UNIVERSITY
of
GLASGOW

The comparison of commercially available coconut water, sports drink and plain water on rehydration and potential benefit for endurance based performance.

Written project report, submitted in fulfillment of the requirements for the Postgraduate degree of Master of Science by Research in Physiology & Sport Science.

School of Life Science
College of Medical, Veterinary and Life Science
University of Glasgow

Name: **Andrew Leishman BSc (Hons)** Date: **August 2015**
0701022

Signed:

Contents

Acknowledgements

This project was funded by Freedom Brands Ltd, a Glasgow based company who market and sell the product Go Coco coconut water.

I would also like to thank Nairn Scobie and Lynsey Johnston for their time and technical assistance throughout this project.

Abstract

Dehydration, the loss of bodily water, results in reduced exercise performance. If athletes become dehydrated, rehydration is essential. Sports drinks are designed to provide fuel for the exercising athlete, and also to help with rehydration. A new alternative to commercial sports drinks is coconut water, which naturally contains electrolytes like potassium, magnesium, calcium and sodium, and natural sugars like glucose and fructose.

Our aim was to investigate whether coconut water could be used as a more effective rehydration beverage compared to a sports drink and plain water while using a 150% fluid replacement strategy. As a secondary aspect to the study we investigated whether there were any differences in rehydration capacity for individuals with differing aerobic fitness.

With institutional ethics approval, 16 subjects (22.9 ± 3.2 years; height 1.81 ± 0.06 m; body mass 75.8 ± 10.2 kg; $\dot{V}O_{2max}$ 3.98 ± 0.68 $l \cdot min^{-1}$) gave written, informed consent and performed a familiarisation and 3 experimental trials. Subjects exercised on a cycle ergometer (65% of peak work rate) in an environmental chamber (temperature 36.7 ± 0.9ºC, relative humidity 91.9 ± 21.2%) until 2-3% body mass was lost. For 2 hours post-exercise, subjects rehydrated to the equivalent of 150% of body mass lost using coconut water, a sports drink or plain water, administered in a randomised, double-blind crossover manner. In these 2 hours, subject's nude body mass, urine osmolality and blood glucose were monitored every 30 minutes. Subjects also completed a questionnaire at each 30 minute interval during rehydration.

No significant differences were seen between the fluids with regards to body mass regained during the rehydration phase, percentage rehydration or rehydration index. Significance was found in measurements of urine osmolality between coconut water and water at the end of the rehydration phase ($P < 0.05$), but not between coconut water and the sports drink. With blood glucose, there was a significantly different profile across time between water and the other two fluids.

Although the fitter individuals were found to be able to upregulate sweat rates compared to the less fit subjects, there was no difference found in the rehydration capacity of individuals with differing aerobic fitness levels. Interestingly, the fitter subjects reported feeling more sick throughout the rehydration phase while rehydrating with a sports drink compared to the less fit individuals, this was not seen when subjects rehydrated with coconut water.

No significant difference was found between coconut water and the sports drink for blood glucose response throughout the rehydration phase. Further research should therefore aim to investigate the potential use of coconut water during exercise to improve endurance performance.

There is no significant difference between Go Coco coconut water and a commercially available sports drink when comparing their ability to rehydrate following dehydrating exercise and that fitter individuals rated feeling more sick while consuming a sports drink compared to coconut water, it is recommended that the naturally occurring coconut water would make an ideal alternative to the manufactured sports drink.

List of Figures

List of Tables

List of Abbreviations

%Rehydration – Percentage Rehydration

ACSM – American College of Sports Medicine

ADH – Anti Diuretic Hormone

ANOVA – Analysis of Variance

CW – Coconut Water

KCl – Potassium Chloride

n – Number of Subjects

NaCl – Sodium Chloride

NATA – National Athletic Trainers Association

RER – Respiratory Exchange Ratio

RI – Rehydration Index

S – Sports Drink

SD – Standard Deviation

$\dot{V}CO_2$ – Carbon Dioxide Production

$\dot{V}O_2$ – Oxygen Uptake

$\dot{V}O_{2\ max}$ – Maximal Oxygen Uptake

W – Plain Water

Introduction

During exercise the requirement for fluid replacement has been a topic of much debate over the years. Opinions have differed and recommendations have often moved along a continuum from not drinking at all during exercise to drinking as much as is tolerable (Noakes, 2007). This is not a subject to be taken lightly as hydration can have detrimental effects on the health and performance of athletes. As little as a 2% loss in body mass during exercise can cause thermal stress, impaired cognitive function, impaired cardiovascular function and accelerated fatigue (Armstrong *et al*, 1985), all of which would impact on an athlete's health. Maughan and Leiper (1995) found that a loss of body mass, in excess of 2.5% can decrease the ability to exercise by as much as 15%, therefore severely inhibiting performance. Dehydration is more commonly seen amongst athletes, however at the other end of the scale, overdrinking can lead to more dangerous problems. The condition exercise-associated hyponatraemia can occur where there is a large decrease in the concentration of sodium within the plasma, it is too dilute, this creates an osmotic gradient and forces water into surrounding cells causing the cells to swell, disrupting cell functions and in extreme cases endanger life (Martini and Nath, 2009).

We have known for some time that dehydration, the loss of bodily water, results in a decrement in exercise performance. Sweat rates differ between individuals, which during exercise can be greater than 1 litre per hour (Costill *et al*, 1976), if this fluid loss is not replaced dehydration ensues. While exercising in warm climates, the need for the body to produce sweat is increased in order to maintain thermoregulation. If the body gets into a state of hyperthermia, exercise tolerance depreciates (Nielsen *et al* 1993). Furthermore, with increasing aerobic capacity the metabolic heat produced during exercise is also increased. Ichinose-Kuwahara *et al* (2010) found that fitter individuals (maximal aerobic capacity ≥ 55 $ml.kg^{-1}.min^{-1}$) had larger sweat rates when compared to less fit individuals (≤ 45 $ml.kg^{-1}.min^{-1}$). This transpires that professional athletes, who generate larger power outputs while they compete compared to recreational athletes, have increased heat production that requires greater sweat rates for cooling. This poses the question: can athletes upregulate their rehydration capacity?

Heavy sweating during exercise decreases the volume of extracellular fluid, temporarily increasing the sodium concentration. This is sensed by osmoreceptors that stimulate the release of anti-diuretic hormone (ADH), reducing water loss from the kidneys and stimulating a feeling of thirst. If plain water is then consumed, water receptors in the pharynx, as well as a decrease in the sodium concentration of extracellular fluid, suppress the release of ADH (Maughan, 1999 & Nose *et al*, 1988a). This drives water losses from the kidneys and reduces feelings of thirst (Gonzalez-Alonzo *et al*, 1992), extracellular fluid volume cannot be suitably restored with plain water.

As a result of dehydration and the reduction of extracellular fluid volume, there is a reduction in blood volume, which will play a key role in exercise capacity being diminished. The working muscles will continue to demand a high supply of blood flow in order to receive sufficient oxygen to fuel the exercise. However, the body also has a demand to increase blood flow to the skin to enable the body to dissipate some of its heat (Maughan, 1999), there must be a compromise.

It is therefore recommended that for endurance exercise, that lasts longer than 1 hour that carbohydrates and electrolytes should be added to the fluid. Commercially available sports drinks are advertised as the best fluid to consume, as they contain the electrolytes lost through sweating but also contain carbohydrates used to fuel exercise. Research has proven that such drinks can prevent dehydration and rehydrate better than water alone. Maughan and Leiper (1995) found that including sodium in a fluid for rehydration was more beneficial than when sodium was not present in the fluid. Further research in this field has suggested that also adding potassium to a rehydration solution has greater benefits than sodium alone (Nadel *et al*, 1990).

If suitable hydration strategies are followed during exercise then the body's fluid balance can be maintained. However, when this is not the case a rehydration strategy is essential. Rehydration, by definition, is the process of restoring lost water within the body. This process of returning the body's fluid balance following a period of dehydration is driven by regulatory responses to retain water and sodium within the kidney as well as behavioural changes to increase thirst. The choice of drink that is consumed for rehydration is often chosen independently due to personal preference, however at the moment this industry is dominated by manufactured drinks. There are now many different brands of sports drinks available on the market, all attracting worldwide consumption and due to the association of these products with their sporting heroes, children are being attracted to them, especially amongst young males. These drinks contain many additives including sweeteners, colourings and preservatives.

In a review by Beltrami *et al* (2008) the authors suggest that large drink brands are even beginning to influence fluid intake recommendations. Companies such as PepsiCo, who manufacture the popular sports drink ‘Gatorade’, supply funding to both the National Athletic Trainers Association (NATA) and the American College of Sports Medicine (ACSM). New peer reviewed scientific research in the field of hydration and rehydration may take months to be accepted and become available to those who need it most, athletes and practitioners within elite sport. However, the sports drink industry can produce new advertising campaigns and claims overnight that need no form of scientific proof in order to be published. These claims are within the public eye and could cause misguidedness among the general public.

In 1996 the ACSM published a Position Stand (Convertino *et al*, 1996) regarding exercise and fluid replacement. Their guidelines stated a generic recommendation for all, to match fluid replacement with the body mass lost during their activity. They have since updated their recommendations. In 2007 they published new guidelines (Sawka *et al*, 2007) that suggested more emphasis on individual hydration strategies, as well as increasing the volume of fluid replacement post-exercise to 1.5 litres of fluid for every kilogram of body mass lost during exercise.

An exciting new product, beginning to grow in worldwide popularity, which has the potential to provide benefits to sporting performance, is coconut water. Coconut water is the liquid found inside young, unripe, green coconuts. It naturally contains electrolytes such as potassium, magnesium, calcium and phosphorus, which is similar to the man-made sports drinks that also contain preservatives and artificial colours. A serving of coconut water contains a high concentration of potassium as well as other various nutrients, vitamins, amino acids, antioxidants, enzymes and minerals (Yong *et al*, 2009).

One of the benefits associated with coconut water that could be of greatest interest for the general public is its potential to reduce cholesterol levels as well as lower blood pressure. Research surrounding these effects is limited, therefore further studies would have to be completed before we have more confidence in these claims. However, research by Bhagya *et al* (2010) found that 3 weeks of feeding rats with coconut water resulted in the rats having significantly lower blood pressure and also reduced total cholesterol, triglycerides and free fatty acids. Manna *et al* (2014) reported that coconut water has large antioxidant properties that can help protect the body against various cancers.

Aragon-Vargas *et al* (2000) investigated what effect coconut water has on rehydration. Their study involved 3 trials, water, coconut water or a sports drink as means of rehydration. On average body mass was significantly lower at the end of the rehydration phase following the water trial compared to both coconut water and sports drink ($P < 0.05$). They concluded that the inability to return the body to euhydration within a warm, humid climate, was due to increased sweat output during the recovery period, in spite of ingestion of fluid equivalent to 125% of the original body mass lost during exercise. Their results showed that water was less effective at regaining bodily fluid compared to coconut water and a sports drink.

A recurring theme within previous research using coconut water is that studies appear underpowered, using very small subject numbers, therefore failing to find any real changes in variables. There is also a lack of research that use the current ACSM guidelines for fluid replacement, replacing 150% of the fluid lost during exercise instead using strategies that fall below these current recommendations. The aim of this study is to investigate the effect of commercially available coconut water, sports drink and plain water on rehydration using a 150% rehydration strategy. We hypothesise that coconut water will be as effective as a sports drink and would therefore be a more natural alternative rehydration aid.

Secondary, we aim to investigate whether differences in aerobic capacity can have significant effect on rehydration capacity.

Literature Review

Rehydration

The earliest study investigating the process of rehydration following exercise eliciting dehydration was carried out in the early 1970's. Costill and Sparks (1973) investigated 'Rapid fluid replacement following thermal dehydration'. 8 male subjects were dehydrated and then monitored during a rehydration phase on 3 separate occasions, which were randomised. The 3 different trials involved rehydrating with demineralised water, a glucose-electrolyte solution or no fluid at all. The subjects were dehydrated by sitting inactive in a heated environment (temperature 70^{o}C, relative humidity 9-12%), they were frequently weighed until a loss of 4% of their original body mass had been reached. After the body mass reductions were met, subjects sat in a cooler environment (23^{o}C) in order to cool down for 30 minutes. At this point subjects began to rehydrate with a volume equivalent to 7.7% of the body mass that had been lost during dehydration. This was repeated at 15 minute intervals for 3 hours until 13 boluses had been consumed and 100% of the body mass lost had been replaced. Before dehydration and at time 0, 30, 90 and 240 minutes of rehydration venous blood samples were taken so that blood, plasma and red cell volumes could be calculated. Haematocrit, haemoglobin, plasma protein and electrolyte as well as plasma osmolality were also assessed.

