was monitored.

6.2.6 Data and Statistical Analyses

As detailed in **Chapter 4** under *section 4.6*, time-trial performance (work completed), changes in body weight (sweat loss) and plasma volume were analysed by one-way (trial) ANOVA whereas all other measures were analysed by two-way (trial x time) ANOVA for repeated measures with *post-hoc* pairwise analyses performed using a paired samples *t*-test (Bonferroni correction if appropriate) where main or interaction

effects occurred. Descriptive values were obtained and reported as means and standard deviation (SD) unless stated otherwise, with statistical significance set at $P < 0.05$.

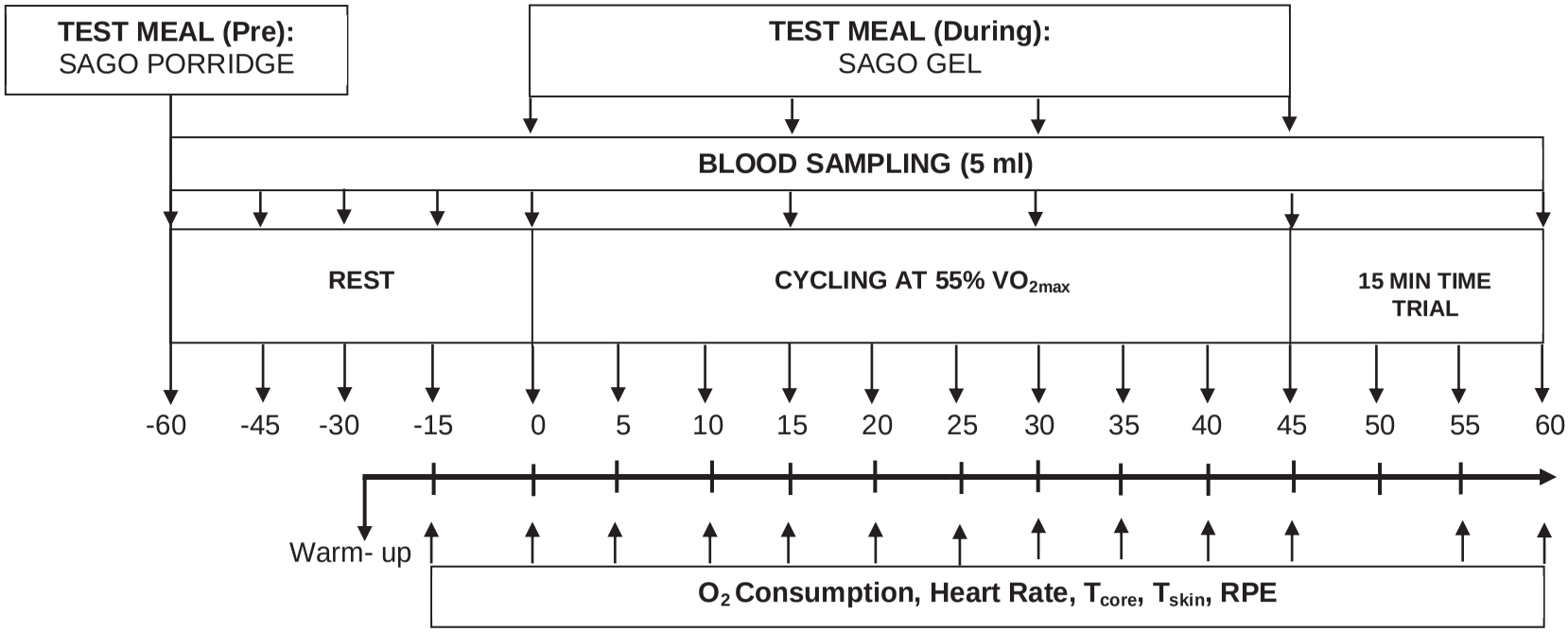

Figure 6. 1: A schematic overview of the experimental protocol

6.3 RESULTS

All eight participants were able to complete all experimental trials in ambient temperature and relative humidity as follows: Control (29.9 ± 1.7^{o}C and 77.9 ± 3.1% RH), Pre-Sago (30.0 ± 1.4^{o}C and 76.4 ± 4.3% RH), and Dur-Sago (29.9 ± 1.6^{o}C and 78.3 ± 2.8% RH) trials.

6.3.1 Time Trial Performance

The average work completed in the 15 min time trial for the Control, Pre-Sago and Dur-Sago trials was 221 ± 33 kJ, 222 ± 31 kJ and 219 ± 32 kJ, respectively (*Figure 6.2*). This equated to a non-significant (P > 0.05) improvement of 0.5 ± 4.0% (Pre-Sago) and decrement of 0.9 ± 2.3% (Dur-Sago) when compared to the Control, respectively.

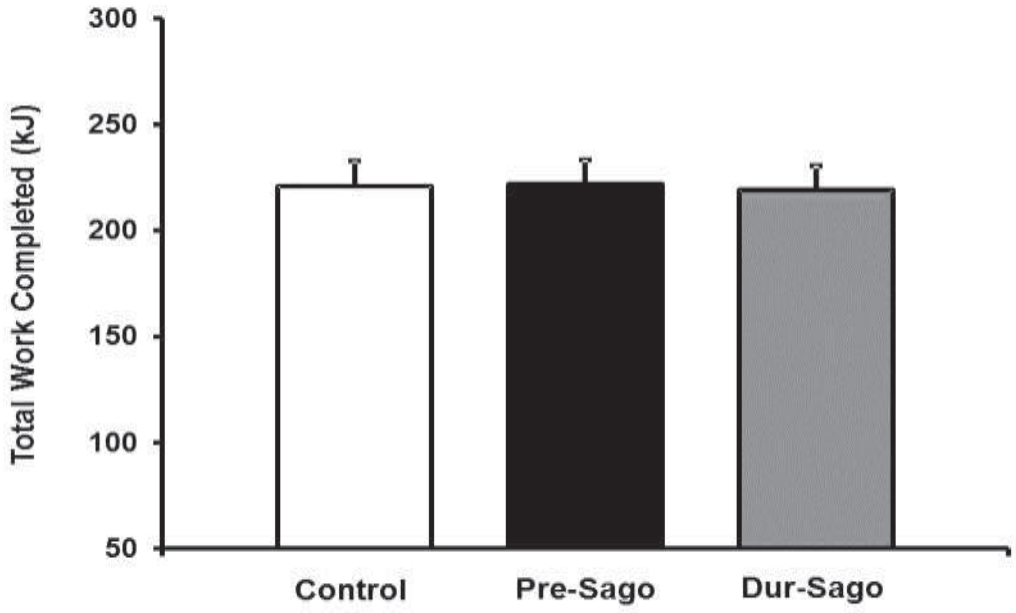

Figure 6. 2: Total work completed (kJ) during the 15-min time-trial for Control, Pre-Sago and Dur-Sago Trial. Data are expressed as mean ± SE.

6.3.2 Metabolic Responses

Plasma glucose and lactate concentration responses for all trials are presented in *Figure 6.3*. There was no difference in baseline values for plasma glucose between trials, however an interaction effect was observed ($P < 0.05$). During rest (-60 to 0 min), glucose concentrations remained stable in Control, whereas they increased during the first 30 min in Pre-Sago such that concentrations were higher than Control from -45 until -15 min. During exercise (0 to 60 min), glucose concentrations increased above basal levels from 30 (Control), 45 (Dur-Sago) and at 60 min (Pre-Sago), such that concentrations were higher than Control at 45 min (Dur-Sago). Similarly, there was no difference in baseline values for plasma lactate between trials, however an effect of time was observed ($P < 0.05$) such that for all three conditions lactate concentrations were only elevated above resting following the time-trial (60 min). The RER and substrate oxidation rates can be seen in *Table 6.1*. None of RER, CHO or fat oxidation during the 45-min steady-state exercise showed any main effects of time, trial or an interaction ($P > 0.05$).

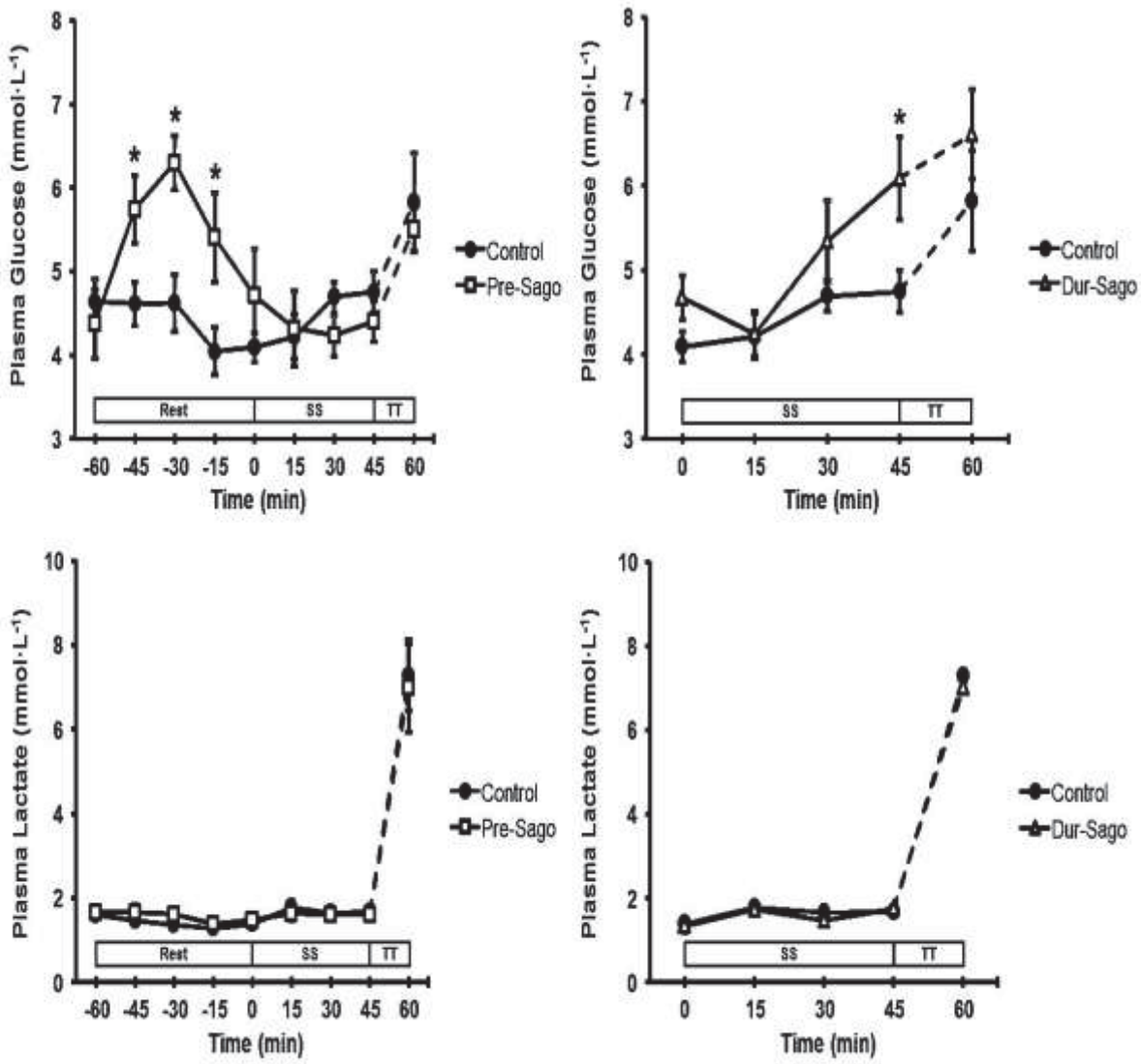

Figure 6. 3: Plasma glucose and lactate concentration during rest, steady-state cycling (SS: **–**) and 15-min time trial (TT: **--**) for Control, Pre-Sago and Dur-Sago trials. Data are expressed as mean ± SE. * indicates significantly different to Control at that time-point ($p < 0.05$).