They found that following dehydration, plasma volume had decreased by 12% which was unable to be restored by the end of the 4 hour rehydration period in all trials. They concluded that this rapid fluid replacement was ineffective at restoring plasma volume and plasma osmolality.

Subjects could not tolerate the hot temperatures for long periods of time, generally found to be between 15-30 minutes. This meant that the subjects had to be placed in the heated environment intermittently for a duration between 2 and 4.5 hours until they could reach the 4% body mass reduction required in this study. This is a long time to ask of subjects to repeatedly enter this environment, considering a rehydration period was still to follow afterwards which lasted 3 hours. The authors suggest that rapid fluid replacement is ineffective at restoring the blood to euhydration, however their protocol for rehydration lasted 3 hours, which in actual practice, may be the difference between going into an event in euhydration or still dehydrated from a previous effort. It may be more likely that rehydrating with only 100% of the body mass lost during dehydration is ineffective at restoring plasma volume and plasma osmolality.

This was later followed up by a group led by Nose. They conducted two studies both published in 1988. The first of their studies was entitled 'Role of osmolality and plasma volume during rehydration in humans'. 6 subjects were used in this investigation in order to determine what effect that rehydrating with different sodium concentrations had on the restoration of the body's fluid compartments. Subjects exercised in a heated environment (36^{o}C, 30% relative humidity) at 40% $\dot{V}O_{2\ max}$ until a 2-3% reduction in body mass was achieved. Subjects were then rested for 1 hour in cooler conditions before rehydration began. In the next 3 hours subjects were rehydrated using tap water, *ad libitum*, along with capsules containing either a placebo (more water) or sodium chloride (0.45g). Body mass, urine volume and blood samples were taken throughout.

During the rehydration period subjects were seen to restore the water lost due to dehydration by 68% and 82% for placebo and sodium chloride trials respectively. This was a significant difference between the trials ($P < 0.05$). Urine production was greater during the placebo trial compared to the sodium chloride trial, again this was significant ($P < 0.05$). Plasma volume was restored to 174% of pre-exercise values following the sodium chloride trial compared to only 78% following the placebo trial. This gave us the early evidence that addition of sodium to a rehydration beverage is beneficial for restoration and retention of body water.

Nose *et al*'s second piece of work published in 1988 was titled 'Shift in body fluid compartments after dehydration in humans'. The methodology was the same as their first study. They measured plasma volume, plasma osmolality, and plasma electrolyte content (sodium, potassium and chloride). Sweat and urine volumes were also investigated before and after dehydration. They were able to estimate the change in the extracellular fluid space from the chloride distribution. Change in the intracellular fluid space could be calculated by subtracting the change in the extracellular fluid from the change in body mass following dehydration. The authors were able to conclude that the movement of fluid out of the intercellular space attenuated the decrease in the extracellular fluid.

Published in 1986 Nielsen *et al* investigated changes in fluid balance during exercise and rehydration with different glucose-electrolyte drinks. They used 6 male subjects, and tested 4 different drinks for their ability to rehydrate and what effect this had on performance following dehydration. The control drink consisted of 139mmol/l glucose & 43mmol/l sodium chloride (NaCl), the next drink was the same but with 51mmol/l potassium chloride (KCl) added, the third drink was also same as the control but with 85mmol/l NaCl extra added to make total NaCl in this beverage 128mmol/l and the last drink was a commercially available sports drink. Drinks were disguised with a lemon flavour to match the sports drink. Drinks were administered in a double blind random order.

Subjects were told to drink 1 litre of water or milk the night before each trial to ensure euhydration. On arrival to the lab subjects voided their bladder then rested in supine position while a venous catheter was inserted for blood sampling. After 30 minutes rest a biopsy was taken from the vastus lateralis muscle and first blood sample taken. Subjects then performed a work capacity test, which involved cycling at 50% $\dot{V}O_{2\ max}$ for 6 minutes, work rate was then increased to 105% $\dot{V}O_{2\ max}$ and subjects continued until exhaustion. Work done in this period was calculated from number of pedal revs and load. Before dehydrating exercise began body mass was taken. The dehydrating exercise was completed on a cycle ergometer for 2 hours in 30^{o}C heat at 50% $\dot{V}O_{2\ max}$. A second blood sample was taken during the last minute of exercise with the next muscle biopsy being taken immediately after exercise, when possible a urine sample was also collected. Subjects then lay on a bed for a 2 hour period of rehydration. The next blood sample was taken 30 minutes after second sample and before fluid replacement began. Each subject drank 300ml of fluid every 15 minutes until 9 drinks were finished (total 2700ml). More blood was taken at 10, 30, 40, 60, 90 and 135 minutes after fluid intake had started. Urine was collected, if possible, every hour. A third muscle biopsy was taken along with the last blood sample at 135 minutes. The same work capacity test was then repeated.

On average subjects in this study lost 3.1% of their pre-exercise body mass. Plasma volume in the dehydrated state was seen to have decreased by ~16% due to exercise in the heat. In the 30 minute rest interval before drinking began plasma volume had already started to return towards pre-exercise values. Within 30-45 minutes of the rehydration phase plasma volume had been restored while consuming the control drink, the added NaCl drink and the sports drink. It took until 90 minutes for the plasma volume to be restored during the added KCl trial. At the end of 2 hour rehydration, plasma volume was greater than pre-exercise values for all 4 trials. Results of the work capacity test showed that the work that could be completed post rehydration was significantly less (~22%) than the work done before dehydration, with no significant difference seen between each of the fluids. The muscle biopsies found that there was a reduction in muscle glycogen stores after rehydration compared to before dehydration and could account for the reduction in work capacity. Nielsen *et al* concluded that the drinks may differ in time taken to pass from the stomach into the gut, where intestinal absorption takes place. They also stated that drinks that are rich in sodium favour the filling of the extracellular water compartment, while drinks high in potassium, as well as sports drinks, favour filling of the intracellular water compartment.

This was the first study to compare beverages rich in sodium and potassium. This is of importance due to the high potassium content within coconut water. They found that the potassium rich beverage and the sports drink both favour the filling of the intercellular space, which may be of benefit for the working muscles during exercise. However they did not find similar results between these two beverages in their ability to restore plasma volume. It took double the time for the potassium drink to restore plasma volume compared to the sports drink.

In 1992 Lambert *et al* investigated the effect of adding carbonation to beverages used for rehydration. Their study used 8 healthy men and involved 4 separate trials. In the evening prior to each trial, subjects were told to ingest 500ml water to ensure euhydration. When the subjects arrived at the lab they emptied their bladder and had their body mass measured. Before exercise began subjects were seated for 15 minutes before collection of a venous blood sample. Subjects then exercised at 50% $\dot{V}O_{2\ max}$ on a cycle ergometer in an environmental heat chamber (40^{o}C and 40% relative humidity) aiming to reduce body mass by 4%. At time points 60, 90 and 105 minutes into exercise subjects were allowed to have a 5 minute recovery period in normal room temperature conditions to dry off and be reweighed. Subjects continued to exercise until desired mass was lost. Immediately after exercise was completed subjects were seated for 15 minutes before a venous blood sample was retaken, this was also repeated at 30, 90, 150 and 240 minutes of rehydration. Subjects were rehydrated with one of the following beverages, administered in a random order, for a 3 hour period. Drink 1 was a carbonated 10% glucose-fructose drink, the second was a carbonated non-carbohydrate containing drink, number 3 was a non-carbonated 10% glucose-fructose drink, and finally drink 4 was non-carbonated as well as non-carbohydrate. The beverages were split into 13 separate feedings, given at 15 minutes intervals, each equating to 7.7% of the body mass lost following dehydration (total 100% body mass replacement). At the end of the rehydration period subjects urinated and were reweighed.

On average subjects reduced body mass by 4.12%, in a time of 128 minutes. Rehydration was evaluated by changes in body mass, plasma volume and plasma protein concentration. Changes in these variables were similar at each time point throughout the rehydration period, however euhydration was not reached by the end of rehydration for each drink. Negative fluid balance at the end of the rehydration period was believed to be due to continued sweating, urine output and water lost through respiration. Quantity of urine produced during rehydration was not different between trials. Plasma glucose was elevated during trials for the carbohydrate containing drinks as expected. Ratings of gastrointestinal distress were also similar for all drinks at each time point. This data suggests that carbonated drinks are as effective as non-carbonated drinks in fluid replacement and recovery from dehydration, and would suggest that there is no difference in the rate of gastric emptying. The authors also concluded that rehydration was seen to be no different when the 10% carbohydrate drink was consumed compared to the non-carbohydrate drink. No difference between the non-carbohydrate drink and the drink high in carbohydrate shows there is no disadvantage for fluid replacement by consuming fluid high in carbohydrate. This therefore suggests high carbohydrate being present in the rehydration fluid may be advantageous for athletes who must compete or train within hours or days of dehydrating performance, as muscle glycogen resynthesis is reported to be 3 times faster when carbohydrate is present in fluid consumed immediately after exercise.

As this study was conducted while research in this area was still fairly new, they only rehydrated subjects with a volume equivalent to 100% of the body mass they had lost during dehydration. They found that subjects were still in negative fluid balance by the end of the rehydration period, suggesting that extra fluid needs to be consumed to overcome the loss of water from urine, sweat and respiration.

Also published in 1992 was a study by Gonzalez-Alonzo *et al*, titled ‘Rehydration after exercise with common beverages and water’. This study assessed 10 subjects during a 2 hour rehydration period following exercise-induced dehydration. They were rehydrated with a caffeinated diet cola, a 6% carbohydrate-electrolyte or plain water. Measurements of whole body rehydration, gastric emptying and blood volume restoration were monitored. Subjects exercised at 60-80% $\dot{V}O_{2\ max}$ in a heated environment (32 ^{o}C, 40% relative humidity) until approximately 2.5% of their body mass was lost. Following exercise, the subjects returned to a cooler environment and received beverages equal in volume to the fluid they had lost. Fluids were consumed in two portions at 0 and 45 minutes of the 2 hour rehydration period. At the end of the rehydration period, they found there to be no fluid remaining within the stomach after all trials. However, the subjects still remained slightly hypohydrated after the rehydration period for all trials, this was believed to be due to water lost as a result of urine formation, respiration, sweat and metabolism. The authors created a formula used as an index of percentage rehydration, where percentage rehydration = (total body mass lost following dehydration - (initial body mass – final body mass) / fluid intake in kg) x 100

They found the diet cola to produce a significantly lower percentage rehydration value (54%) compared to water and the carbohydrate-electrolyte drink which gave values of 64% and 69%, respectively ($P < 0.05$). Percent rehydration has been used as a very useful indicator to measure effectiveness of a particular rehydration drink, however due to the variations in level of dehydration, volume ingested, duration of rehydration period and composition it is difficult to make meaningful comparisons between different protocols.

Coconut Water for Rehydration

Aragon-Vargas *et al* (2000) investigated what effect coconut water has on rehydration. Their study involved 19 heat acclimated young males who were members of the athletics school in Costa Rica. Their protocol consisted of 3 trials, involving either water, coconut water or a sports drink as means of rehydration, with each drink administered in a random order. Diet was monitored 48 hours before each trial using questionnaires and subjects followed specific instructions regarding fluid and sodium intake in the 24 hours prior to the trial. Body mass was measured and urine collected before the exercise began. Subjects exercised for several 20 minute bouts outdoors, with body mass measurement being taken until 2% of original body mass was lost. This was then followed by a period of recovery before subjects consumed one of the drinks, in a single dose with volume equal to 125% of body mass lost. Urine and body mass were measured throughout the 3 hour recovery period. Exercise and recovery were both completed within the same environmental conditions of 26.5^{o}C.

Body mass was used as a measure of fluid balance throughout the experiment. Subjects typically lost 2.3% of their original body mass following exercise. On average body mass was significantly lower at the end of the rehydration phase following the water trial compared to both coconut water and sports drink ($P < 0.05$). No significant difference was seen in urine output between all trials during the 3 hour rehydration period. They concluded that the inability to return the body to euhydration within a warm, humid climate, was due to increased sweat output during the recovery period, in spite of ingestion of fluid equivalent to 125% of the original body mass lost during exercise. The extent of hypohydration at the end of the recovery period was similar to that seen after subjects had been dehydrated following exercise. Their results showed that water was less effective at regaining bodily fluid compared to coconut water and a sports drink. However, this difference was only able to be detected by differences in final body mass of the subjects, as the urine production was not significantly different between trials.