Table 6. 1: CHO and fat oxidation rates and RER during steady-state exercise.

	Time (min)				
	5	**15**	**25**	**35**	**45**
CHO Oxidation (g.min^{-1})					
Control	2.8 ± 0.3	2.6 ± 0.3	2.5 ± 0.4	2.6 ± 0.3	2.7 ± 0.3
Pre-Sago	2.8 ± 0.4	2.6 ± 0.3	2.8 ± 0.4	2.9 ± 0.4	2.8 ± 0.3
Dur-Sago	2.3 ± 0.1	2.4 ± 0.2	2.4 ± 0.2	2.4 ± 0.2	2.6 ± 0.5
Fat Oxidation (g.min^{-1})					
Control	0.2 ± 0.1	0.3 ± 0.1	0.4 ± 0.1	0.4 ± 0.1	0.4 ± 0.1
Pre-Sago	0.2 ± 0.1	0.4 ± 0.1	0.3 ± 0.1	0.2 ± 0.1	0.4 ± 0.1
Dur-Sago	0.4 ± 0.1	0.4 ± 0.1	0.5 ± 0.1	0.5 ± 0.1	0.3 ± 0.1
RER					
Control	0.94 ± 0.02	0.93 ± 0.02	0.92 ± 0.01	0.93 ± 0.02	0.91 ± 0.02
Pre-Sago	0.94 ± 0.01	0.95 ± 0.02	0.94 ± 0.01	0.94 ± 0.02	0.94 ± 0.02
Dur-Sago	0.92 ± 0.01	0.93 ± 0.02	0.92 ± 0.02	0.92 ± 0.01	0.92 ± 0.03

Data are presented as mean ± SE; *N* = 8

6.3.3 Thermoregulatory Responses

Thermoregulatory measures of rectal (T_c) and mean skin temperatures (T_{skin}) are depicted in *Figure 6.4.* There was no difference in baseline values for T_c between trials, however an interaction effect was observed ($P < 0.05$). During exercise T_c increased above basal levels from 5 (Control) and 15 (Dur-Sago and Pre-Sago) minutes and continued to rise, such that T_c was higher than Control between 5 and 25 min (Pre-Sago), with changes in T_c of 2.1 ± 0.5, 1.8 ± 0.4 and 2.0 ± 0.6^{o}C for Control, Pre-Sago and Dur-Sago, respectively. Similarly, there was no difference in baseline values for T_{skin} between trials, however an effect of time was observed ($P < 0.05$) such that for all three conditions T_{skin} increased until 15 min and plateaued thereafter.

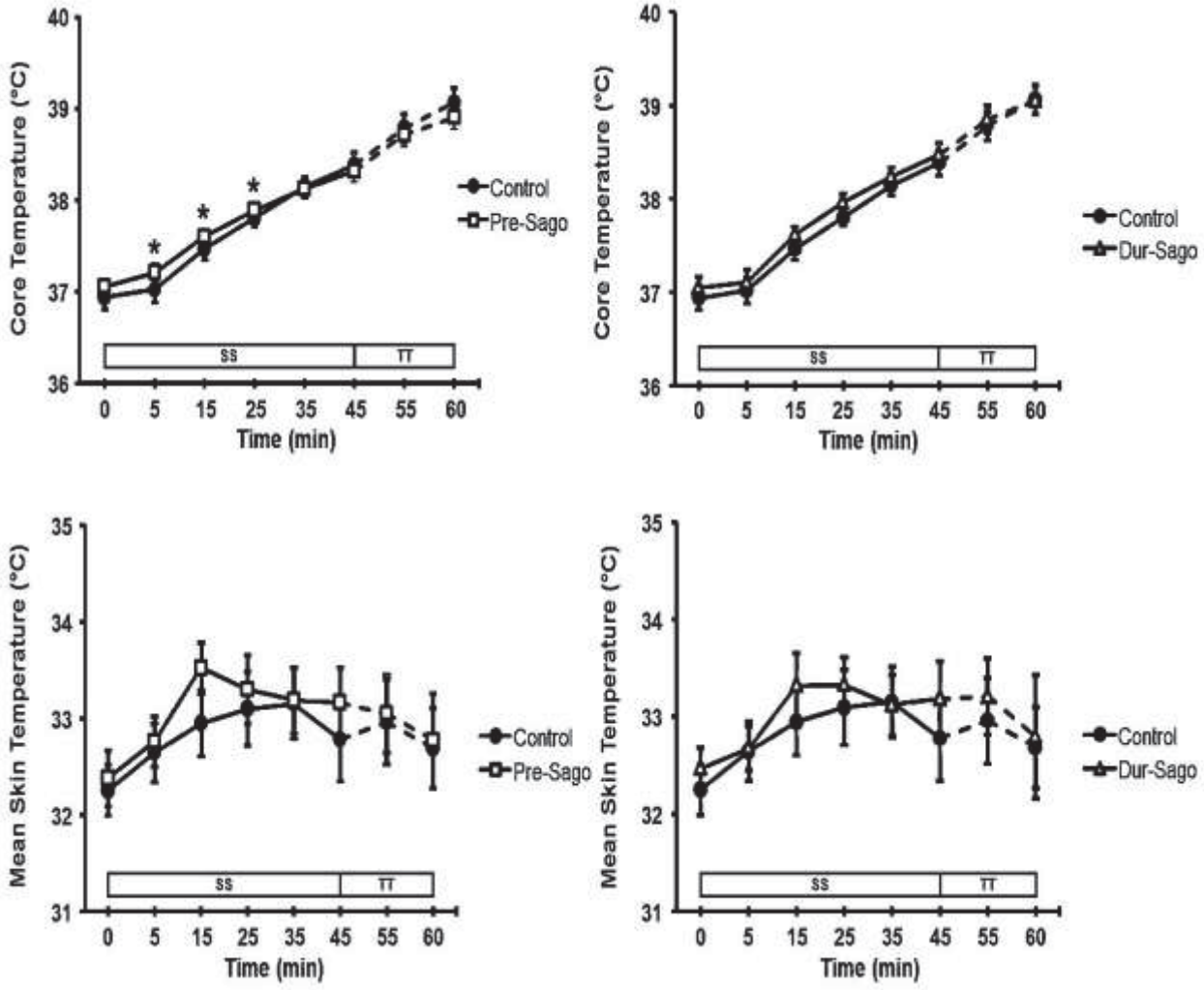

Figure 6. 4: Core and mean skin temperature at rest, during steady-state cycling (SS: –) and 15-min time trial (TT: --) for Control, Pre-Sago and Dur-Sago trials. Data are expressed as mean ± SE. * indicates significantly different to Control at that time-point ($p < 0.05$).

Water consumption was not different between trials ($P > 0.05$) at 752 ± 267, 656 ± 306 and 622 ± 302 ml for Control, Pre-Sago and Dur-Sago, respectively. However, whole-body sweat loss was smaller ($P < 0.05$) for Dur-Sago (1236 ± 398 g) than Control (1704 ± 583 g) with neither different to Pre-Sago (1486 ± 331 g), which led to a smaller decrease of plasma volume following Dur-Sago (-4 ± 8%) than Control (-15 ± 11%) but neither was different to Pre-Sago (-9 ± 18%).

Plasma concentrations of sodium and potassium can be seen in *Table 6.2.* Plasma concentrations of sodium showed an effect of trial, such that values for sodium were higher for Dur-Sago (140 ± 5 mmol/L) than Control (138 ± 4 mmol/L) and Pre-Sago (137 ± 6 mmol/L), whilst plasma concentrations of potassium showed an effect of time ($P < 0.05$) with values increasing above resting from 15 min onwards.

Table 6. 2: Plasma sodium and potassium concentrations during exercise. Values are mean ± SD.

		Time (min)				
		0	**15**	**30**	**45**	**60**
Sodium (mmol/L)	Control	138 ± 4	138 ± 6	139 ± 6	139 ± 1	139 ± 1
	Pre-Sago	138 ± 5	137 ± 3	136 ± 6	138 ± 7	135 ± 8
	Dur-Sago	139 ± 5	139 ± 8	142 ± 6	142 ± 4	142 ± 2
Potassium (mmol/L)	Control	3.9 ± 0.3	4.4 ± 0.3	4.4 ± 0.3	4.4 ± 0.3	4.7 ± 0.6
	Pre-Sago	3.8 ± 0.3	4.4 ± 0.2	4.3 ± 0.3	4.3 ± 0.6	4.4 ± 0.4
	Dur-Sago	4.1 ± 0.3	4.3 ± 0.5	4.6 ± 0.5	4.7 ± 0.2	4.7 ± 0.4

6.3.4 Cardiorespiratory and Perceptual Responses

There was no difference in baseline values for heart rate between trials, however a trial*time interaction effect was observed ($P < 0.05$). During exercise heart rate increased progressively although to a greater extent in Pre-Sago (5 min: 119 ± 11 bpm, 45 min: 139 ± 16 bpm, 60 min: 172 ± 6 bpm) and Dur-Sago (5 min: 118 ± 11 bpm, 45 min: 141 ± 17 bpm, 60 min: 171 ± 9 bpm) compared to Control (5 min: 116 ± 13 bpm, 45 min: 132 ± 18 bpm, 60 min: 169 ± 10 bpm), such that heart rate was lower during Control from 15-25 min and at 45 min compared to both sago treatments. Similarly, there was no difference in 5 min values for ventilation between trials (61 ± 8 L/min), however an effect of time was observed ($P < 0.05$) such that for all three conditions ventilation increased until 25 min and plateaued thereafter (69 ± 8 L/min). Finally, perceived exertion during steady-state exercise remained constant

(11 ± 1 units) but increased ($P < 0.05$) following the time-trial (17 ± 1 units), with no difference between trials or any interaction (both $P > 0.05$).

6.4 DISCUSSION

This is the first study to determine whether sago, a starch staple found across Southeast Asia and prepared through boiling pearls into porridge/gel, influences cycling performance under conditions that simulate a tropical environment i.e. warm-humid. The main finding is that in a post-prandial state feeding sago before or during such exercise does not confer any performance benefit (or detriment) when compared to a control. However, there was a smaller reduction in plasma volume found when consuming sago during steady-state exercise through reduced whole-body sweating, with a concomitant higher plasma sodium concentration. Heart rate was also higher when sago was ingested either before or during exercise compared to control. Lastly, core temperature was greatest at the beginning of exercise when sago was ingested prior, but then in this trial the rise in core temperature was attenuated compared to the control condition.

In **Chapter 5** (*Study A*) it was demonstrated that using the same experimental standardization in trained, familiarized males a protocol of 45-min steady-state at 55% VO_2peak followed by a 15-min time trial at ~75% of VO_2peak in warm-humid conditions is a highly reliable protocol, with a test-retest coefficient of variation of 2-4% for physiological and performance variables. Therefore, it can be said with confidence that the observed similarities in time-trial performance in this chapter are real. The careful exercise and dietary control applied not only likely isolated the effects of our dietary intervention but also mimicked typical pre-competition

behaviour i.e. reduced physical activity and a CHO-rich diet to ensure skeletal muscle and hepatic glycogen stores are filled. Whilst ecologically-valid however, the consumption of a low-GI breakfast 2-3 hours prior to their experimental trial could well have overwhelmed the effects of a more subtle sago intervention, at least when comparing timing of ingestion (pre- vs. during). Importantly, many previous studies (Below *et al.*, 1995; Febbraio *et al.*, 1996a; Carter *et al.*, 2003) that have investigated CHO supplementation during exercise heat stress had participants complete their exercise following an overnight fast. This may go some way in explaining any performance discrepancy as the maintenance of glycaemia becomes more challenging in overnight fasted exercise (Thomas, Brotherhood & Brand, 1991) whilst at the same time the contracting muscle's CHO requirement increases in the heat (Febbraio, 2001).