This study was unique as they used subjects that were already acclimatised to the heat, as they were natives of Costa Rica. Previous studies had all used subjects that were being put into an unfamiliar environmental chamber in order to elicit dehydration. However, their protocol was completed outdoors meaning they were unable to completely standardise conditions as you would be able to within a laboratory. Earlier studies had only rehydrated with fluid equal to 100% of the body mass lost during dehydration, this study used 125% fluid replacement and still found subjects were in negative fluid balance by the end of the rehydration phase.

More recently, Saat *et al* (2002) published research investigating ‘Rehydration after exercise with fresh young coconut water, carbohydrate-electrolyte beverage and plain water’. 8 healthy males were used within this study, subjects attended the lab 2-3 hours after a standardised breakfast and drinking ~500 ml water to ensure normal hydration. Subjects were exercised in a hot environment (31.1^{o}C, 51.4% relative humidity) at 60% $\dot{V}O_{2\ max}$ for 90 minutes until 2.5 - 3.0% of their original body mass had been lost. Subjects then had to follow a 2 hour rehydration period, sitting in a thermoneutral environment, while drinking either coconut water, a carbohydrate-electrolyte beverage or plain water. The volume of fluid consumed equated to 120% of the body mass lost due to dehydration. This was split into 3 separate feedings and drank at set points 0, 30 and 60 minutes within the rehydration phase. Blood samples were taken to measure haematocrit, serum osmolality and serum electrolyte (sodium, potassium and chloride) content. Urine output was collected and analysed for urine osmolality, as well as urine electrolyte content. In addition nude body mass was also recorded. Net fluid balance was calculated, based on body mass loss, volume of fluid ingested and urinary volume produced, as suggested by Maughan *et al*, 1994. The authors also used the percentage rehydration equation from Gonzalez-Alonso (1992). The final parameter used for estimation of the extent of rehydration was the rehydration index. Mitchell *et al* (1994) were responsible for this measurement which gives an indication of how much of the fluid ingested was responsible for the restoration of body mass. Rehydration Index = (total volume of fluid administered (ml) / total body mass gain during rehydration (g) / % rehydration / 100), a value of 1 is believed to be optimal, anything greater indicates a less effective use of the ingested fluid.

Subjects lost on average 2.78% body mass during dehydration, and were rehydrated with an average of 1875ml of fluid. They found that at the end of the rehydration period that all beverages left subjects hypohydrated. There was no significant difference seen in the percentage rehydration, however it was seen to be highest following the carbohydrate-electrolyte trial (80%). They also found no significant difference in the rehydration index across all trials either. No significant difference was seen in blood volume and urine volume produced at any time points for all trials. Plain water produced significantly lower urine osmolality compared to coconut water and the carbohydrate-electrolyte drink at 90 and 120 minutes into the rehydration period. As previously mentioned, net fluid balance was negative at end of rehydration and was similar between all 3 trials. Serum osmolality was found to be significantly higher immediately at the end of exercise compared to pre-exercise for all trials, as expected due to dehydration. Serum osmolality was seen to return to, or even be less than, pre-exercise values by end of rehydration period in all trials. During rehydration the carbohydrate-electrolyte drink produced significantly higher blood glucose values compared to plain water at all of the time points. The blood glucose during the carbohydrate-electrolyte trial was also significantly higher than the coconut water at 30 and 60 minutes into rehydration. Coconut water produced significantly higher blood glucose values than water at 30, 60 and 90 minutes into rehydration but not at the final time point of 120 minutes.

They concluded that rehydrating with plain water diluted the blood as serum osmolality was lower at the end of the rehydration period than pre-exercise values at the beginning of the trial. Plain water also produced lower urine osmolality which suggested that there was increased fluid clearance by the kidneys leading to additional urine production. Importantly they suggested that results from other studies which may use an *ad libitum* rehydration strategy should be interpreted with caution when comparing to studies that use a forced fluid consumption strategy. They state that this is because different amounts of fluids are ingested and that subjects do not voluntarily drink a volume equal to or more than their fluid losses.

This study was able to state that coconut water could be used for whole body rehydration following exercise induced dehydration. The authors suggested that further investigation would be to add sodium to coconut water to make it equivalent to the values seen within common sports drinks.

In 2007, Ismail *et al* completed an investigation into what effect adding additional sodium to coconut water had on its ability to rehydrate. The study was entitled 'Rehydration with sodium-enriched coconut water after exercise-induced dehydration'. 10 healthy males volunteered for the study. There were 4 separate trials involved in the study. The beverages used during rehydration were coconut water, coconut water with added sodium, a sports drink and plain water. Diet and physical activity were recorded in the 48 hour period before the first trial and was then replicated prior to the rest of the trials. Before each trial, subjects arrived at the lab at 7am for a standardised breakfast and 500ml of water. 1 hour later subjects emptied their bladder and had nude body mass measured. A venous catheter was inserted for blood sampling (haematocrit, haemoglobin & glucose). At 9am (2 hours after breakfast) subjects started to exercise on a treadmill at 65% $\dot{V}O_{2\ max}$ for 90 minutes in a heat chamber (32^{o}C, relative humidity 70%) with the aim of dehydrating the body by 3% of its original mass. After completing the exercise a blood sample was taken, and subjects given 10 minutes to cool down in a thermo-neutral room (23^{o}C, 60% relative humidity). Once the subjects were completely dried of sweat, nude body mass was re-measured. 30 minutes after exercise had finished another blood sample was taken, as well as urine collection and nude body mass. It was after this that the subjects were given their first drink which was equivalent to 50% of body mass they had lost during exercise, this was the start of a 2 hour rehydration period. 30 minutes into the rehydration period the second drink was given to subjects, this time the volume was only equivalent to 40% of the body mass lost. The final drink, equating to 30% body mass lost, was given at 60 minutes into the rehydration phase. Blood and urine were collected every 30 minutes during rehydration. At the end of the 2 hour rehydration period, urine was collected before final nude body mass was measured. A questionnaire was also completed during the rehydration phase.

Subjects lost on average 3.08% of their original body mass as a result of exercise in a heated environment. Fluid volumes used to rehydrate the subjects averaged 2200ml. Subjects were seen to be still slightly dehydrated at the end of the rehydration phase. Percentage rehydration was found to be higher for all drinks compared to water. Rehydration index was also used and produced values of 2.5, 1.8, 2.0 and 1.75 for water, sports drink, coconut water and sodium enriched coconut water respectively. Plasma volume at end of rehydration had returned to pre-values for all drinks except water. Urine production was lower during the trials where subjects rehydrated with the sports drink and both coconut waters compared to water. Urine osmolality after dehydration was similar in all trials. After the 2 hour rehydration, urine osmolality following consumption of water was significantly lower ($P < 0.05$) than when the sports drink or coconut waters were used. Net fluid balance at end of the rehydration period was not significantly different between trials but was negative for all. Serum osmolality was significantly higher at end of the exercise period ($P < 0.01$) for all trials, and had returned to euhydration levels by end of rehydration period. However, serum osmolality while rehydrating with water was significantly lower compared to all other drinks ($P < 0.05$) at 90 and 120 minutes into the rehydration period. Blood glucose was the same for all trials before and after exercise. During the rehydration period, the sports drink trial and both coconut water trials were seen to produce higher values of blood glucose compared to the water trial. The questionnaire results found that feeling of thirst was not significantly different between trials. Subjects also reported that both coconut waters and the sports drink were much sweeter than water, but no significant difference was seen between each of them. Subject's feeling of nausea was similar for all trials, however at 30 and 60 minutes into the rehydration period significantly lower scores were reported during the sodium enriched coconut water trial compared to all others. Feeling of fullness was also significantly less during the sodium enriched coconut water trial at 30 and 60 minutes. Sensation of stomach upset was seen to be generally lower while rehydrating with both coconut waters compared to the sports drink and water, this was only seen to be significant at 30, 60 and 90 minutes into the rehydration period.

Ismail *et al* began to conclude by saying that their data suggests that, firstly, sodium enriched coconut water is as effective as the sports drink for fluid replacement and recovery following dehydration. Secondly, rehydration was similar when coconut water and sports drink solutions were ingested. Previous studies have shown percentage rehydration can be between 50-80% following a rehydration phase of 2-3 hours, using many different rehydration strategies. The percentage rehydrations seen in this study of 68 and 69% for sports drink and sodium enriched coconut water were similar to other studies (Gonzalez-Alonso 1992 and Singh 2002). Other studies may give the rehydration fluid in one large volume to drink, in this study drinks spaced out every 30 minutes. This was planned to match possible rates of ingestion which might be used in actual practice in order to avoid extreme stomach fullness. Maughan and Leiper (1995), Maughan (1994) and Kovacs (2002) followed rehydration for 5-6 hours which obviously provides a much more complete picture of the effect that a fluid consumed has on kidney function, however, sometimes this might not be feasible to follow. Maughan (1997) has shown that to optimise rehydration you must drink a volume greater than the total body mass that was lost during exercise and that the drink should contain electrolytes in order to prevent urine production. Even when large volumes of fluid are consumed they appear to not adequately rehydrate if sodium levels are low (Shirreffs 1996). Rehydration Index ranges 1.80 - 2.60 have been reported with sodium levels of 20 mmol/l typical of most sports drinks. The sports drink used in this study had a rehydration index of 1.80 which also falls within this range. However, the rehydration index seen following rehydration with sodium enriched coconut water was 1.75 which is better than that reported in studies using sports drinks, which may be due to the increased potassium content of the coconut water. They also state that rehydrating with 120% of body mass lost may not be a sufficient volume in order to restore fluid loss as all trials were still seen to be in negative fluid balance by the end of the rehydration period.

In the study by Saat *et al* (2002) they found that percent rehydration was higher with a sports drink compared to coconut water perhaps due to lower sodium content in coconut water. Ismail *et al* added sodium to coconut water in this study and saw similar results in percent rehydration and rehydration index when compared to a sports drink, coconut water alone and plain water. Major target during rehydration is to maintain plasma volume so that circulation and sweating can continue optimally (Leiper and Maughan 1986). Previous studies suggest high potassium content of drinks, as seen in coconut water, may delay recovery of plasma volume due to increased intracellular fluid restoration instead of extracellular. However, no difference was seen in this study between coconut water and sports drink.

Coconut Water for Performance

Most of the studies that use coconut water focus on its ability to rehydrate following dehydration. The first study that looked at a performance aspect to coconut water ingestion was not completed until very recently, by Kalman *et al* (2012).

Their study used 12 subjects, who underwent 4 different trials. When they arrived at the lab they were given a standardised breakfast as well as 470ml water. 1 hour later, they began exercising to elicit dehydration, in a heated environment (36^{o}C, relative humidity 48%). Exercise involved two 30 minute bouts of walking/jogging on a treadmill separated with a 10 minute recovery period. Subjects lost between 2-3% of their initial body mass by following this exercise protocol. Subjects returned to a thermoneutral environment for a 3 hour rehydration period, before completing an exercise performance test. Measurements of body mass, plasma osmolality, urine specific gravity and subjective questionnaire scores were taken throughout the rehydration period. Subjects were assigned a different beverage during the 4 different trials administered in a randomised order. Drinks investigated were bottled water, commercially available coconut water, coconut water from concentrate and a carbohydrate-electrolyte drink. Subjects were rehydrated by volumes equivalent to 125% of the body mass lost during dehydration, which they were given in a single bolus and allowed 60 minutes to finish. After the rehydration phase, subjects completed a performance test which involved running on a treadmill at 4.2 miles/hour with gradient being increased from 0% in 2.5% increments every 3 minutes until volitional exhaustion, total exercise time was recorded. Subjects lost on average 1.7kg (~2% of original body mass) following dehydration. There were no significant differences seen in the measurements taken throughout rehydration between any of the trials. It was concluded that coconut water, from natural or concentrate sources, is as effective for rehydration as water and a carbohydrate-electrolyte drink.

The main focus of this study was on performance, and it was found that there was no significant difference in the performance test results of total exercise time between each condition. Although this study looked at a performance aspect to coconut water consumption, it was only following a rehydration phase, meaning previous dehydration had taken place. The use of the incremental protocol for the performance test to assess the effectiveness of the rehydration beverage is strange. An incremental test designed to elicit exhaustion may lead to subjects ceasing exercise due to localised muscular fatigue, which may be more a test of subjects' ability to clear metabolic by-products or how they tolerate the accumulation of these by-products when production exceeds clearance. We still don't know to date if coconut water can be used as a natural replacement, for sports drinks, for an athlete during endurance sport. To investigate this, a study using coconut water to fuel time trial performance would need to be conducted, where subjects are told to cover a set distance or complete a set amount of work as quickly as possible.

A new piece of research by Laitano *et al* (2014) is the latest study to investigate the effect coconut water may have on exercise performance. 8 subjects were used during this study, with 3 different beverages being tested. The beverages used were plain water, an orange flavoured drink and coconut water, which were administered in a randomised order. The difference in this study compared to all others before was that they were testing the effect of drinking coconut before performing exercise and whether it was beneficial for exercise capacity. An hour before beginning the exercise test subjects began to drink one of the selected beverages, volume equalling 10 ml/kg. Drinks were divided into 7 equal boluses and given to subjects every 10 minutes during the hour. The exercise test began 20 minutes after the last bolus was consumed and was performed in a heated environment (34^{o}C, 55% relative humidity). The test involved cycling at 60% of maximum power output, with a steady cadence and continued until subjects were unable to keep cadence above 60 rev·min^{-1}.

The authors found a reduced urine volume was produced during the coconut water trial compared to water and flavoured drink ($P < 0.05$). Sweat rates and fluid balance were similar throughout the exercise test between all trials. Interestingly, they found that exercise capacity was increased following previous consumption of coconut water compared to the other drinks ($P < 0.05$). This shows early indication that coconut water may be beneficial for endurance performance, however this study did not compare coconut water's effect with a sports drink. Also exercise performance test was a maximal test with no consumption of fluid during the trial. Investigation is required comparing the consumption of coconut water and a sports drink during longer endurance exercise on markers of performance.

In summary, the use of coconut water as a rehydration beverage is still a fairly new concept. Many of the studies that use coconut water use small subject numbers therefore it is hard to gain much confidence from these results. These studies also use a variety of different rehydration strategies and it is still unknown which method is optimal.

Methods

Subjects

For homogeneity 16 males volunteered to take part in this project, all of whom were healthy and recreationally active. Subject characteristics can be seen below in Table 1. Subjects were provided with information sheets (see Appendix 1) outlining the required commitments of their involvement, before written informed consent was obtained (Appendix 2), prior to the subjects beginning the study. A subject health questionnaire was also completed and any subjects that evidenced a history of disease, illness, injury or family history of sudden death were excluded. All protocols and procedures used in the study were approved by the School of Life Sciences Ethical Review Committee for non-clinical Research, University of Glasgow.

Table 1. *Physical and physiological subject characteristics at baseline*

n	16
Age (years)	22.9 ± 3.2
Height (cm)	180.6 ± 6.4
Mass (kg)	75.8 ± 10.2
$\dot{V}O_{2\ max}$ ($l \cdot min^{-1}$)	3.98 ± 0.68
$\dot{V}O_{2\ max}$ ($ml \cdot kg^{-1} \cdot min^{-1}$)	52.7 ± 7.4

Values are means ± SD; n, number of subjects.

Study design

Subjects were required to attend the laboratory on 5 separate occasions, with each visit separated by at least 72 hours. Subjects consumed their normal diet throughout the study, however they were asked to avoid alcohol consumption and also to arrive for each test following a 2 hour fast. Water consumption was allowed before each trial in order to establish a euhydrated state. Subjects were also asked to avoid exhaustive exercise 48 hours prior to each test.

Maximal oxygen uptake test

The initial visit to the laboratory consisted of a maximal oxygen uptake test. The test was conducted as a step-wise ramp protocol on a cycle ergometer (Lode, Groningen, Netherlands). Subjects performed a 10 minute warm-up before the test began. Resistance on the bike was then increased by 25 watts per minute ($W \cdot min^{-1}$) until voluntary exhaustion or the subject was no longer able to maintain a cadence of greater than 50 $rev \cdot min^{-1}$. At the end of the test subjects were required to complete a cool down period allowing their heart rate to return to warm up values.

Subjects were required to wear a headset (Hans Rudolph, Kansas, USA) for a Two-Way Non-Rebreathing Valve mouthpiece (2700 series, Hans Rudolph, Kansas, USA). A nose clip was also required to be worn during each test to prevent any of the expired air being lost to the atmosphere. Therefore, subjects breathed through the two-way valve connected to a piece of tubing, 1.5 m in length and 5.0 cm in diameter, which allowed the expired air to be collected in a Douglas bag.

Douglas bag collections allowed for expired gas concentrations to be attained by analysis using a gas analyser (Servopro 4100 gas analyser, Servomex, Crowborough, UK), leading to calculation of the gas exchange variables $\dot{V}O_2$ and $\dot{V}CO_2$. The gas analyser was calibrated using precision analysed gases that span the range of inspired and expired gas concentrations. Concentrations were checked both pre and post analysis to check the stability of the calibration. The volume of gas collected in the Douglas bags was found by a volume analyser (Dry gas meter, Harvard Apparatus, Edenbridge, UK).

Finally a Polar heart rate monitor (FT2, Polar Electro Oy, Kempele, Finland) was also worn to allow reading of the subject’s heart rate to be observed throughout the test.

Experimental protocol

The next 4 visits were part of the experimental trial. The trials involved subjects being dehydrated by exercising within an environmental chamber heated to a temperature of $36.7 \pm 0.9^{o}C$ and $91.9 \pm 21.2\%$ relative humidity, before being rehydrated using various fluids.

Before each of the tests began, various baseline measurements were recorded. These included subject's height, nude body mass, urine osmolality and blood glucose. Subjects were also required to complete a simple subjective feelings questionnaire (Appendix 3), involving 7 questions all scored on a scale of 1 -10.

Blood samples were drawn using a lancet to make a small puncture in the skin of the thumb by a suitably qualified individual. A sample was drawn into a capillary tube, containing reactants used to prevent the blood from coagulating. The blood was then mixed in the tube, allowing for the reaction to take place. This was achieved by simply holding the tube between the thumb and fore finger and spinning the tube moving the blood along the full length of the tube. This was continued until the blood underwent a colour change from red to brown indicating the reaction was complete. The blood was then ready to be analysed. This sample was used to measure blood glucose (Analox GM7 analyser, London, UK). The glucose analyser was calibrated before each test using a standard glucose solution of known concentration 8.0 mM. A pipette was used to draw a 7 micro litre sample of the glucose solution that was then expelled into the reaction chamber of the glucose analyser, this was repeated until 2 consecutive samples gave a glucose reading within 0.1 mM of each other, this was then accepted as an 8.0 mM sample. Each blood sample was analysed using a 7 micro litre sample from the capillary tube that was expelled into the reaction chamber of the glucose analyser. Again, samples were analysed until 2 consecutive samples were within 0.1 mM of each other. A 20 micro litre sample of the urine collected was used to assess urine osmolality (Advanced Micro-Osmometer, Model 3300, Massachusetts, USA). The osmometer initiated calibration by selecting the 'calibration' option from the machine's menu setting. A 20 micro litre sample was drawn of the first calibration standard (50 mOsm) and placed in the sample cradle, the cradle was then pressed down so that the sample entered the reaction chamber. This was repeated until the machine prompted the use of the second calibration standard (850 mOsm). The same process was followed for the 850 mOsm standard until the machine displayed 'calibration complete'. The calibration could then be checked by following the same sampling protocol with a 290 mOsm reference solution.

When experiments like this are conducted in a heated environment, core temperature of subjects has to be monitored throughout. If core temperature rose to 39^{o}C the subject was closely monitored, and if core temperature reached 40^{o}C the test was stopped and the subject was allowed to cool down by exiting the heat chamber and being placed in a cool room with a fan. To monitor core temperature the subject was required to insert a rectal thermometer 10 cm beyond the anal sphincter. Again, a Polar heart rate monitor (FT2, Polar Electro Oy, Kempele, Finland) was worn to allow reading of heart rate to be observed throughout the test.

Subjects then exercised on a cycle ergometer at 65% $\dot{V}O_{2\,max}$ (determined from the maximal oxygen uptake test) for 60 minutes, in order to lose 2-3% of body mass via sweat loss. Chamber temperature, subject core temperature and chamber relative humidity were recorded at 5 minute intervals throughout the exercise period. After 60 minutes of exercise within the chamber, subjects were removed and asked to towel dry before body mass was re-measured. The test was ended if the subject had been found to have decreased in nude body mass by between 2-3%. However, the amount of sweat produced during exercise is variable between individuals, therefore, some subjects were not able to lose between 2-3% nude body mass within 60 minutes. These subjects had to return to the chamber and continue exercising in intervals of 10 minutes (to a maximum of 90 minutes) until sufficient body mass was lost. After each of the 10 minute periods of exercise the subject was again removed from the chamber and asked to towel dry before nude body mass was re-measured.

Once the subject had reached the target body mass, they were returned to the laboratory. It was here that the subject's urine osmolality, blood glucose and subjective questionnaire scores were re-measured. In the 2 hour period following exercise cessation subjects rehydrated to the equivalent of 150% of body mass lost. The total volume required to be consumed was broken down into 3 equal boluses, subjects were asked to consume each portion within 40 minutes of being received. Throughout the 2 hour rehydration phase, subjects' nude body mass, urine osmolality, blood glucose and subjective feelings questionnaire scores were monitored every 30 minutes and at the end of the 2 hours of rehydration.

The first test in this series was a familiarisation test and subjects were allowed to consume their own beverage of choice and in an *ad libitum* manner. The remaining 3 experimental tests involved subjects consuming either coconut water (Go Coco), a commercially available sports drink or plain water, administered in a randomised, double-blind crossover manner.

Statistical analysis

The (minimum) sample size of 36 was calculated to ensure that the width of the resulting 95% confidence interval for the difference in population mean for the same subject is at most 2%. Implicit in this calculation is the assumption of population standard deviation (SD) of 3% in the distribution of differences between treatments on the same subject. During analysis subjects were split into two groups depending on their maximum oxygen capacity, group one had a maximum oxygen capacity of < 50 $ml \cdot kg^{-1} \cdot min^{-1}$ with group two > 50 $ml \cdot kg^{-1} \cdot min^{-1}$. Statistical analysis was performed using Minitab 17 (Minitab Ltd., Coventry, UK). Analyses of variance (ANOVAs) were used to assess any differences in the results between trials. Significance was determined with a P value < 0.05. Furthermore Cohen's d calculations of effect sizes were also used to determine potential differences between each beverage that had not been detected from the ANOVAs due to the lower sample size used. When d is less than 0.2, effect sizes are said to be trivial, between 0.2 – 0.4 effect size is small, between 0.4 – 0.8 are medium effect sizes and large effect sizes are d values greater than 0.8.

Results

Maximal oxygen uptake test

Mean $\dot{V}O_{2\ max}$ was 3.89 ± 0.76 $l \cdot min^{-1}$ (52.3 ± 7.4 $ml \cdot kg^{-1} \cdot min^{-1}$) with subjects reaching the limit of tolerance at a mean power output of 293 ± 94 W. The mean RER recorded at the limit of tolerance was 1.2 ± 0.1 and mean maximum heart rate 189 ± 8 $beats \cdot min^{-1}$.

Experimental protocol

Subjects' recorded body mass at each time point throughout the rehydration phase for each of the trials can be seen below in Table 2.

Table 2. *Mean body mass (kg) ± SD recorded for each time point for each of the trials, values expressed in brackets are percentages of the pre body mass values.*

	CW	S	W
Pre	75.7 ± 10.3 (100.0 ± 0.0)	75.7 ± 10.4 (100.0 ± 0.0)	75.7 ± 10.5 (100.0 ± 0.0)
0 min	74.0 ± 10.0 (97.7 ± 0.4)	73.9 ± 10.1 (97.6 ± 0.5)	73.9 ± 10.1 (97.6 ± 0.5)
30 min	74.5 ± 10.1 (98.4 ± 0.3)	74.5 ± 10.1 (98.4 ± 0.5)	74.3 ± 10.2 (98.3 ± 0.4)
60 min	75.1 ± 10.1 (99.1 ± 0.4)	75.2 ± 10.2 (99.3 ± 0.5)	75.1 ± 10.3 (99.2 ± 0.5)
90 min	75.6 ± 10.2 (99.9 ± 0.4)	75.7 ± 10.3 (99.9 ± 0.6)	75.7 ± 10.5 (100.1 ± 0.3)
120 min	76.0 ± 10.4 (100.4 ± 0.3)	76.0 ± 10.5 (100.4 ± 0.6)	76.0 ± 10.8 (100.3 ± 0.5)

CW = Coconut Water, S = Sports Drink, W = Plain Water.