The (resting) glycaemic response to (pre-exercise) sago ingestion is similar to that found previously with ingestion of other high GI foods, and confirms that sago is quickly absorbed and metabolised to glucose, i.e. has a high GI (Ahmad *et al.*, 2009). That plasma glucose was then slightly depressed as exercise progressed with pre-ingestion compared to the control condition again replicates previous work (Stannard, Constantini & Miller, 2000) and likely reflects the combined effects of insulin- and contraction-mediated glucose uptake. That being the case, we expected RER to be greater in Pre-Sago (reflecting increased CHO uptake and oxidation by muscle), but this was not found. It may be that a whole-body measure such as RER does not have the sensitivity to resolve the small increase in muscle CHO uptake and utilization that a single meal would bring, or that insulin-induced inhibition of hepatic glucose release explains the early exercise transient hypoglycaemia. In contrast, when ingested only during exercise (Dur-Sago), plasma glucose was higher than control; again this has been observed elsewhere with ingestion of a

CHO supplement with similar physical properties (Febbraio *et al.*, 1996b). It is less surprising, in this trial, that RER was not significantly different from control, as insulin release is blunted during exercise (Galbo, 1983).

Perhaps the most interesting observation was that when sago was supplemented during exercise (Dur-Sago), fluid regulation was altered, with a higher plasma sodium concentration, attenuated reduction in plasma volume and lower whole-body sweat rate. Carbohydrate consumption could enhance fluid retention through one of two potential mechanisms (Osterberg, Pallardy, Johnson & Horswill, 2010): (1) gastric contents with a higher energy density and osmolality decrease the rate of emptying and absorption (Vist & Maughan, 1994; Gisolfi, Summers, Lambert & Xia, 1998), that in turn could cause a slower movement of fluid into the bloodstream, sustain a higher plasma osmolality and attenuate urine production, and/or (2) the insulinaemic response invoked by carbohydrate ingestion has been shown to increase urinary sodium reabsorption (Galvan, Natali, Baldi, Frascerra, Sanna, Ciociaro & Ferrannini, 1995). The latter is less likely, because as previously noted insulin release is reduced with CHO ingestion once exercise begins.

That heart rate was increased during both types of sago feeding can be explained by the additional digestive load (Kelbaek, 1989). Additionally, that rectal temperature was higher at the start of exercise with Pre-Sago, one hour following consumption, can be explained by dietary-induced thermogenesis (Giickmak, Mitochell, Lambert & Keeton, 1948). However, our observation of a subsequent attenuated rise in rectal temperature when sago was consumed prior to exercise (Pre-Sago) was unexpected and contrary to previous reports (Horswill *et al.*, 2008). Our measures most closely related to metabolic heat production and loss (i.e. work completed, mean skin temperature and sweat loss) for Pre-Sago were not different to Control,

and whilst it has previously been demonstrated that hyperosmolality (see previous paragraph: sago and fluid regulation) elevates the threshold for sweating (Fortney, Wenger, Bove & Nadel, 1984) this would result in the opposite effect. Therefore, it remains to be determined whether this effect can be explained by more specific measures not taken within this study (i.e. local sweat rate, skin blood flow) or as a consequence of non-thermal factors.

Although the primary aim with the current chapter was to identify whether there was any difference between supplementing sago at different time-points i.e. before *versus* during exercise, we used a control condition where nothing was consumed to see if sago ingestion at either time was beneficial or detrimental. Had we observed (more) significant differences, especially ones pertaining to performance, the next logical step would be to assess this against a suitable and known CHO source (e.g. Pre-Sago *versus* pasta, Dur-Sago *versus* glucose) to determine efficacy. However, the resting glycaemic response to sago ingestion (*Figure 6.3*) showing that sago is quickly digested to glucose and absorbed (high GI), indicates that supplementing sago following exercise may be beneficial when recovering for subsequent exercise bouts; this will be the focus of **Chapter 7**.

In conclusion, the present chapter has shown that whilst consuming equal total volumes of sago porridge an hour before and sago gel during exercise in warm-humid conditions does confer some physiological benefit, these are not ergogenic above a control condition when in a post-prandial state.

CHAPTER SEVEN

7.0 The Effects of Sago Supplementation during Recovery from Exercise in a Warm-Humid Environment on Physiology and Performance

Publication based on this chapter:

Che Jusoh, M. R., Stannard, S. R., & Mündel, T. (2016). Sago supplementation for recovery from cycling in a warm-humid environment and its influence on subsequent cycling physiology and performance. Temperature: 1-11.

Abstract

This study determined whether sago porridge ingested immediately after exercise (Exercise 1) in warm-humid conditions (30 ± 1 °C, 71 ± 4 % RH; 20 km/h frontal airflow) conferred more rapid recovery, as measured by repeat performance (Exercise 2), compared to a control condition. Eight well-trained, male cyclists/triathletes (34 ± 9 y, VO_2peak 70 ± 10 ml/kg/min, peak aerobic power 413 ± 75 W) completed two 15 min time-trials pre-loaded with 15 min warm-up cycling following >24h standardization of training and diet. Mean power output was not different between trials during Exercise 1 (286 ± 67 vs. 281 ± 59 W), however, was reduced during Exercise 2 for control (274 ± 61 W) but not sago (283 ± 60 W) that led to a significant performance decrement (vs. Exercise 1) of 3.9% for control and an improvement (vs. control) of 3.7% for sago during Exercise 2 ($P < 0.05$). Sago ingestion was also associated with higher blood glucose concentrations during recovery compared to control. These results indicate that feeding sago during recovery from exercise in a warm-humid environment improves recovery of performance during a subsequent exercise bout when compared to a water-only control. As these effects were larger than the test-retest coefficient of variation for work completed during the 15-min time-trial (2.3%) it can be confidently concluded that the observed effects are real.

7.1 INTRODUCTION

The relationship between reduced carbohydrate availability and the onset of fatigue has been known for some time (Christensen & Hansen, 1939). Specifically, the progressive depletion of skeletal muscle's limited glycogen stores and reduction in circulating blood glucose as exercise progresses are linked to performance deterioration and volitional fatigue (Cermak & van Loon, 2013). Following the cessation of exercise, muscle glycogen content can be restored to near pre-exercise levels within 24 hours provided adequate amounts of CHO are consumed (Costill, Sherman, Fink, Maresh, Witten & Miller, 1981), however for athletes training or competing multiple times daily or on successive days it is ideal that glycogen stores be replenished more rapidly (Millard-Stafford, Childers, Conger, Kampfer & Rahnert, 2008) to assist optimal rates of recovery. There exists a 'window of opportunity' as glycogen synthesis rates are at their highest during the first few hours following exercise when CHO is consumed (Ivy, Katz, Cutler, Sherman & Coyle, 1988). Therefore, it follows that the consumption of CHO early in the post-exercise period can enhance performance in a subsequent bout of exercise (Fallowfield, Williams & Singh, 1995); hence the consensus prescription (Rodriguez, DiMarco & Langley, 2009a) of CHO as soon as practical post-exercise to maximise recovery between sessions. Furthermore, many competitive situations are such that only few hours separate the next bout of competitive effort, so it is important that the first CHO-containing meal is consumed as soon as possible after the initial bout, and is palatable enough to be ingested when often food intake is not desired.

Many major sporting events take place during the summer, in warm environments or at the hottest part of a day (Burke, 2001). During exercise with heat stress, there is consensus that performance is decreased and there is an increased risk of heat

illness, especially with high humidity (Wendt *et al.*, 2007). Heat stress during exercise also results in alterations in CHO metabolism with Febbraio (2001) concluding that heat stress increases CHO and decreases fat utilization. For example, Yaspelkis & Ivy (1991) demonstrated that exercise in the heat accelerated fatigue because of an increase in reliance upon CHO as a substrate, whilst Jentjens et al., (2002) demonstrated that when ambient temperatures increase so does CHO oxidation during exercise largely due to an increased muscle glycogen use. Therefore, Jentjens, Underwood, Achten, Currell, Mann, & Jeukendrup (2006) proposed that glycogen stores may be sub-optimal in athletes training or competing multiple times daily or on successive days in hot environments.

To date, there has been no investigation of sago meals ingested following exercise, although in the previous chapter (**Chapter 6**) no performance effect of feeding 0.8 g per kilo bodyweight sago before (porridge) or during (gel) exercise under warm-humid conditions was observed despite several beneficial physiological responses. However, in that study participants' skeletal muscle and hepatic glycogen stores were likely full due to our careful exercise and dietary control, mimicking typical pre-competition behaviour i.e. reduced physical activity and a CHO-rich diet. Sago was nevertheless quite palatable and therefore would likely provide a suitable and easily obtainable meal post exercise for many in the Asian region. Further, the resting glycaemic response to sago ingestion confirms that sago is quickly absorbed and metabolised to glucose i.e. has a high glycaemic index (GI), (Ahmad *et al.*, 2009) and the finding of **Chapter 6** indicating that supplementing sago following exercise may be beneficial when recovering for subsequent exercise bouts, at least in terms of rapid glycogen repletion.

Therefore, the purpose of the present chapter was to determine whether sago ingestion in recovery between two exercise bouts under conditions of heat stress conferred a performance and/or physiological benefit(s) compared to a control condition. In order to collect both meaningful physiological data during a fixed-intensity pre-load period and include a measure of performance, the protocol developed and tested in **Chapter 5** (*Study B*) was used knowing that it is highly reliable (CV=2.3%, ICC=1.00) when using the same cohort and experimental control.

7.2 METHODS

7.2.1 Participants

Eight healthy, male cyclists/triathletes agreed to participate in this study (Age, 34 ± 9 years; Height, 1.80 ± 0.11 m; Weight, 79 ± 16 kg; VO_2peak, 70 ± 10 ml/kg/min HR_{max}, 185 ± 5 bpm; Peak Power Output, 413 ± 75 W).

7.2.2 Experimental Overview

All the participants visited the laboratory on four separate occasions: 1) preliminary submaximal and maximal tests, 2) experimental familiarization, 3 and 4) experimental trials. Full methodological details can be found in **Chapter 4**, however, a brief description follows with any specific details pertinent to this chapter only expanded upon.

7.2.3 Preliminary Testing and Familiarisation

Following weight and height measurements, this session was conducted in a moderate laboratory environment (18-22^{o}C) with a fan located in front of the

participants with an airflow of 20 km/h. A submaximal and maximal exercise test was carried out to determine a linear relationship between the mean rate of VO_2 during the last 2 min of each submaximal stage and power output was determined and used to calculate a power output which would approximately elicit ~75% (time-trial) of VO_2peak for each participant for the remaining trials (see **Chapter 4** under *section 4.2.1*). The familiarization trial was undertaken to ensure participants were accustomed to the procedures employed during the investigation and to minimise any potential learning effects during the experimental trials. These trials replicated entirely the experimental trials outlined below.

7.2.4 Diets and Exercise Control

Twenty-four hours prior to each visit, participants completed a standardized training ride and were then provided with a standardized snack, dinner and breakfast as well as euhydration encouraged (see **Chapter 4** under *section 4.3*).