On average subjects lost 2.36 ± 0.45% (equating to 1.8 ± 0.5 kg) of their initial body mass as a result of the exercise prescribed, taking on average 64 ± 8 minutes to reach the desired body mass loss. Subjects were then rehydrated with an average volume of 2647 ± 691 ml of fluid.

Table 3. *Mean percentage mass lost ± SD, exercise duration and volume of fluid consumed during each of the trials.*

Trial	Body mass lost (%)	Exercise duration (min)	Rehydration fluid volume (ml)
CW	2.3 ± 0.4	62 ± 7	2585 ± 545
S	2.4 ± 0.5	64 ± 8	2718 ± 707
W	2.3 ± 0.5	66 ± 8	2638 ± 827

CW = Coconut Water, S = Sports Drink, W = Plain Water

Table 4. *Mean body mass lost ± SD, exercise duration and estimated sweat rates between each group during all trials. Group 1 = maximum oxygen uptake < 50 ml·kg^{-1}·min^{-1}, Group 2 = maximum oxygen uptake > 50 ml·kg^{-1}·min^{-1}.*

Group	Body mass lost (kg)	Exercise Duration (min)	Estimated Sweat Rate (g/min)
1	1.7 ± 0.1	66 ± 8	25.7 ± 6.1
2	1.9 ± 0.1	62 ± 7	31.7 ± 9.9

CW = Coconut Water, S = Sports Drink, W = Plain Water

The fitter subjects (group 2) lost a greater amount of weight compared to the group 1 subjects, although the difference was not significant (P = 0.08) a large effect size was found (d = 2.07). Group 2 subjects were found to require less exercise time to reach the desired weight loss (P < 0.05) compared to the individuals in group 1 (medium effect size, d = 0.42). Estimated sweat rates were calculated by dividing the weight lost, in grams, by the exercise duration, in minutes. Group 2 subjects had a significantly greater sweat rate compared to group 1 subjects (P < 0.05), a medium effect size of d = 0.56 was also seen.

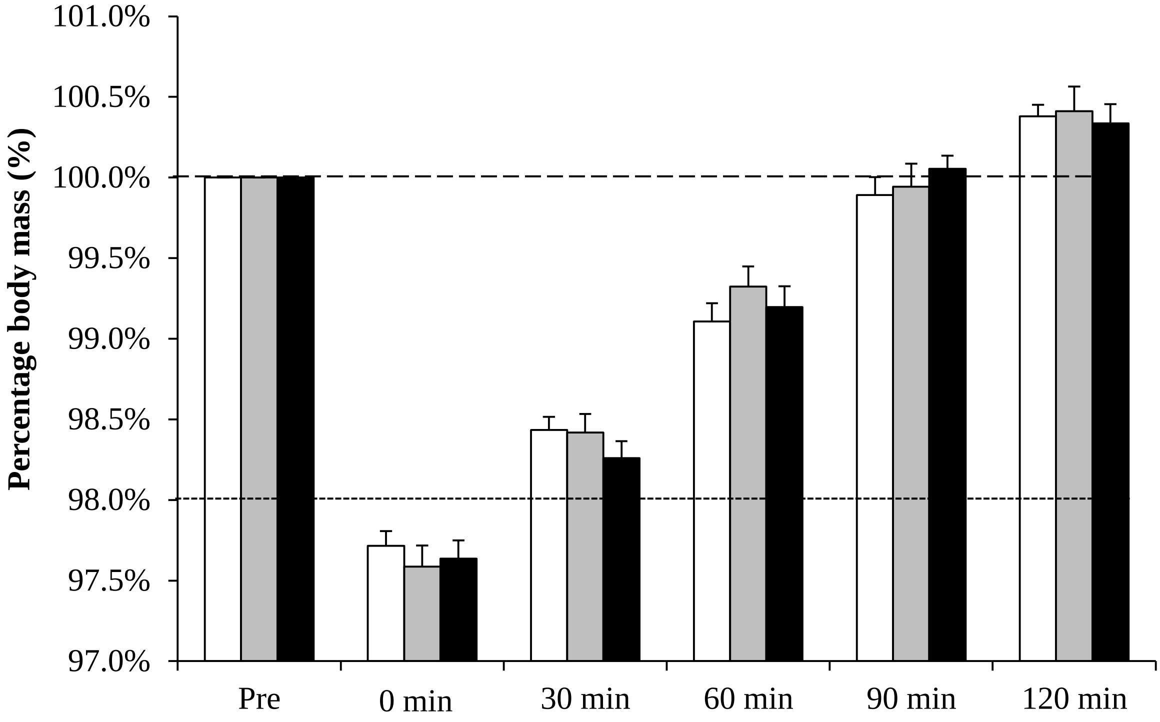

Fig. 1. Average body mass of subjects throughout each trial expressed as a percentage of their initial body mass. Dashed black line indicates initial body mass, dotted line shows 2% body mass loss. White bars – Coconut Water, Grey Bars – Sports Drink, Black Bars – Plain Water.

The results in figure 1 show the variation in body mass over the course of each of the trials, clearly highlighting the initial reduction in body mass due to the dehydration effect of the prescribed exercise. The figure also shows the gradual recovery of body mass during the rehydration phase during each of the trials. At the end of rehydration phase (120 minutes) body mass had recovered to pre-exercise measurements, with body mass recovering to 100.4 ± 0.3; 100.4 ± 0.6 and 100.3 ± 0.5% following the coconut water, sports drink and water trials respectively (fig. 1). It is evident that there are no significant differences seen in the body mass of the subjects at any of the time points during each of the three trials, *P* values 0.417, 0.462, 0.596 and 0.904 for time points 30, 60, 90 and 120 minutes into the rehydration phase respectively. Cohen effect size (*d*) calculations were also used and were all found to be trivial effects, *d* = 0.06, 0.10 and 0.11 for coconut water compared to sports drink, coconut water compared to plain water and sports drink compared to plain water respectively.

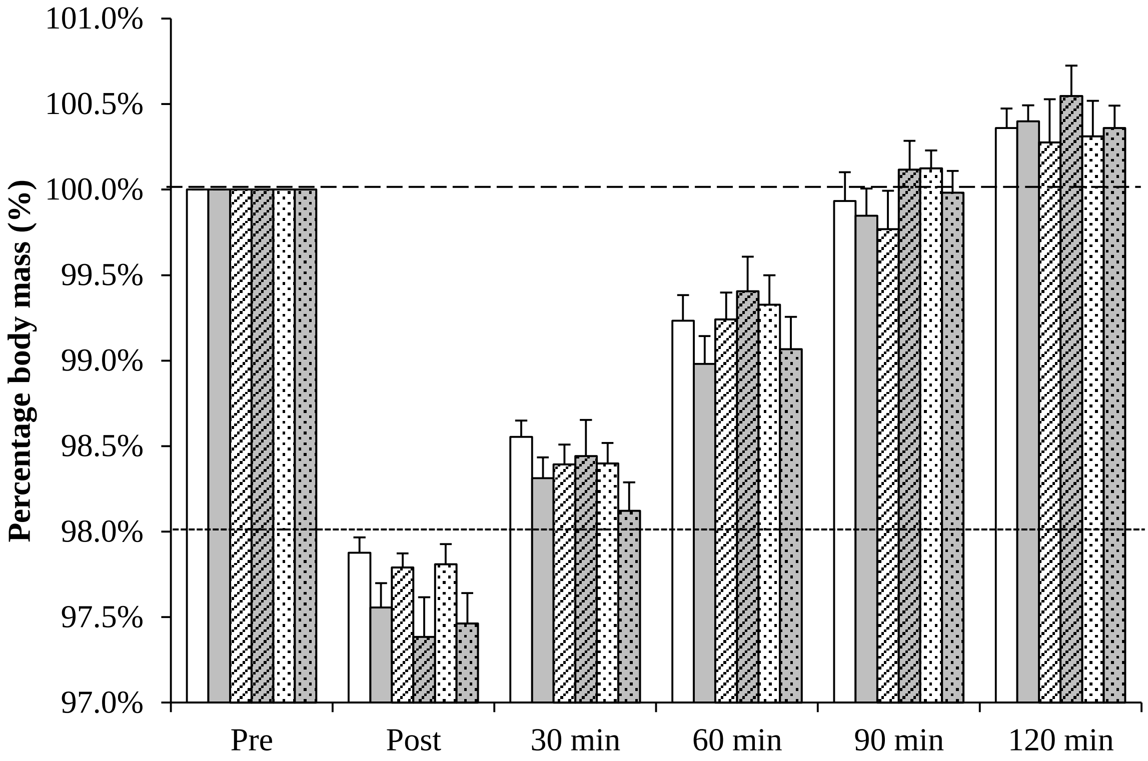

Fig. 2. Average body mass of subjects throughout each trial and split into group 1 (< 50 ml·kg^{-1}·min^{-1}) and group 2 (> 50 ml·kg^{-1}·min^{-1}), expressed as a percentage of their initial body mass. Dashed black line indicates initial body mass, dotted line shows 2% body mass loss. White bars – Group 1, Grey Bars – Group 2, plain bars - coconut water trial, striped bars - sports drink trial and dotted bars - plain water trial.

Figure 2 clearly shows that following all 3 trials the fitter subjects lost more body weight than the group 1 subjects, large effect sizes of *d* = 0.84, 0.78 and 0.71 were found for coconut water, sports drink and plain water trials respectively. During only the sports drink trial did the fitter subjects recover more body weight at each time point compared to the less fit subjects, however these differences were only found to have effect sizes of *d* = 0.08 (trivial), 0.25 (small), 0.53 (medium) and 0.38 (small) for 30, 60, 90 and 120 minutes into rehydration respectively. It took until the final time point (120 minutes) for the fitter subjects to recover larger percentage body weight compared to group 1 subjects, although both effect sizes were found to be trivial, while rehydrating with both coconut water (*d* = 0.11) and plain water (*d* = 0.09).

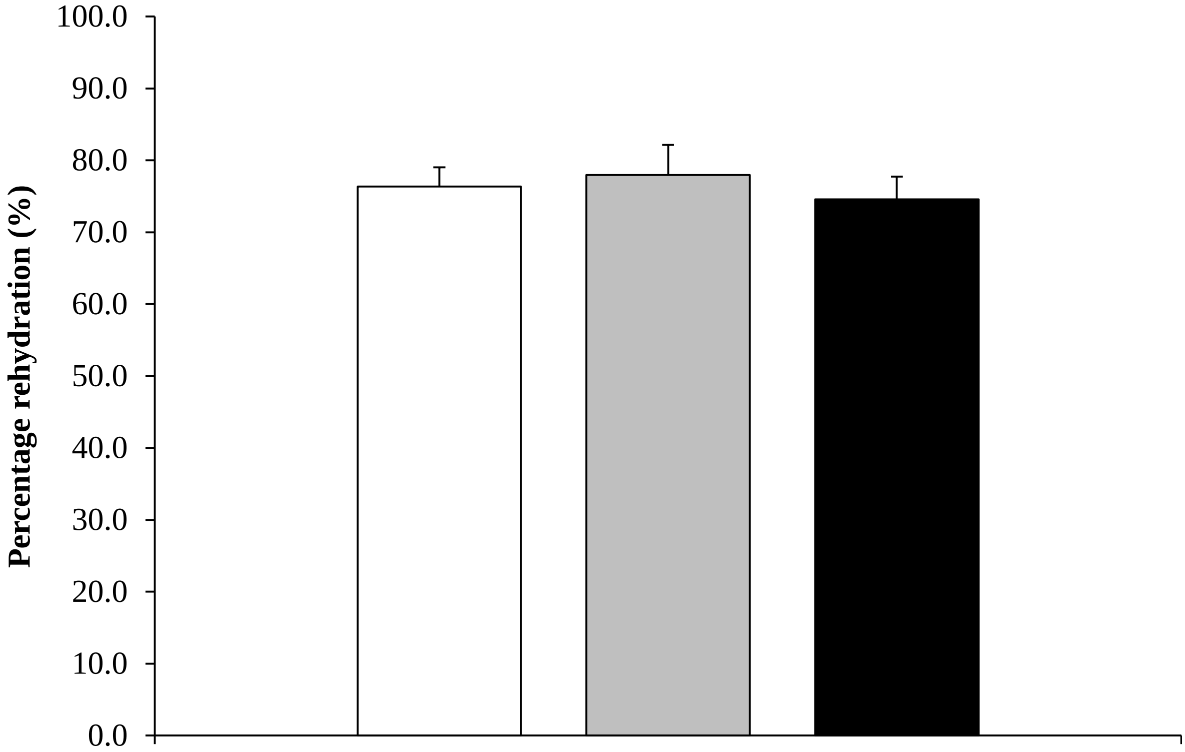

Fig. 3. Percentage rehydration at the end of the rehydration phase. White bars – Coconut Water, Grey Bars – Sports Drink, Black Bars – Plain Water.

The measurement of percentage rehydration reflects the amount of fluid that remains within the body following rehydration. On average the percent rehydration was not significantly different, 76.4 ± 11.0; 78.0 ± 17.3; 74.6 ± 13.0% (P = 0.871) for coconut water, sports drink and water respectively, seen in figure 2 above. Again effect sizes were calculated, results were as follows: d = 0.05, 0.20 and 0.10 for coconut water compared to sports drink, coconut water compared to plain water and sports drink compared to plain water respectively. Effect sizes were therefore trivial between coconut water and the sports drink and well as between the sports drink and plain water. There was a small effect size found between coconut water and plain water.

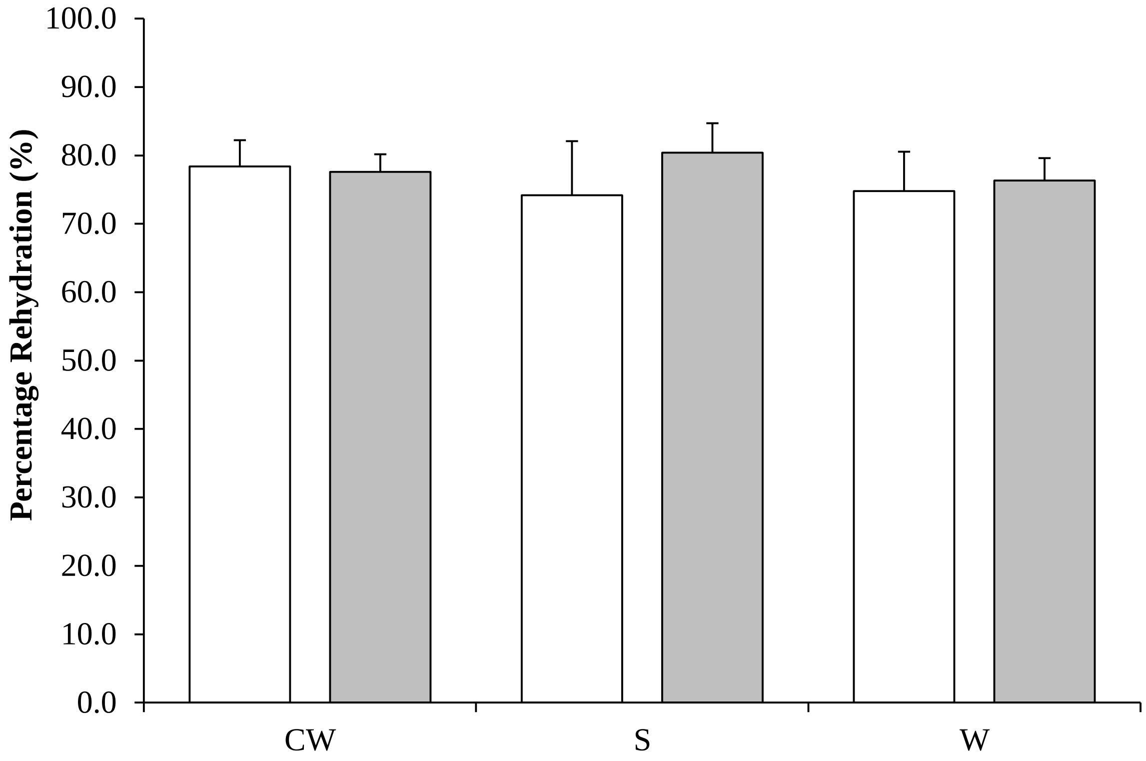

Fig. 4. Percentage rehydration at the end of the rehydration phase, with subjects split dependant on aerobic fitness. White bars – Group 1, Grey Bars – Group 2, CW – coconut water trial, S – sports drink trial and W – plain water trial.

No significant differences (*P* = 0.86, 0.27 and 0.79 following coconut water, sports drink and plain water trials respectively) were found in the percentage rehydration values when group 1 and 2 were compared following the coconut water, sports drink and plain water trials. Percentage rehydration values of 78.4 ± 10.8% (group 1) and 77.6 ± 7.2% (group 2) were found following the coconut water trial (*d* = 0.07), values of 74.2 ± 22.3% (group 1) and 80.4 ± 12.2% (group 2) were seen following the sports drink trial (*d* = 0.31) and values of 74.8 ± 16.2% (group 1) and 76.3 ± 9.3% (group 2) were seen following the plain water trial (*d* = 0.10).

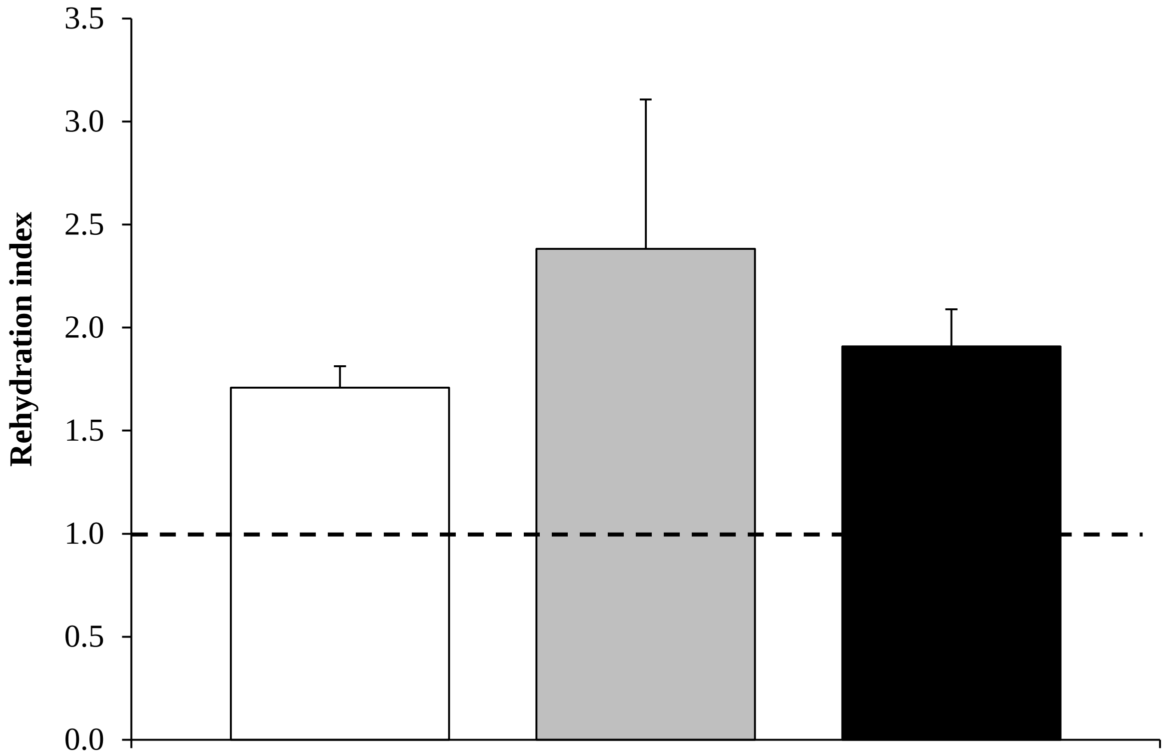

Fig. 5. Rehydration index of each fluid. Dashed line at 1.0 shows the optimum value. White bars – Coconut Water, Grey Bars – Sports Drink, Black Bars – Plain Water.

Rehydration index (RI) is a calculation used to give an estimation of the effectiveness of a rehydration fluid at restoring the body mass lost following dehydration. RI in this study was also not found to be significantly different between trials 1.7 ± 0.4; 2.4 ± 2.9; 1.9 ± 0.7 (P = 0.537) for coconut water, sports drink and water respectively (seen in figure 3). Cohen effect size (d) results were as follows: d = 0.30, 0.30 and 0.20 for coconut water compared to sports drink, coconut water compared to plain water and sports drink compared to plain water respectively. All differences were found to be small effect sizes.

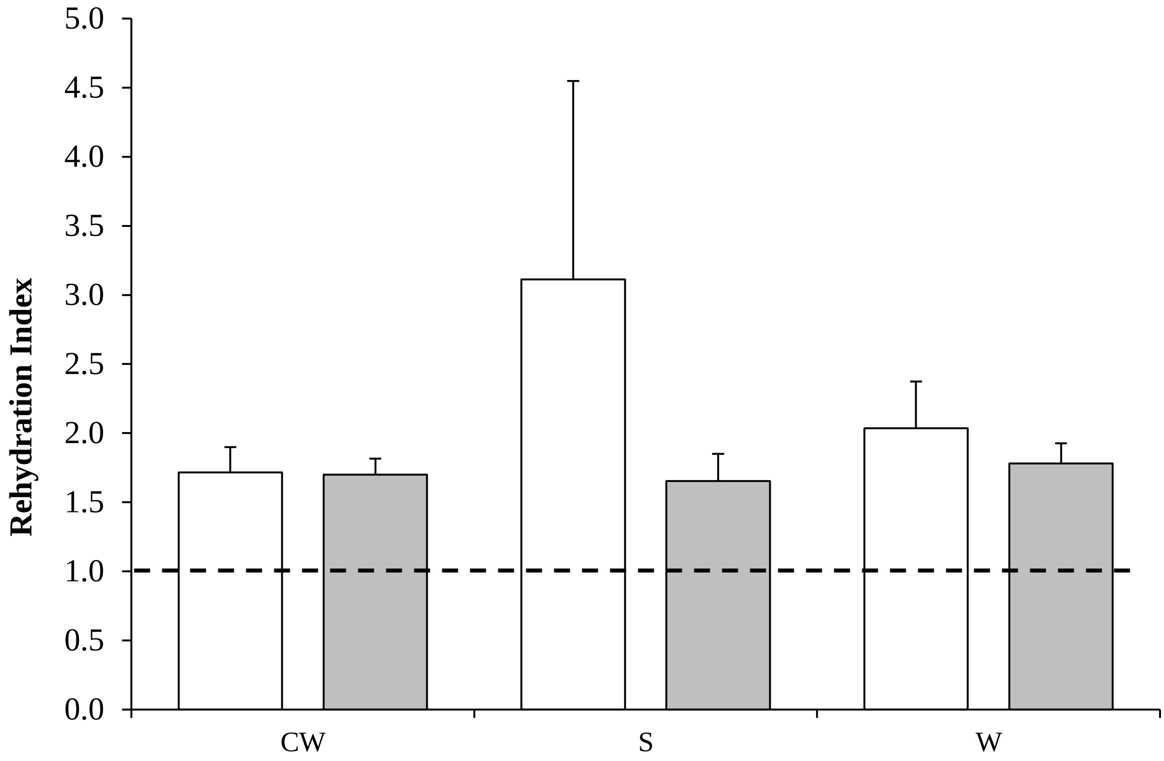

Fig. 6. Rehydration index of each fluid, showing subjects split dependant on aerobic fitness. Dashed line at 1.0 shows the optimum value. White bars – Group 1, Grey Bars – Group 2, CW – coconut water trial, S – sports drink trial and W – plain water trial.

RI was not found to be significantly different between group 1 and 2 following the coconut water trial (P = 0.94, d = 0.03). Although not significant (P = 0.30 and 0.47 for sports drink and plain water trials respectively) there were small effect sizes found between group 1 and 2 following the sports drink trial (d = 0.36) and plain water trials (d = 0.25).