7.2.5 Experimental Protocol and Measurement

A week after the familiarization, the participants completed a randomised crossover design of two trials separated by at least 7 days; these trials were Control (nothing) and Sago (Sago consumed during recovery) where a 2h recovery period separated two identical exercise bouts (a schematic diagram accompanying the following section can be seen in *Figure 7.1*). For further details on sago supplementation see **Chapter 4** *section 4.5*, however, briefly for Sago 0.8 g per kilo body weight Sago was consumed as a bolus on completion of exercise bout 1.

On arrival to the laboratory participants voided and they then self-inserted a rectal thermistor 10 cm beyond the anal sphincter. A cannula was inserted into a forearm vein and a baseline venous blood sample (5 ml) taken. Following measurement of

weight participants entered the environmental chamber wearing only cycling shorts, shoes and socks. Once seated on the ergometer, the heart rate monitor was positioned across the chest and four skin surface thermistors were attached to the chest, arm, thigh, and calf on the right side of the body and connected to a USB-based Temperature Measurement Device. Resting values for all measurements were recorded.

Participants completed a warm-up consisting of 5 min fixed-intensity cycling at each of three consecutive workloads: 100, 150 and 200 W. Expired gas samples were collected during the final 2 min of every stage as was a venous blood sample, with heart rate, core and skin temperatures also recorded every 5 min throughout the trial. Tap water was provided to drink of 3 ml/kg body weight either at pre-exercise or when requested during exercise to minimise dehydration. Following the 15-min warm-up, the ergometer was set to linear mode to complete as much work as possible in the 15 min time-trial and the only information they received being when every 3 min had elapsed. Following completion of the time-trial, participants performed a low-intensity cool-down for at least 5 min where recovery was monitored. On exiting the environmental chamber, participants were weighed and allowed to towel down and then remained semi-reclined in a comfortable moderate laboratory environment (20-22^{o}C) for the following 2 hours. At the start of this 2 hours, participants received either sago (0.8 g per kilo body weight) or control (nothing) and were allowed/ encouraged to drink water during this recovery. Venous blood samples were taken at 15 min intervals (first hour) and then 30 min intervals (second hour). Following this recovery period, the above exercise protocol (and measures) was then subsequently repeated.

7.2.6 Data and Statistical Analyses

As detailed in Chapter 4.6, all measures were analysed by two-way ANOVA for repeated measures. Where an interaction effect was found subsequent analyses included whether there was any effect of exercise bout (Exercise 1 vs. 2) as another factor within ANOVA. Where main or interaction effects occurred *post-hoc* pairwise analyses were performed using a paired samples *t*-test (Bonferroni correction if appropriate). Descriptive values were obtained and reported as means and standard deviation (SD) unless stated otherwise, with statistical significance set at $P < 0.05$.

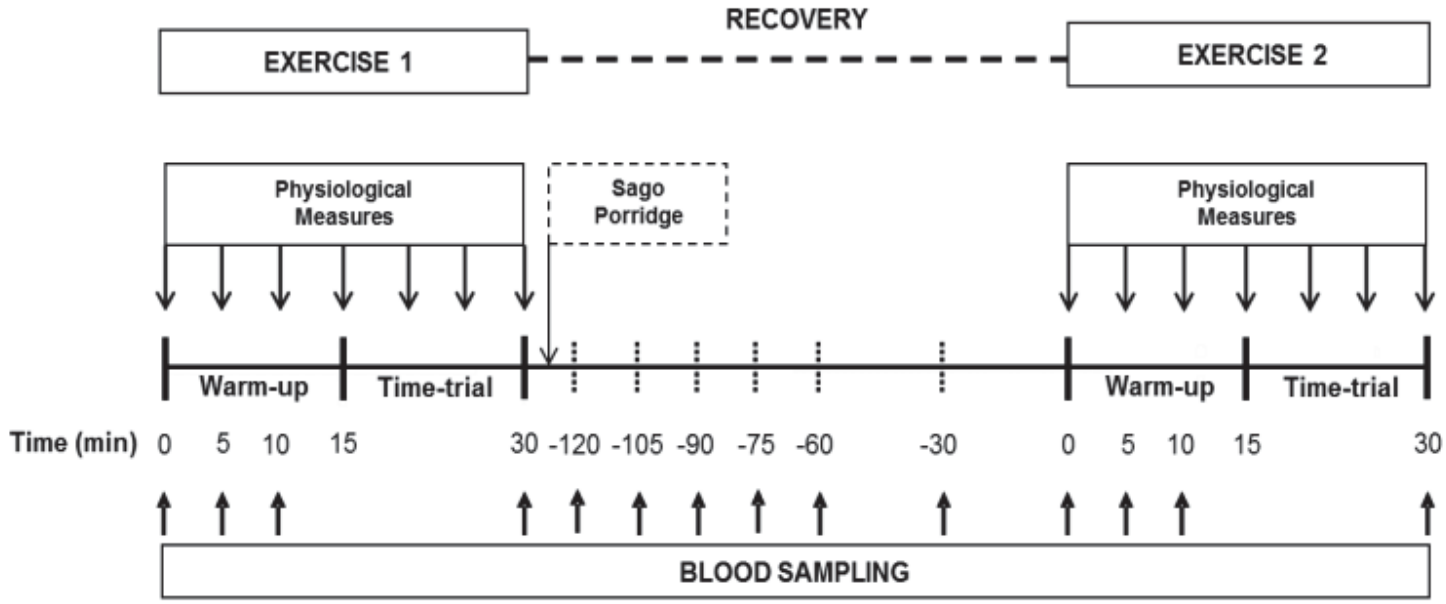

Figure 7. 1: A schematic overview of the experimental protocol timeline

7.4 RESULTS

All eight participants were able to complete all experimental trials. Unfortunately, freezer plasma samples for time-point 15-min were destroyed due to freezer malfunction.

7.4.1 Time Trial Performance

The average work completed in the 15-min time-trials for both trials before and following recovery can be seen in *Figure 7.2*. A significant interaction effect for work completed ($P < 0.05$) indicates that during Control, work completed during the Exercise 2 (246 ± 55 kJ) was less (3.9 ± 3.7%, $P < 0.05$) than the Exercise 1 (257 ± 61 kJ), whereas for Sago work completed during Exercise 2 (255 ± 54 kJ) was no different (0.6 ± 4.4%, $P > 0.05$) than Exercise 1 (253 ± 53 kJ). Therefore, sago supplementation at the start of a 2-h recovery between exercise bouts maintained performance (vs. Exercise 1) and Control did not (difference equating to 3.7 ± 5.1%, $P < 0.05$).

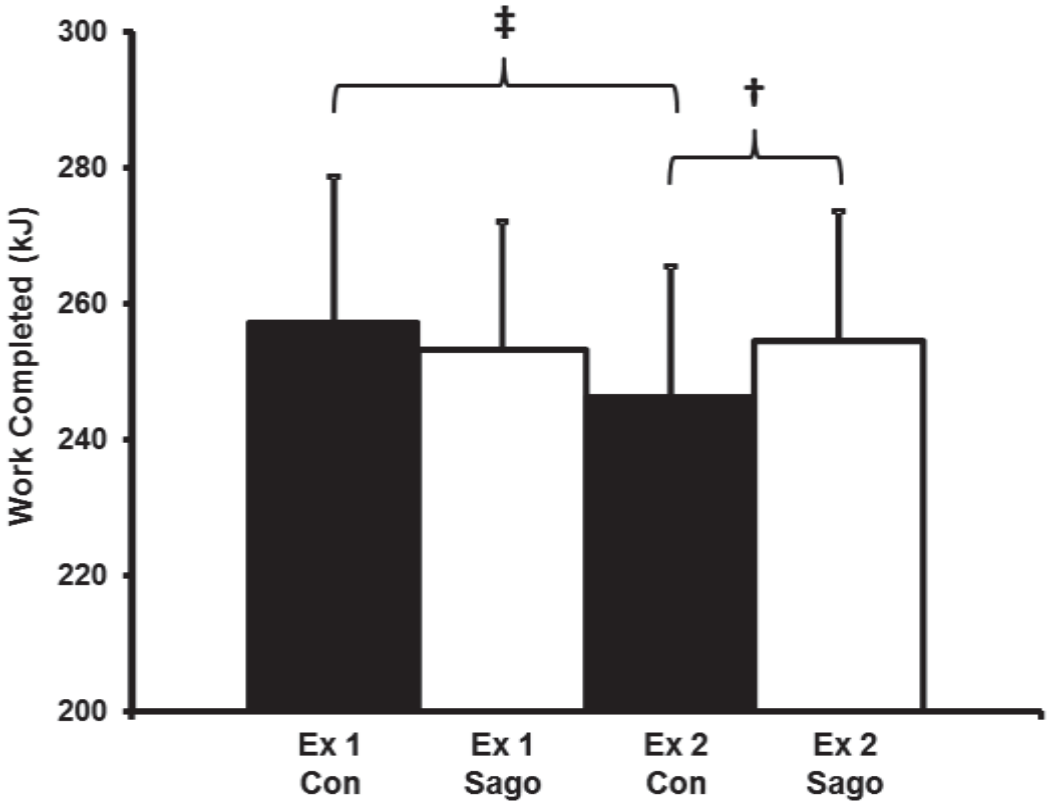

Figure 7. 2: Mean total work completed (kJ) during the 15-min time trial for Control and Sago trials before (Ex 1) and after (Ex 2) a 2-h recovery. ‡ indicates significantly different to Ex 1. † indicates significantly different to Con.

7.4.2 Metabolic Responses

Figure 7.3 shows the plasma glucose and lactate responses during exercise and recovery for both trials.

Main effects of time and time*trial were observed for glucose (both $P < 0.05$) although interestingly no effect of the exercise bout was observed (i.e. Exercise 1 vs. Exercise 2). During Exercise 1, glucose concentrations had only increased above resting at the end of the time-trial in both trials. As far as the recovery glucose response is concerned, a divergent response was observed; Control concentrations

began to decrease towards pre-exercise values from 30 min onwards whereas for Sago concentrations were maintained elevated throughout this period. This led to a higher glucose concentration at pre-exercise for Exercise 2 than 1 with Sago. During Exercise 2, glucose concentrations decreased below resting in both trials, before being elevated above resting at the end of the time-trial for the Control trial only. Therefore, representative glucose concentrations were: start (Control: 4.2 ± 1.0, Sago: 4.2 ± 1.2 mmol/L) and end (Control: 6.0 ± 1.4, Sago: 5.6 ± 1.1 mmol/L) of Exercise 1, start (Control: 5.7 ± 1.1, Sago: 5.6 ± 1.0 mmol/L) and middle (Control: 4.8 ± 0.5, Sago: 5.6 ± 2.0 mmol/L) of recovery and start (Control: 4.7 ± 0.7, Sago: 5.0 ± 0.9 mmol/L) and end of Exercise 2 (Control: 5.8 ± 0.7, Sago: 5.4 ± 1.1 mmol/L).

Main effects of time, trial and time*trial were observed for lactate (all $P < 0.05$), although akin to plasma glucose, no main effect of the exercise bout was observed. During Exercise 1, lactate concentrations had only increased above resting at the end of the time-trial in both trials. As far as the recovery lactate response is concerned, lactate concentrations began to decrease towards pre-exercise values from 15 (Control) and 30 (Sago) minutes onwards. At the start of Exercise 2, lactate concentrations were lower for Sago than Control and also lower than Exercise 1 for Sago only. During Exercise 2, lactate concentrations only increased above resting at the end of the time-trial in both trials where values for Sago were significantly higher than Control. Therefore, representative lactate concentrations were: start (Control: 1.6 ± 0.3, Sago: 1.4 ± 0.2 mmol/L) and end (Control: 6.4 ± 3.5, Sago: 6.2 ± 3.1 mmol/L) of exercise 1, start (Control: 2.7 ± 1.0, Sago: 2.5 ± 1.8 mmol/L) and middle (Control: 1.6 ± 0.8, Sago: 1.6 ± 1.0 mmol/L) of recovery and start (Control: 1.4 ± 0.4, Sago: 1.1 ± 0.2 mmol/L) and end of exercise 2 (Control: 5.0 ± 2.4, Sago: 6.3 ± 3.5 mmol/L).

The RER and substrate oxidation rates can be seen in *Table 7.1*. As expected, a main effect of time was observed for both RER and carbohydrate oxidation rates (both $P < 0.05$) - specific *post-hoc* results can be seen in *Table 7.1* - however, no effects of trial or exercise bout were evident (both $P > 0.05$).

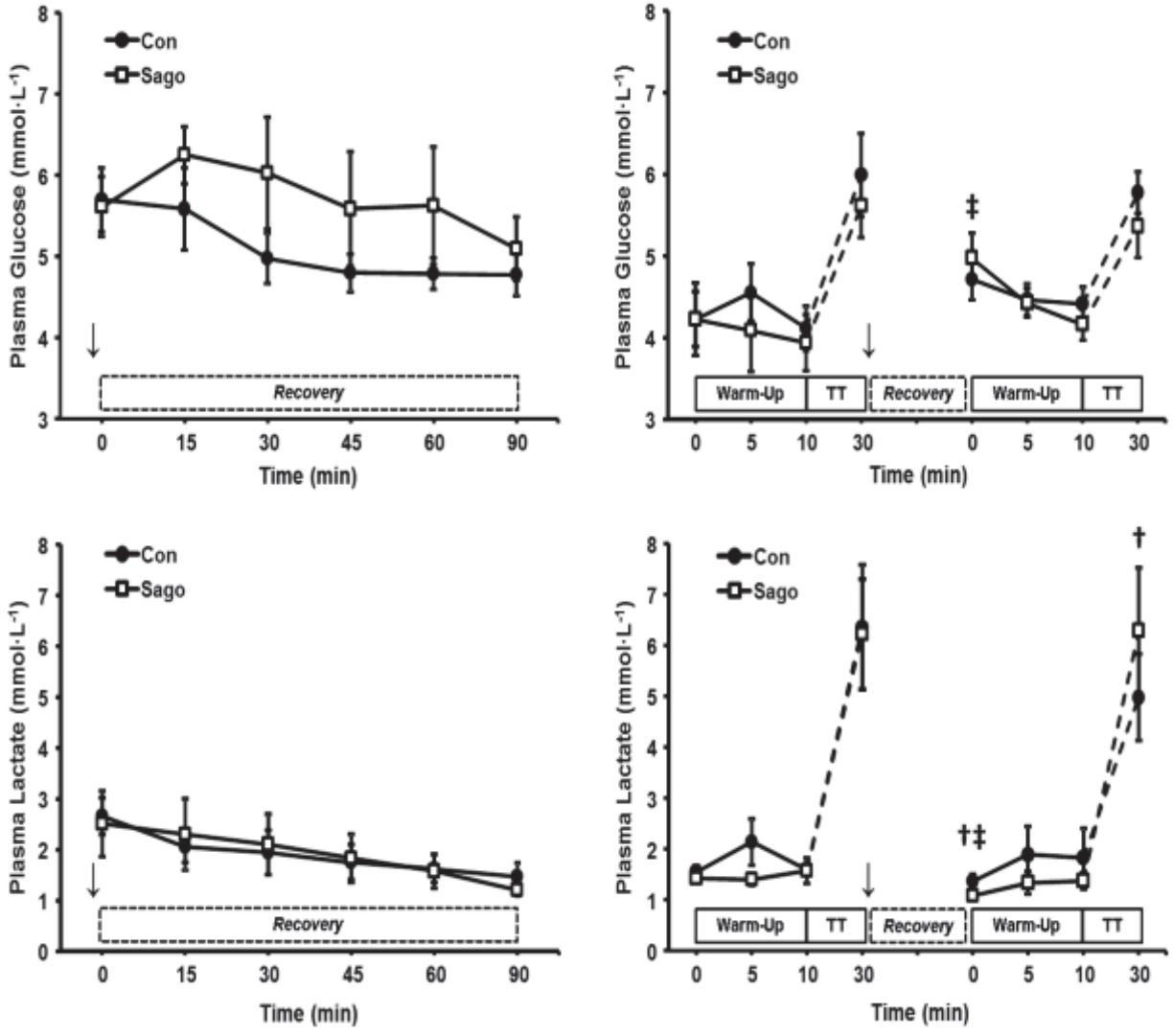

Figure 7. 3: Plasma glucose and lactate concentrations during recovery (left panels) and Exercise 1 and 2 (right panels) for Control and Sago trials. TT: 15-min time-trial. Arrow indicates Sago ingestion. Data are expressed as mean ± SE. ‡ indicates significantly different to corresponding Exercise 1 time-point. † indicates significantly different to Con at that time-point.

Table 7. 1: Carbohydrate and fat oxidation rates (g/min) and RER during warm-up/ steady-state exercise.

	Time (min)					
	Exercise 1			Exercise 2		
	5	**10**	**15**	**5**	**10**	**15**
Carbohydrate						
Control	1.1 ± 0.4	2.2 ± 0.7*	2.6 ± 0.5*	0.8 ± 0.7	1.7 ± 0.6*	2.3 ± 1.0*#
Sago	1.2 ± 0.4	2.2 ± 0.7*	2.3 ± 1.1*	1.3 ± 0.5	1.6 ± 0.6	2.0 ± 0.6
Fat						
Control	0.6 ± 0.2	0.5 ± 0.3	0.6 ± 0.2	0.7 ± 0.4	0.6 ± 0.3	0.7 ± 0.5
Sago	0.6 ± 0.3	0.5 ± 0.3	0.7 ± 0.5	0.5 ± 0.3	0.7 ± 0.3	0.8 ± 0.3
RER						
Control	0.87 ± 0.03	0.88 ± 0.04	0.91 ± 0.05*	0.83 ± 0.03	0.85 ± 0.04	0.87 ± 0.04*
Sago	0.86 ± 0.05	0.90 ± 0.05*	0.92 ± 0.06*	0.87 ± 0.05	0.87 ± 0.04	0.89 ± 0.05*#

Data are presented as mean ± SE; *N* = 8; * denotes different to 5 min; # denotes different to 10 min.

7.4.3 Thermoregulatory Responses

The rectal and mean skin temperatures can be seen in *Figure 7.4*. A main effect of time was observed for rectal temperature ($P < 0.05$) such that values increased progressively at each time point. Therefore, representative values were: start (Control: 37.1 ± 0.4, Sago: 37.0 ± 0.5°C) and end (Control: 38.3 ± 0.4, Sago: 38.0 ± 0.3°C) of Exercise 1, and start (Control: 36.9 ± 0.4, Sago: 37.0 ± 0.4°C) and end of Exercise 2 (Control: 38.2 ± 0.3, Sago: 38.4 ± 0.3°C). Main effects of time and time*trial were observed for mean skin temperature (both $P < 0.05$) although no effect of the exercise bout was observed i.e. Exercise 1 vs. Exercise 2. During both exercise bouts and both Control and Sago, values increased progressively until 15 minutes, plateauing thereafter. Therefore, representative values were: start (Control: 32.4 ± 0.7, Sago: 32.1 ± 1.2°C) and 15 min (Control: 33.2 ± 1.0, Sago: 33.1 ± 1.1°C) during Exercise 1, and start (Control: 32.5 ± 0.6, Sago: 32.3 ± 1.0°C) and 15 min during Exercise 2 (Control: 33.3 ± 0.9, Sago: 33.1 ± 1.1°C).

There was no difference in the volume of water consumed (0.48 ± 0.26 L) or sweat lost (0.93 ± 0.23 L) during exercise between trials or exercise bouts (both $P > 0.05$), which resulted in a fluid deficit of 0.45 ± 0.36 L (0.6 ± 0.4% of body mass) by the end of exercise. This was, however, restored with water consumption during the recovery period as pre-exercise body weight was similar ($P > 0.05$) between Exercise 1 and 2 (77.9 ± 15.0 vs. 78.4 ± 15.0 kg).

A main effect of time only ($P < 0.05$) was observed for plasma concentrations of sodium and potassium, such that concentrations increased from start (sodium: 133 ± 2 mmol/L, potassium: 4.2 ± 0.1 mmol/L) to end (sodium: 138 ± 2 mmol/L, potassium: 4.9 ± 0.1 mmol/L) of Exercise 1. Concentrations then decreased and returned to resting levels mid-way during the recovery period (sodium: 133 ± 3 mmol/L, potassium: 4.3 ± 0.1 mmol/L) before increasing again from start (sodium: 134 ± 2 mmol/L, potassium: 4.3 ± 0.1 mmol/L) to end (sodium: 135 ± 2 mmol/L, potassium: 4.7 ± 0.1 mmol/L) of Exercise 2.

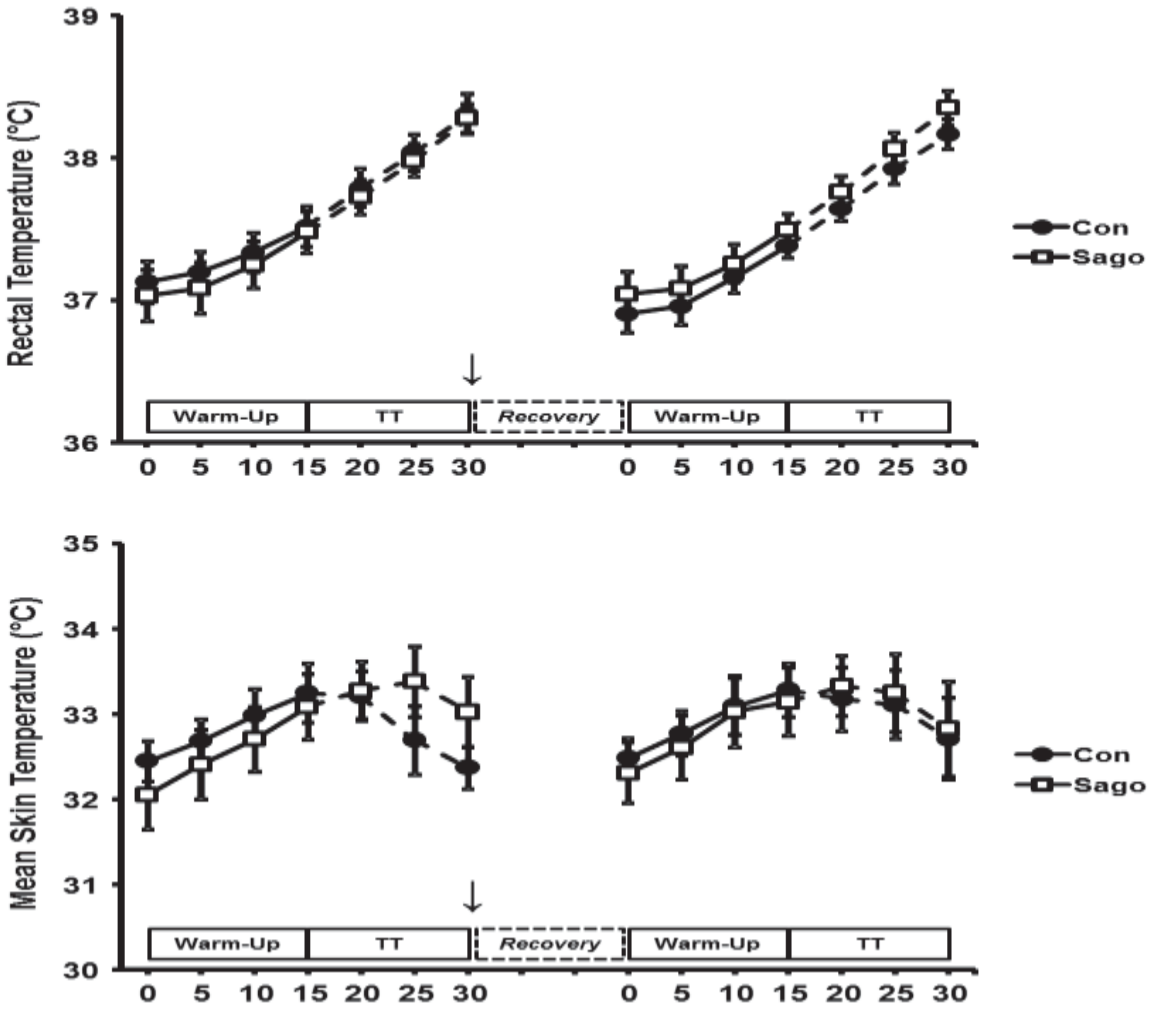

Figure 7. 4: Rectal and mean skin temperatures during Exercise 1 and 2 for Control and Sago trials. TT: 15-min time-trial. Arrow indicates Sago ingestion. Data are expressed as mean ± SE.