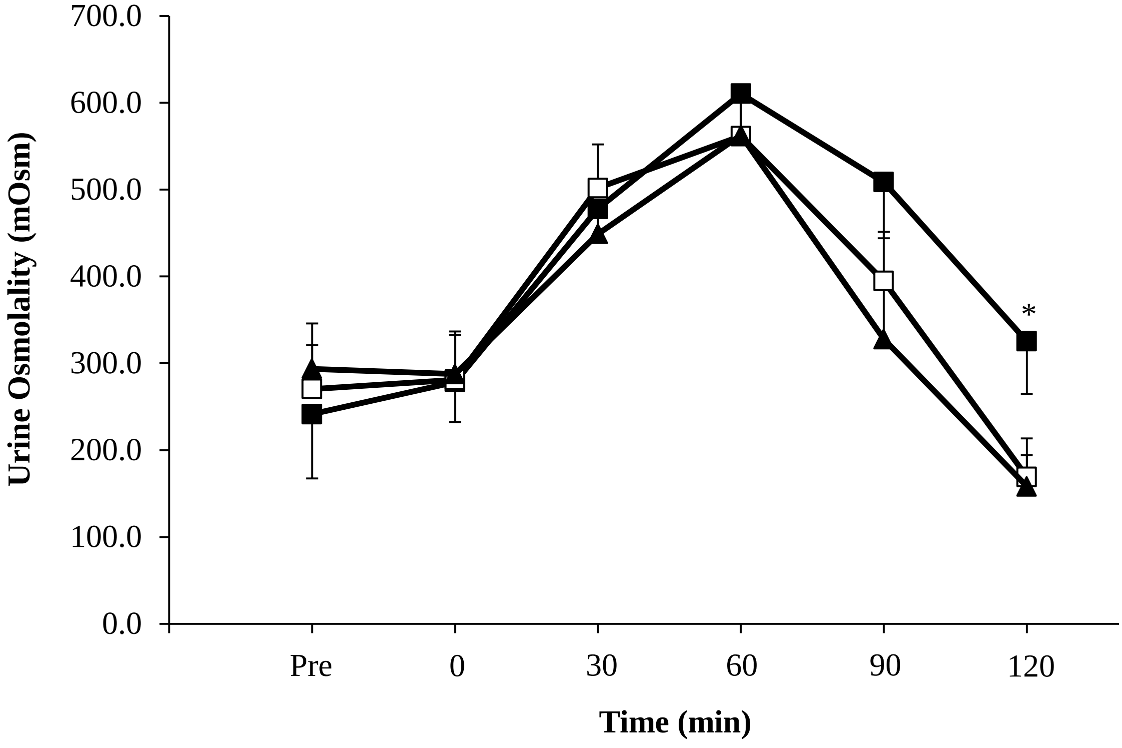

Fig. 7. Urine osmolality measured at each time point throughout the experimental trials. ■ – Coconut Water, □ – Sports Drink, ▲ – Plain Water. * – denotes a significant difference compared Plain Water.

It can be seen from figure 4 that urine osmolality followed a similar trend for all trials. There appears to be a delay in the detection of dehydration using urine osmolality as pre exercise values measured were 241.5 ± 296.5, 270.4 ± 201.8 and 293.6 ± 208.9 mOsm for coconut water, sports drink and plain water respectively. These values were not significantly different post exercise with osmolality measured as 278.6 ± 185.7, 281.1 ± 206.8 and 287.5 ± 183.6 mOsm for coconut water, sports drink and plain water respectively. The values then rose from post exercise to a peak at 60 minutes (610.6 ± 182.4, 561.6 ± 182.3 and 562.8 ± 177.6 mOsm for coconut water, sports drink and plain water respectively) into the rehydration phase. Thereafter urine osmolality began to decrease back to euhydration values. No significant differences were seen between each of the trials before exercise (P = 0.961), immediately after exercise (P = 0.992), or at 30 (P = 0.876), 60 (P = 0.688) and 90 minutes (P = 0.124) into the rehydration phase. Significance was found at the end of the rehydration phase, 120 minutes (P = 0.03), for coconut water compared to plain water with coconut water producing significantly higher values of urine osmolality. There was no significant difference found between coconut water and the sports drink at the same time point.

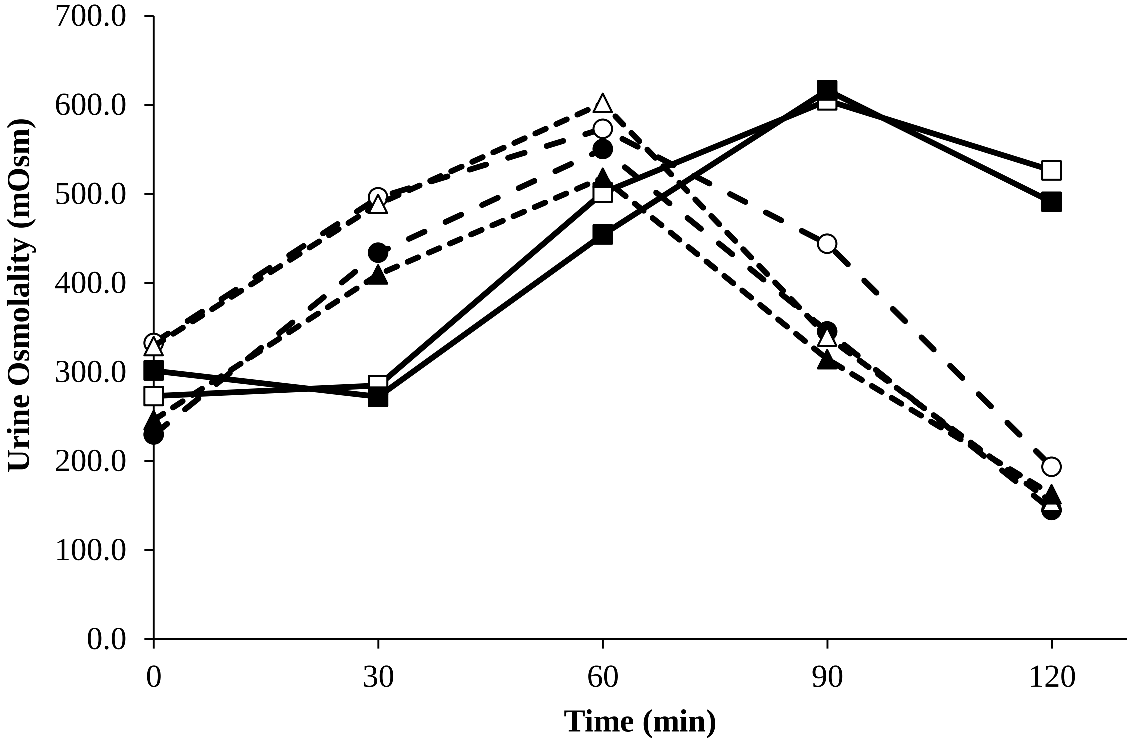

Fig. 8. Urine osmolality measured at each time point throughout the experimental trials with subjects split dependant on aerobic fitness. □- coconut water (group 1), ■ – coconut water (group 2), ○ – sports drink (group 1), ●– sports drink (group 2), △– plain water (group 1), ▲ – plain water (group 2).

Throughout all 3 trials the traces of urine osmolality followed a similar trend for group 1 and group 2 subjects. No significant differences were found in the urine osmolality values between the groups throughout all 3 trials, P values all > 0.05 and effect sizes all small, d < 0.40.

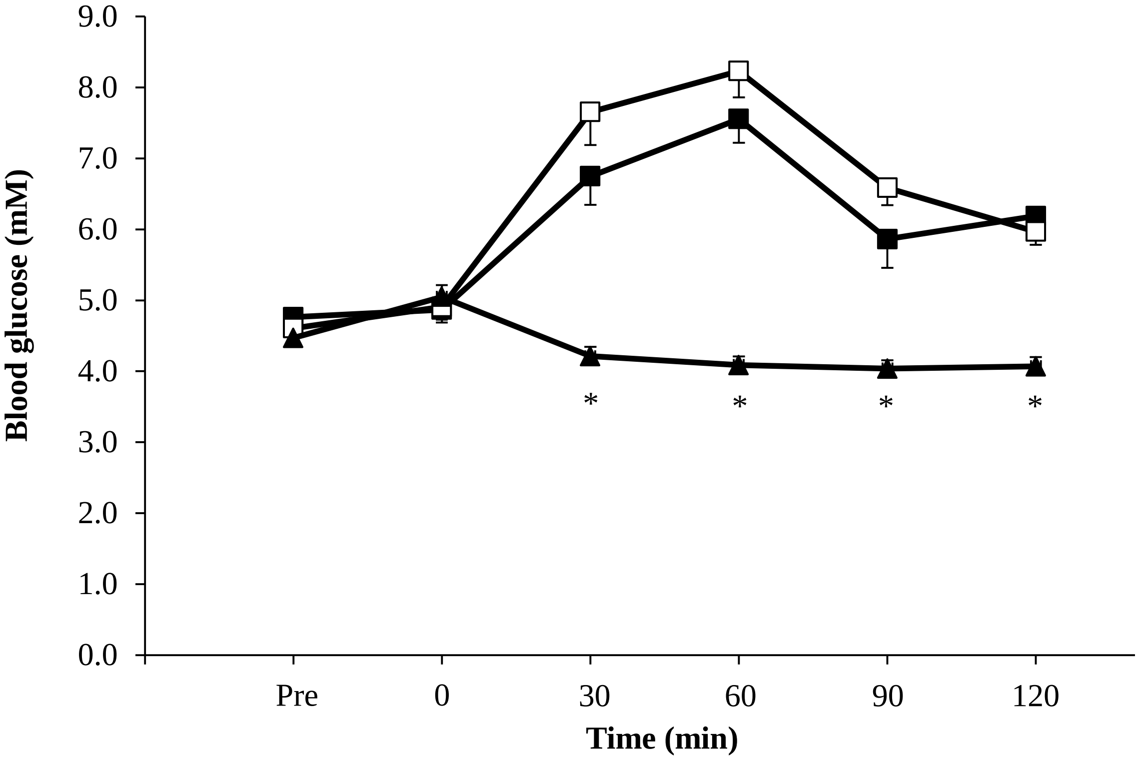

Fig. 9. Blood glucose measured at each time point throughout the experimental trials. ■ – Coconut Water, □ – Sports Drink, ▲ – Plain Water. * – denotes a significant difference compared to Coconut Water & Sports Drink.

There was no significant difference found between any of the trials pre exercise ($P = 0.835$), with mean values found to be 4.8 ± 0.6, 4.6 ± 0.7 and 4.5 ± 0.6 mM for coconut water, sports drink and plain water trials respectively. As expected, it was found that blood glucose was significantly greater across all the time points within the rehydration phase during the coconut water and sports drink trials compared to the water trial (all $P < 0.005$). During the coconut water and sports drink trials subjects reached a peak blood glucose value at 60 minutes into the rehydration phase, with values of 7.6 ± 1.3 and 8.2 ± 1.5 mM for coconut water and sports drink respectively. Interestingly although coconut water and the sports drink followed a similar profile over time, there was a consistent difference between the two with coconut water producing lower blood glucose values than the sports drink from 30 to 90 minutes of rehydration. Although these differences were not significant, Cohen's effect sizes (*d*) at 30, 60 and 90 minutes into rehydration were found to be 0.44, 0.40 and 0.41 respectively indicating a medium effect size between coconut water and the sports drink at these time points.

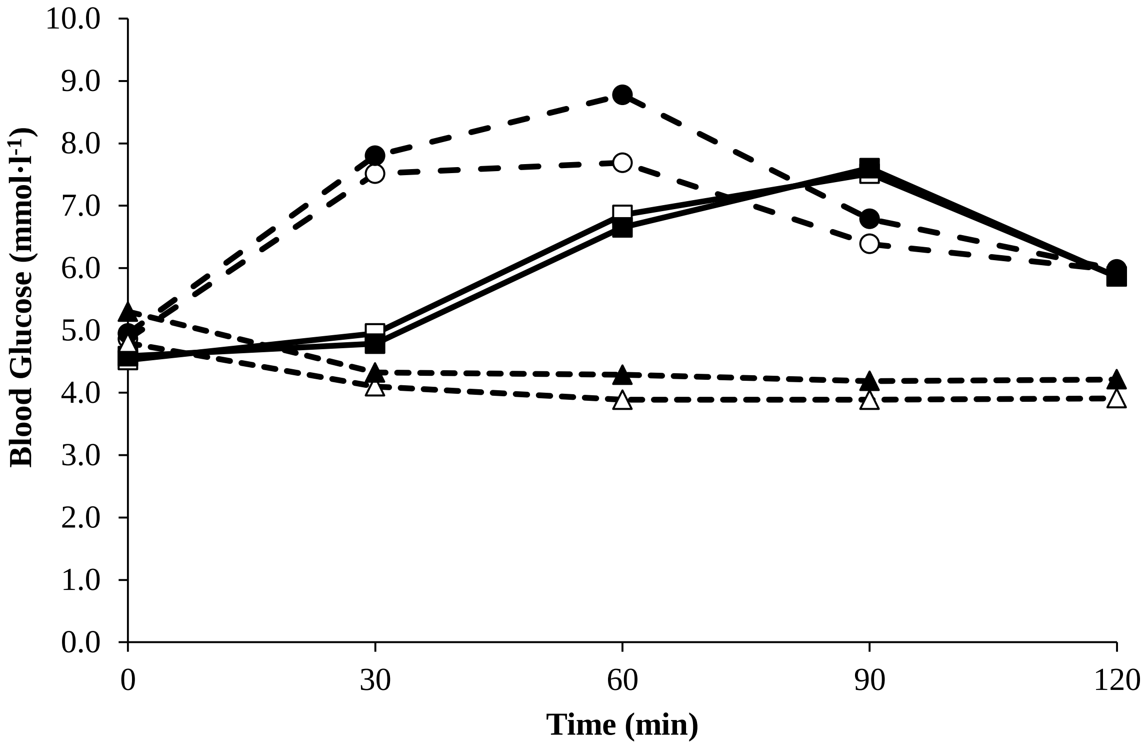

Fig. 10. Blood glucose measured at each time point throughout the experimental trials, showing subjects grouped dependant on fitness levels. □– coconut water (group 1), ■ – coconut water (group 2), ○ – sports drink (group 1), ● – sports drink (group 2), △ – plain water (group 1), ▲ – plain water (group 2).