7.4.4 Cardiorespiratory Responses

During the warm-up stages, participants were exercising at an intensity eliciting 40 ± 6, 52 ± 6 and 63 ± 8% VO_2peak ($P < 0.05$) with no effects of trial or exercise bout (both $P > 0.05$). Similarly, an effect of time but not trial or exercise bout was observed for ventilation such that values increased ($P < 0.05$) from 38 ± 5 to 50 ± 5 and 59 ± 10 L/min during the warm-up stages, respectively. Finally, an effect of time, time*trial and exercise bout (all $P < 0.05$) was observed for heart rate such that

values increased progressively throughout exercise from 71 ± 4 bpm at rest to 143 ± 5 bpm at the end of the warm-up and 174 ± 4 bpm at the end of the time-trial, respectively, with values during Exercise 2 being 3 ± 1 bpm higher than Exercise 1.

7.5 DISCUSSION

This is the first study to determine whether sago, a starch staple found across Southeast Asia and prepared through boiling pearls into porridge, influences cycling performance after recovering from an exercise bout 2h previous under conditions that simulate a tropical environment. The main finding is that feeding sago after such exercise maintains performance and thus enhances recovery compared to a control and this is likely due to the enhanced supply of exogenous carbohydrate. Furthermore, in **Chapter 5** (*Study B*) this protocol under these conditions was found to be highly reliable (a test-retest coefficient of variation of 2.3%), therefore it can be said with confidence that the observed differences in time-trial performance in this chapter (3.7 and 3.9%) are real.

For athletes training or competing multiple times daily or on successive days (i.e. <24h recovery between exercise bouts) the consensus recommendation for post-exercise CHO consumption (meal/snack) is 0.8-1.0 g per kilo bodyweight per hour within 30 minutes of exercise cessation (Rodriguez *et al.*, 2009a). However, these recommendations are based on rates of skeletal muscle glycogen re-synthesis, not exercise performance, and do take into consideration the possible additive effect of a hot ambient environment (Jentjens *et al.*, 2006). Therefore, when making recommendations based on performance of a repeated exercise bout (usually following a 4-h recovery within the literature) it appears that exercise performance is

enhanced when a bolus of CHO (≥ 50g) is consumed within 30 minutes of exercise cessation above rehydration alone (Fallowfield *et al.*, 1995; Wong, Williams & Adams, 2000) but that a bolus (Fallowfield & Williams, 1997) or serial feeding (Wong & Williams, 2000) with greater CHO content confers no additional performance benefit; additionally, the form (e.g. liquid vs. solid) that the CHO takes has no effect (Keizer, Kuipers, Van Kranenburg & Geurten, 1987). Thus, our observations of an improved performance following recovery from a previous exercise bout having consumed ~60g CHO supports previous studies and extends the available literature i) as the exercise was performed under conditions of humid heat, ii) was performed using a more face-valid self-paced (cf. fixed-intensity endurance) model, iii) the recovery period was only 2h (cf. 4h), and iv) the CHO source was a palatable whole food (cf. CHO-electrolyte solution) that is easily sourced across Southeast Asia.

The mechanisms responsible for this performance maintenance (from Exercise 1) and improvement (from Control) with sago almost certainly concern an enhanced, or at least maintained, supply of CHO within the system as demonstrated by a higher than resting blood glucose for longer during recovery (*Figure 7.3* upper left panel), elevated blood glucose at the start of Exercise 2 compared to Exercise 1 (*Figure 7.3* upper right panel), and greater blood lactate upon completion of the time-trial with Sago (*Figure 7.3* lower left panel). Unfortunately, it was beyond the resources of the current study to be able to partition the source of this CHO i.e. exogenous vs. endogenous (hepatic vs. muscular vs. circulating), however this would be valuable in future investigations. That we observed no differences between exercise bouts or trials for substrate oxidation (*Table 7.1*) indicates no 'real' effect of repeated exercise or this CHO intervention, a lack of sensitivity with this measure or perhaps that an assumption of the methodology has been violated, for example gluconeogenesis (Frayn, 1983; Jeukendrup & Wallis, 2005); the former may be as a

result of the additional “stress” that ambient heat presents to hepatic glucose output (Hargreaves *et al.*, 1996; Angus *et al.*, 2001). It is also possible that improved CHO status has a central ergogenic effect that is not related to or detectable by whole body (indirect) calorimetry.

As far as the timing of ingestion is concerned, whether consumed before or during (**Chapter 6**), or following exercise (this chapter), sago exerts no detrimental effects (beyond an elevated heart rate of ~5 bpm likely related to the additional digestive load) but is associated with increased fluid retention and an attenuated rise of rectal temperature, and in the current chapter with an improved exercise performance.

The primary aim with the current chapter was to identify whether there was any benefit of supplementing sago during recovery from exercise, therefore we used a control condition where nothing was consumed other than water to maintain similar levels of hydration. This was performed in order to compare these results with those of the previous chapter (**Chapter 6**). The next logical step would be to assess sago against a suitable and known whole-food (e.g. pasta) or CHO-electrolyte fluid to determine relative efficacy, as it has previously been shown that a solution high in waxy starch for 12h following glycogen-depleting exercise restores muscle glycogen and influences work completed in a subsequent 30-min time-trial similarly as equicaloric solutions with glucose or maltodextrin (Jozsi *et al.*, 1996). Including a whole-food or fluid placebo would also be worthwhile, as a placebo effect has been demonstrated previously with CHO (Clark, Hopkins, Hawley & Burke, 2000), something that cannot be determined in the present study.

In summary, the present chapter has shown that consuming 0.8 g per kilo bodyweight cooked sago porridge upon completion of an initial exercise bout

confers a performance advantage during a second exercise bout following a 2 h recovery when compared to a control condition.

CHAPTER EIGHT

8.0 General Discussion

This chapter will discuss the results of the experimental chapters (**Chapters 5, 6** and **7**) in relation to the thesis aims and hypotheses outlined in **Chapter 3**, detail considerations appraising the limitations, provide future direction for research avenues, and also make conclusions. As specific discussion pertinent to each experimental chapter has already occurred, repetition will be minimised.

The purpose of this thesis was to investigate sago starch, found and used across parts of tropical Southeast Asia: a) if it's use conferred a performance and/or physiological benefit whilst cycling in a warm-humid environment (General Aim I); b) whether it's efficacy (as a nutritional ergogenic aid) was apparent as a "top-up" before, a supplement during, or recovery from exercise (General Aim II).

It is clear that sago meals, a Malaysian CHO source, are safe to be consumed before, during and after exercise. It was unfortunate that this work could not include further details on the economics of development raw sago and producing (commercial) a supplement as an alternative to 'Western' dietary supplements commonly available on the market (e.g. CHO-electrolyte solutions). Due to this limitation, this work cannot conclusively assert that a (basic) cooked meal of sago is indeed a 'cheaper' local alternative.

8.1 General Aim I

General Aim I first involved developing two cycling protocols and establishing their sensitivity/reliability with the intended sample population completing these protocols under standardized conditions of diet and exercise (**Chapter 5**, *Study A* and *B*), in order to collect both meaningful physiological (steady-state) and performance (time-trial) data in the ensuing intervention studies (**Chapters 6** and **7**). Subsequently, sago porridge and gel was prepared according to local/traditional Malaysian methods and supplemented to determine whether exercise physiology and/or performance was enhanced when compared to a control condition (**Chapters 6** and **7**). It was found that both cycling protocols were highly reliable (i.e. CV ≤5% for performance and physiological variables), comparable to other studies and that heat stress did not affect this reliability (**Chapter 5**). Knowing the typical error, it was found that supplementing sago porridge and gel conferred some physiological advantage, but whilst no detriment was found performance benefits were inconsistent (**Chapters 6** and **7**).

8.2 General Aim II

Chapters 6 and 7 attempted to expand further on General Aim I by investigating supplement timing. Specifically, sago supplementation before, during and in recovery from exercise were compared to water-only control trials. It was found that: i) supplementing sago porridge before exercise attenuated the rise in core temperature but did not influence performance; ii) supplementing sago gel during exercise reduced plasma volume contraction through reduced whole-body sweating, with a higher plasma sodium concentration although again performance remained unchanged; and iii) supplementing sago porridge following exercise maintained

subsequent performance, thereby enhancing recovery when compared to a non-caloric condition.

8.3 Hypotheses

Following the General Aims**,** specific (alternative) hypotheses were tested in the experimental studies of this thesis and the null hypothesis either accepted or rejected.

Specific Hypotheses:

1. The amount of work completed (kJ) within the 15-min time-trials *was* reliable and sensitive (i.e. a coefficient of variation <5%) when performing a test-retest (**Chapter 5**). *Null hypothesis rejected, alternative hypothesis accepted.*
2.
    a. The metabolic response (blood glucose) to sago porridge at rest *was* (**Chapter 6**) appropriately higher than a control. *Null hypothesis rejected, alternative hypothesis accepted.*
    b. The metabolic response (blood glucose) to sago porridge at rest *was not* (**Chapter 7**) appropriately higher than a control. *Null hypothesis accepted, alternative hypothesis rejected.*
3.
    c. Sago supplementation *did not* improve work completed during the 15-min time-trial above the typical error and when compared to a control (**Chapter 6**). *Null hypothesis accepted, alternative hypothesis rejected.*
    d. Sago supplementation *did* improve work completed during the 15-min time-trial above the typical error and when compared to a control (**Chapters 7**). *Null hypothesis rejected, alternative hypothesis accepted.*

4. The timing of sago supplementation ***did*** influence the ergogenic effect (**Chapters 6** and **7**). *Null hypothesis rejected, alternative hypothesis accepted.*
5. Sago supplementation ***did*** influence the physiological responses to exercise when compared to a control (Chapters 6 and 7). *Null hypothesis rejected, alternative hypothesis accepted.*

8.4 Recommendation for Future Research

The present series of studies has been successful in extrapolating these initial findings to a trained population and under ambient conditions that mimic those of tropical Southeast Asia. Nonetheless, when attempting to generalise these results further consideration must be given to some of the limitations of the current research and hence what future research is warranted, as discussed below.

As discussed briefly in **Chapters 6** and **7** (Discussions), the strongest limitation of this work lies in the potential for a placebo effect, especially as there was no specific blinding of participants with their sago meals. However, this was discussed *a priori* and due to the strict experimental controls used the choice was to thoroughly investigate the timing of ingestion or efficacy of CHO intervention; the former was chosen. This work was also limited by the absence of a calorie-matched 'control' as in the first instance hydration was maintained constant (water-only control) instead. As the standardised diet was not scaled to body mass, participants with very large body mass and different energy requirements may have been 'underfed' and this could have influenced some results; however, as can be seen from *Table 4.1* this was likely the case in less than a quarter of participants. Furthermore, as no measure of (muscle) glycogen was made any of our discussion remains speculative

and we cannot assert that sago (in)directly influenced endogenous CHO stores, or that this contributed to the results observed. It is also recommended that subsequent investigations into acute exercise measure stress markers such as the hormonal response, something that was beyond the time and financial constraints of this work.

Whilst the studies herein were completed using a widely-used Malaysian starch and in warm-humid conditions akin to the tropical Malaysian climate, participants were residents of New Zealand and thus not heat-adapted as would likely be the case with those completing exercise regularly outdoors in Malaysia or indoors without air-conditioning. As acclimation to heat influences the metabolic (and thermoregulatory) response to exercise (Febbraio *et al.*, 1994b) it is unknown whether supplementing sago to those regularly completing (thus heat-adapted) exercise in a tropical climate, such as Malaysia, would yield similar results. Equally, the mode of exercise chosen within this thesis (cycle-ergometry) cannot necessarily be extrapolated to that of (treadmill) running as gastro-intestinal distress due to supplementation of carbohydrate occurs more frequently and lasts for longer with running (Peters, van Schelven, Verstappen, de Boer, Bol, Erich, van der Togt & de Vries, 1993); with hindsight, it is unfortunate that no data on gastro-intestinal distress/comfort was collected in the present thesis. Both of these avenues warrant further research.

Only one previous study had developed and demonstrated reliability of a cycling protocol with heat stress (Marino *et al.*, 2002) similar in duration to the "gold-standard" hour time-trial, (Jeukendrup *et al.*, 1996), however, as this was entirely self-paced in nature it does not provide a fixed-intensity component (pre-load) to reliably assess physiological responses such as demonstrated by Jeukendrup et al., (1996). Therefore, the two studies that formed **Chapter 5** sought to develop

protocols that were appropriate for collection of both fixed-intensity physiological and self-paced performance data. Consideration was given, and pilot testing demonstrated limitations with protocols in the heat as specific combinations of intensity and duration made it unrealistic to complete without premature fatigue (due to thermal strain). Therefore, a protocol lasting 60 (**Chapter 6**) and 30 (**Chapter 7**) minutes was developed, the latter reflecting further concern on full recovery within 2h in order to repeat the test. It has been suggested that when exercise heat stress is compensable, and the thermoregulatory system is not necessarily the primary limiting factor, endogenous carbohydrate stores become further depleted and that exogenous supplementation may be more effective (Febbraio, 2001). As can be seen in the continual rise in rectal temperature during *Study A* and *B* of **Chapter 5**, the combination of exercise intensity and ambient heat stress was uncompensable, most likely a result of the high(er) ambient humidity. Therefore, future studies should investigate sago supplementation during more compensable heat stress i.e. lower-intensity, longer-duration exercise and/or lower-humidity environments, as ingestion of other CHO sources have been shown to be ergogenic in these conditions e.g. Carter *et al.* (2003).

Numerous studies, reviewed carefully by Cermak & van Loon (2013), and the consensus position statement by the ACSM (Rodriguez *et al.*, 2009b) recommend that for endurance athletes protein (or amino acid) ingestion should be consumed 'near' to exercise in order for maintenance of or enhancing gains in skeletal muscle. Whilst there is some evidence that adding protein to carbohydrate during exercise enhances performance (Stearns, Emmanuel, Volek & Casa, 2010) and recovery (Richardson, Coburn, Beam & Brown, 2012), there is stronger evidence that adding protein to carbohydrate in recovery from exercise enhances muscle repair and a more anabolic hormonal profile (Rodriguez *et al.*, 2009b). In fact, Ghosh et al.,

(2010) observed a significant improvement in time to exhaustion following sago-soy supplementation than sago alone or placebo although these results may have been due to a greater overall caloric content. Nevertheless, it would be worthwhile in determining whether iso-caloric supplementation of sago-soy (or other suitable protein) enhances performance and/or the hormonal profile during and in recovery from exercise when compared to sago alone. Equally, as the form of carbohydrate provided does not alter the ergogenic effect (Cermak & van Loon, 2013) and taking into consideration the need for athletes exercising in hot (especially humid) environments to prevent dehydration, there is merit in developing sago into a soluble form (perhaps with added sodium/potassium) that can consumed in place of existing commercially-available carbohydrate-electrolyte drinks/powders.

8.5 Conclusion

The purpose of this thesis was to investigate if supplementation of sago starch conferred a performance and/or physiological benefit whilst cycling in a warm-humid environment and whether the timing of supplementation was of importance when compared with a water-only control. This was determined by completing four studies, grouped into three chapters, where first appropriately reliable protocols were developed (**Chapter 5**, *Study A* and *B*) to then test the supplementation before, during (**Chapter 6**) and in recovery (**Chapter 7**) from exercise. Accordingly, from the studies presented as part of this thesis it can be concluded that:

1. The amount of work completed (kJ) within a 15-min time-trial is **highly reliable** when performing a test-retest in conditions of significant thermal stress, whether pre-loaded by a 45-min (CV = 3.6%) or 15-min (CV = 2.3%)

period of fixed-intensity cycling. This is comparably reliable to protocols without heat stress.

2. The physiological responses to exercise are also **very reliable** when performing a test-retest in conditions of significant thermal stress, whether pre-loaded by a 45-min (CV = 2.4-4.1%) or 15-min (CV = 2.9-5.2%) period of fixed-intensity cycling.
3. The glycaemic response (blood glucose dynamics) to ingesting sago porridge at rest *before* exercise is **higher** than a water-only control.
4. The glycaemic response to ingesting sago porridge at rest *following* exercise is **not higher** than a water-only control.
5. Supplementing sago porridge *before* exercise **does not improve** work completed during the 15-min time-trial above the typical error and when compared to a water-only control.
6. Supplementing sago gel *during* exercise **does not improve** work completed during the 15-min time-trial above the typical error and when compared to a water-only control.
7. Supplementing sago porridge *in recovery* from exercise **does improve** subsequent work completed during the 15-min time-trial above the typical error and when compared to a water-only control.
8. Supplementing sago porridge *before* exercise **attenuates the rise in rectal temperature** during exercise when compared to a water-only control.
9. Supplementing sago gel *during* exercise **reduces plasma volume contraction** through reduced whole-body sweating, with a higher plasma sodium concentration when compared to a water-only control.
10. Supplementing sago porridge *in recovery* from exercise **does not influence physiological responses** during subsequent exercise when compared to a water-only control.

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APPENDIX A

Statement of Contribution

Chapter Two

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Name/Title of Principal Supervisor: Dr Toby Mundel

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Name/Title of Principal Supervisor: Dr Toby Mundel

Name of Published Research Output and full reference:

Physiologic and performance effects of sago supplementation before and during cycling in a warm-humid environment

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Name of Candidate: Che Jusoh, Mohd Rahimi

Name/Title of Principal Supervisor: Dr Toby Mundel

Name of Published Research Output and full reference:

Sago supplementation for recovery from cycling in a warm-humid environment and its influence on subsequent cycling physiology and performance

In which Chapter is the Published Work: Chapter Seven

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Date

GRS Version 3– 16 September 2011

APPENDIX B

Published Papers

Chapter Two

TEMPERATURE
2016, VOL. 3, NO. 3, 1–10
http://dx.doi.org/10.1080/23328940.2016.1211072

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PRIORITY REVIEW

OPEN ACCESS

Sago supplementation for exercise performed in a thermally stressful environment: Rationale, efficacy and opportunity

Mohd Rahimi Che Jusoh, Stephen R. Stannard, and Toby Mündel

School of Sport and Exercise, Massey University, Palmerston North, New Zealand

ABSTRACT

Sago (*Metroxylin sagu*), a carbohydrate (CHO) based dietary staple of Southeast Asia is easily digestible and quickly absorbed, and thus has potential to be prescribed as an affordable pre-and post-exercise food in this part of the world. Compared to other CHO staples, research into the physiological response to sago ingestion is sparse, and only a few recent studies have investigated its value before, during, and after exercise. The purpose of this review is to describe the published literature pertaining to sago, particularly as a supplement in the peri-exercise period, and suggest further avenues of research, principally in an environment/climate which would be experienced in Southeast Asia i.e. hot/humid.

ARTICLE HISTORY
Received 9 May 2016
Revised 30 June 2016
Accepted 2 July 2016

KEYWORDS
Carbohydrate; Cycling; Heat; Physiology; Performance; Recovery; Southeast Asia; Starch; Tropical

Introduction

The relationship between reduced carbohydrate (CHO) status and the onset of fatigue has been known for some time.[1] Specifically, the progressive depletion of skeletal muscle's limited glycogen stores and reduction in circulating blood glucose as exercise progresses are linked to performance deterioration and volitional fatigue.[2] It follows that supplementing CHO can delay the onset of fatigue and improve work output and capacity.[3] The right combination of an appropriate CHO composition and administration regimen can potentiate this ergogenic effect; [4] hence, for example, the consensus prescription of CHO before, during and after exercise to maximise performance and optimise recovery.[5]

Many major sporting events take place during the hottest season, in warm-to-hot environments/climates or at the hottest part of a day.[6] During exercise with heat stress, there is consensus that endurance performance is decreased compared with cooler conditions, and there is an increased risk of heat illness, especially with high humidity.[7] Another consequence of exercise heat stress is an alteration in CHO metabolism. Yaspelkis and Ivy[8] demonstrated that exercise in the heat accelerated fatigue because of an increase in reliance upon CHO as a substrate. Further, Jentjens and Jeukendrup[9] demonstrated that when ambient temperatures increase so does CHO oxidation rate during exercise largely due to an increased muscle glycogen use. This led the same authors[10] to suggest that glycogen stores may be sub-optimal in athletes training or competing multiple times daily or on successive days in hot environments. Accordingly, the accepted paradigm is that increasing CHO availability before and during exercise can enhance performance when exercise is completed in the heat, even for shorter (<1 h), more intense (~80% $\dot{V}O_2$max) bouts (see refs. 11,12).

The hot/humid environment awaiting athletes at the upcoming 2016 Summer Olympics in Rio de Janeiro, the 2018 Commonwealth Games on the Gold Coast and the 2022 Soccer World Cup in Qatar, requires athletes and their support teams to take these environmental conditions into consideration for best preparation. Furthermore, at least a third of the world's population now live in the Tropical Zone, close to the equator where ambient temperatures are hotter and more physically challenging than in the Temperate or Frigid Zones.[13] Therefore optimisation of physical work capacity in the tropics requires understanding the risks and ways in which these can be minimised. These include best practice nutrition and hydration in the peri-event period.

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Published Papers

Chapter Five

Scand J Med Sci Sports 2015: 25 (Suppl. 3): 296–302
doi: 10.1111/sms.12332

SCANDINAVIAN JOURNAL OF MEDICINE & SCIENCE IN SPORTS

A reliable preloaded cycling time trial for use in conditions of significant thermal stress

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Accepted for publication 4 September 2014

The purpose of this study was to assess the reliability of a 15-min time trial preloaded with 45 min of fixed-intensity cycling under laboratory conditions of thermal stress. Eight trained cyclists/triathletes (41 ± 10 years, VO_2peak: 69 ± 8 mL/kg/min, peak aerobic power: 391 ± 72 W) completed three trials (the first a familiartzation) where they cycled at ~ 55% VO_2peak for 45 min followed by a 15-min time trial (~75% VO_2peak) under conditions of significant thermal stress (WBGT: 26.7 ± 0.8 °C, frontal convective airflow: 20 km/h). Seven days separated the trials, which were conducted at the same time of day following 24 h of exercise and dietary control. Reliability increased when a familiartzation trial was performed, with the resulting coefficient of variation and intraclass correlation coefficient of the work completed during the 15-min time trial, 3.6% and 0.96, respectively. Therefore, these results demonstrate a high level of reliability for a 15-min cycling time trial following a 45-min preload when performed under laboratory conditions of significant thermal stress using trained cyclists/triathletes.

Performance is one of the most common outcome measures within the exercise sciences and often used to assess the efficacy of treatment effects, such as training programs and a number of possible ergogenic aids (nutritional, pharmacological, physiological, etc.). When performance is measured, it is necessary to know the reliability of such a test, as lack of this knowledge might result in wrongfully concluding no difference because of high test variability or intra-/inter-subject variation. Therefore, knowledge of the typical variance associated with a performance test used on a certain sample under those (often laboratory) conditions allows for a more informed decision on the magnitude of a treatment effect. Another of the advantages of using laboratory protocols and equipment that display low variation (high reliability) is that "real" differences can be determined with realistically small sample sizes, especially when concurrent with lifestyle standardization (e.g., diet, exercise, time of day, etc.) and a within-subject design.

Traditionally, submaximal exercise capacity tests using an ergometer have been used to cycle at a fixed percentage of maximal workload (W_{max})/O_2 uptake (VO_{2max}) to volitional exhaustion (or a predetermined marker thereof). Such tests have largely been used to give basic/mechanistic data during a physiological steady state; however, their face validity is poor. Furthermore, such tests have usually yielded a high level of variability even when using trained participants. For example, Jeukendrup et al. (1996) observed a test-retest coefficient of variation (CV, a common measure reporting the within-subject variation expressed as a percentage of the mean) of ~27% using trained cyclists/triathletes when they cycled to exhaustion at 75% W_{max}; they argued that "open-ended" tests are influenced more heavily by psychological factors such as motivation and boredom. In contrast to these fixed-intensity capacity tests, protocols that have a known end point (time trial) and allow participants to alter their intensity – often according to a pacing strategy – not only have greater face validity but also display a greater test-retest reliability. In the same study, Jeukendrup et al. (1996) observed a CV of 3.4% when participants were allowed to complete a set amount of work (based on 1 h at 75% W_{max}) that was self-paced. Variations on the time trial protocol have included sprints within a protocol (e.g., Marino et al., 2002) and a "preload" of fixed-intensity cycling preceding the time trial (e.g., Jeukendrup et al., 1996). The latter, in particular, allows data (perceptual/physiological) to be collected to further determine the efficacy of an intervention to complement a performance measure, with Jeukendrup et al. (1996) having observed a similarly reliable CV (3.5%) when participants cycled for 45 min at 70% W_{max} followed by as much work completed as possible within the 15-min time trial.

Many competitive sporting events take place during the warmer summer months or in climates that considerably exceed the typical laboratory ambient thermal profile (20 °C and 50% relative humidity) used while

Published Papers

Chapter Six

TEMPERATURE
2016, VOL. 3, NO. 2, 318–327
http://dx.doi.org/10.1080/23328940.2016.1159772

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RESEARCH PAPER

OPEN ACCESS

Physiologic and performance effects of sago supplementation before and during cycling in a warm-humid environment

Mohd Rahimi Che Jusoh, Stephen R. Stannard, and Toby Mündel

School of Sport and Exercise, Massey University, Palmerston North, New Zealand

ABSTRACT

The present study determined whether 0.8g/kg bodyweight sago ingested before (Pre-Sago) or during (Dur-Sago) exercise under warm-humid conditions (30 ± 2°C, 78 ± 3 % RH; 20 km·h^{-1} frontal airflow) conferred a performance and/or physiological benefit compared to a control (Control) condition. Eight trained, male cyclists/triathletes (45 ± 4 y, VO_2peak: 65 ± 10 ml·kg^{-1}·min^{-1}, peak aerobic power: 397 ± 71 W) completed 3 15-min time-trials (~75% VO_2peak) pre-loaded with 45 min of steady-state (~55% VO_2peak) cycling following > 24 h standardization of training and diet. Measures of work completed, rectal and mean skin temperatures, heart rate, expiratory gases and venous blood samples were taken. Compared to Control, Pre-Sago resulted in a smaller rise in rectal temperature (0.3 ± 0.5°C) while heart rate increased to a greater extent (6 ± 13 beats·min^{-1}) during exercise (both $P < 0.05$), however, compared to Control time-trial performance remained unaffected (Pre-Sago: −0.5 ± 4.0%, $P > 0.05$). During exercise, plasma glucose concentrations were maintained higher for Dur-Sago than Control ($P < 0.05$), however substrate oxidation rates remained similar ($P > 0.05$). Dur-Sago also resulted in a higher plasma sodium concentration (2 ± 2 mmol·l^{-1}) and lower whole-body sweat loss (544 ± 636 g) and, therefore, reduced plasma volume contraction (all $P < 0.05$). Heart rate increased to a greater extent (5 ± 13 beats·min^{-1}) during Dur-Sago, yet compared to Control time-trial performance remained unaffected (+0.9 ± 2.3%, $P > 0.05$). Uniquely, these results indicate that during exercise heat stress feeding sago can result in some 'beneficial' physiological responses, however these do not translate to changes in exercise performance when performed in a post-prandial state.

ARTICLE HISTORY
Received 4 February 2016
Revised 24 February 2016
Accepted 25 February 2016

KEYWORDS
exercise; malaysia; starch; tropical heat

Introduction

Consuming carbohydrate (CHO) before and/or during prolonged exercise can delay the onset of fatigue and improve work output and capacity.[1] The main goals for CHO supplementation are to fill skeletal muscle and liver glycogen stores prior to exercise and to provide exogenous glucose during prolonged exercise; the latter to partly offset skeletal muscle and central nervous system CHO requirements when glycogen stores run low. The combination of an appropriate CHO composition and administration regimen can subsequently deliver major benefits to endurance sport performance; [2] hence the prescriptive use of CHO-containing sports drinks.[3]

Glycogen takes some hours to form following CHO ingestion, and cannot be manufactured and stored while a muscle fiber is contracting. Thus, CHO ingestion in the hour before exercise practically provides the only opportunity to "top up" hepatic glycogen stores and maximize exogenous carbohydrate availability as exercise begins. The performance effects of CHO ingestion in the hour prior to exercise are varied but are generally positive despite an oft-seen transient hypoglycaemia as exercise begins.[4]

Many major sporting events take place during the summer, in warm environments or at the hottest part of a day.[5] During exercise with heat stress, there is consensus that performance is decreased and there is an increased risk of heat illness, especially with high humidity.[6] Heat stress during exercise also results in alterations in CHO metabolism. Febbraio[7] concluded that heat stress increases CHO and decreases fat utilization, while Jeukendrup[8] concurs that the ambient environmental conditions can affect substrate utilization at rest or during exercise. For example, Yaspelkis and Ivy[9] demonstrated that exercise in the heat accelerated fatigue because of an increase in reliance upon CHO as a substrate, while

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Published Papers

Chapter Seven

TEMPERATURE
2016, VOL. 3, NO. 3, 1–11
http://dx.doi.org/10.1080/23328940.2016.1179382

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RESEARCH PAPER

OPEN ACCESS

Sago supplementation for recovery from cycling in a warm-humid environment and its influence on subsequent cycling physiology and performance

Mohd Rahimi Che Jusoh, Stephen R. Stannard, and Toby Mündel

School of Sport and Exercise, Massey University, Palmerston North, New Zealand

ABSTRACT

This study determined whether sago porridge ingested immediately after exercise (Exercise 1) in warm-humid conditions (30 ± 1°C, 71 ± 4 % RH; 20 km·h^{-1} frontal airflow) conferred more rapid recovery, as measured by repeat performance (Exercise 2), compared to a control condition. Eight well-trained, male cyclists/triathletes (34 ± 9 y, VO_2peak 70 ± 10 ml·kg^{-1}·min^{-1}, peak aerobic power 413 ± 75 W) completed two 15-min time-trials pre-loaded with 15-min warm-up cycling following >24h standardization of training and diet. Mean power output was not different between trials during Exercise 1 (286 ± 67 vs. 281 ± 59 W), however, was reduced during Exercise 2 for control (274 ± 61 W) but not sago (283 ± 60 W) that led to a significant performance decrement (vs. Exercise 1) of 3.9% for control and an improvement (vs. control) of 3.7% for sago during Exercise 2 ($P < 0.05$). Sago ingestion was also associated with higher blood glucose concentrations during recovery compared to control. These results indicate that feeding sago during recovery from exercise in a warm-humid environment improves recovery of performance during a subsequent exercise bout when compared to a water-only control. As these effects were larger than the test-retest coefficient of variation for work completed during the 15-min time-trial (2.3%) it can be confidently concluded that the observed effects are real.

ARTICLE HISTORY
Received 24 March 2016
Revised 7 April 2016
Accepted 11 April 2016

KEYWORDS
exercise; heat stress; humidity; southeast Asia; starch

Introduction

The relationship between reduced carbohydrate (CHO) availability and the onset of fatigue has been known for some time.[1] Specifically, the progressive depletion of skeletal muscle's limited glycogen stores and reduction in circulating blood glucose as exercise progresses are linked to performance deterioration and volitional fatigue.[2] Following the cessation of exercise, muscle glycogen content can be restored to near pre-exercise levels within 24 hours provided adequate amounts of CHO are consumed,[3] however for athletes training or competing multiple times daily or on successive days it is ideal that glycogen stores be replenished more rapidly (see ref.[4]) to assist optimal rates of recovery. There exists a 'window of opportunity' as glycogen synthesis rates are at their highest during the first few hours following exercise when CHO is consumed.[5] Therefore, it follows that the consumption of CHO early in the post-exercise period can enhance performance in a subsequent bout of exercise;[6] hence the consensus prescription[7] of CHO as soon as practical post-exercise to maximise recovery between sessions. Furthermore, many competitive situations are such that only few hours separate the next bout of competitive effort, so it is important that the first CHO-containing meal is consumed as soon as possible after the initial bout, and is palatable enough to be ingested when often food intake is not desired.

Many major sporting events take place during the summer, in warm environments or at the hottest part of a day.[8] During exercise with heat stress, there is consensus that performance is decreased and there is an increased risk of heat illness, especially with high humidity.[9] Heat stress during exercise also results in alterations in CHO metabolism with Febbraio[10] concluding that heat stress increases CHO and decreases fat utilization. For example, Yaspelkis and Ivy[11] demonstrated that exercise in the heat accelerated fatigue

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Title of your thesis / dissertation	The Effects of Sago Supplementation for Exercise in a Hot- Humid Environment
Expected completion date	May 2016
Expected size (number of pages)	170
Requestor Location	Mohd Rahimi Che Jusoh Schoolof Sport and Exercise Massey University Palmerston North, New Zealand 4442 Attn: Mohd Rahimi Che Jusoh
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