Again throughout all 3 trials the traces for group 1 and group 2 were found to follow the same trend. No significant differences were found in blood glucose values between group 1 and 2, P values all > 0.05 and effect sizes all small, d < 0.40.

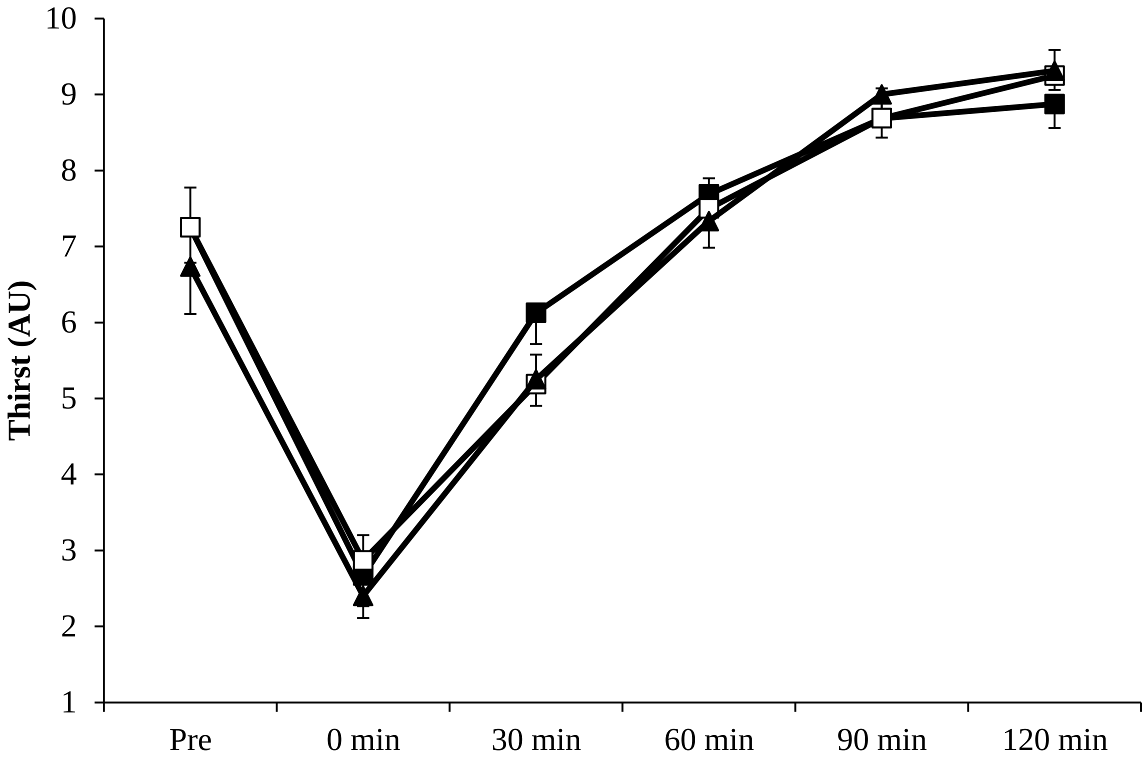

Fig. 11. Feelings of thirst that the subjects expressed at each time point throughout the trials. 1 = very thirsty, 10 = not thirsty at all. ■ – Coconut Water, □ – Sports Drink, ▲ – Plain Water.

Throughout all the trials the trends seen in subjective feeling of thirst follow the same pattern. Subjects initially scored 7.3 ± 1.8, 7.3 ± 1.9 and 6.7 ± 2.4 for the coconut water, sports drink and plain water trials respectively. Subjects were found to be most thirsty following the dehydrating exercise (2.7 ± 1.5, 2.9 ± 1.3 and 2.4 ± 1.1 for the coconut water, sports drink and plain water trials respectively). Feelings of thirst scores surpassed pre exercise values by the end of the rehydration phase during all trials (8.9 ± 1.3, 9.3 ± 1.3 and 9.3 ± 1.0 for the coconut water, sports drink and plain water trials respectively). No significant differences were found between any of the trials, *P* = 0.164, 0.819, 0.706 and 0.548 for time points 30, 60, 90 and 120 minutes during rehydration.

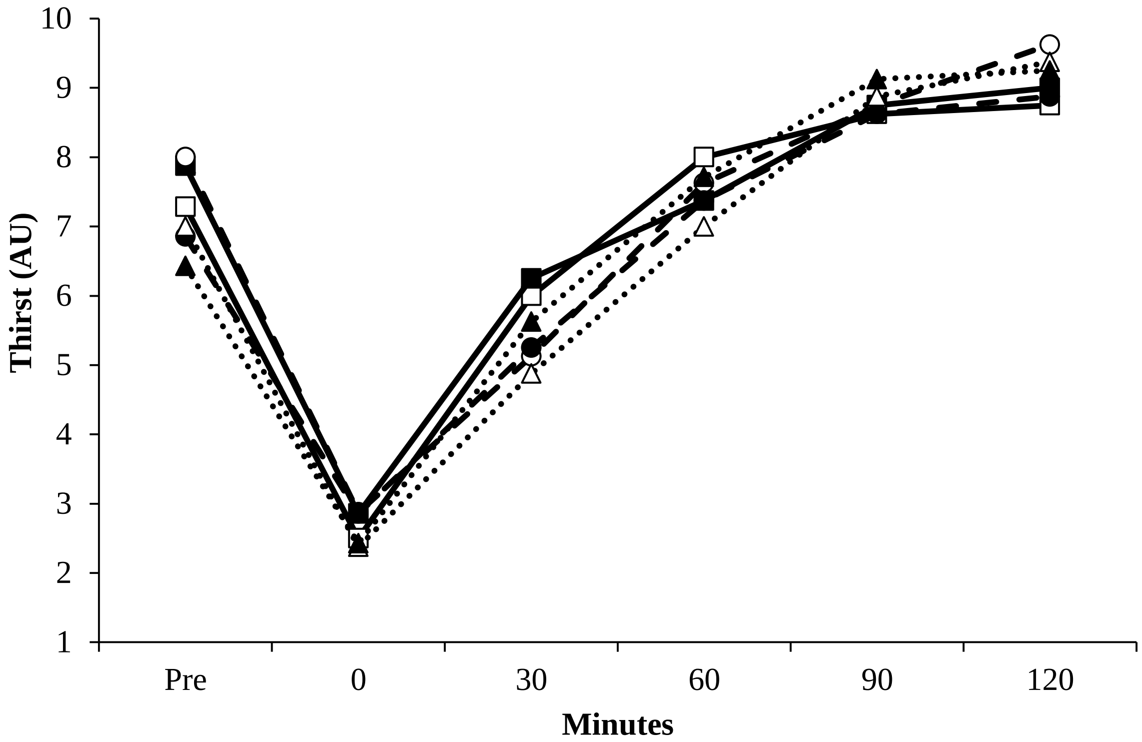

Fig. 12. Feelings of thirst that the subjects expressed at each time point throughout the trials, with subjects divided into groups dependant on aerobic fitness levels. 1 = very thirsty, 10 = not thirsty at all. □ – coconut water (group 1), ■ – coconut water (group 2), ○ – sports drink (group 1), ● – sports drink (group 2), △ – plain water (group 1), ▲ – plain water (group 2).

There were no significant differences found between group 1 and group 2 subjects at the beginning of all 3 trials, P = 0.51, 0.16 and 0.48 for coconut water, sports drink and plain water trials respectively. Effect sizes were found to be small or trivial except for at 120 minutes into the rehydration phase where a medium effect size was found between group 1 and 2 during the sports drink trial (d = 0.03).

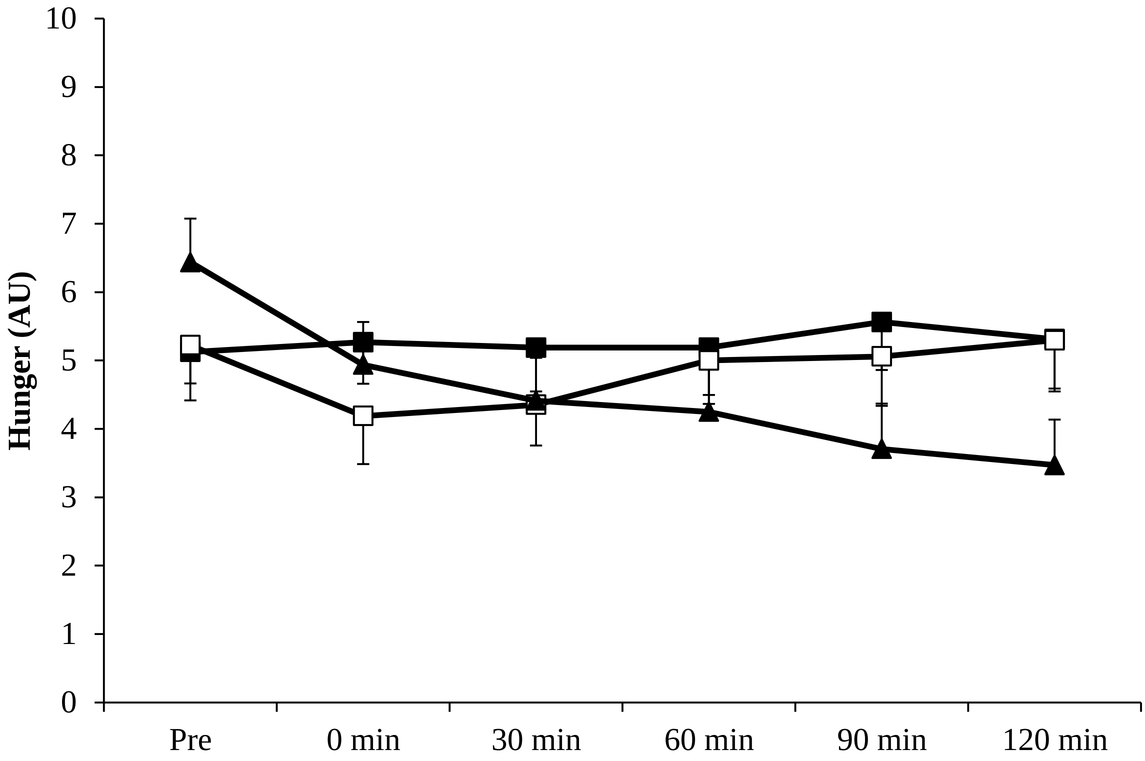

Fig. 13. Feelings of hunger that the subjects expressed at each time point throughout the trials. 1 = very hungry, 10 = not hungry at all. Closed Squares – Coconut Water, Open Squares – Sports Drink, Closed Triangles – Plain Water.

As can be seen in figure 7, subjects reported feelings of hunger to be reasonably stable throughout both the coconut water and sports drink trials. It would appear that over time throughout the plain water trial that subjects' scores for feelings of hunger steadily decreased, meaning subjects were becoming increasingly hungry with time. However, no significant differences were found between any of the trials, P = 0.0661, 0.658, 0.185 and 0.153 for time points 30, 60, 90 and 120 minutes during rehydration.

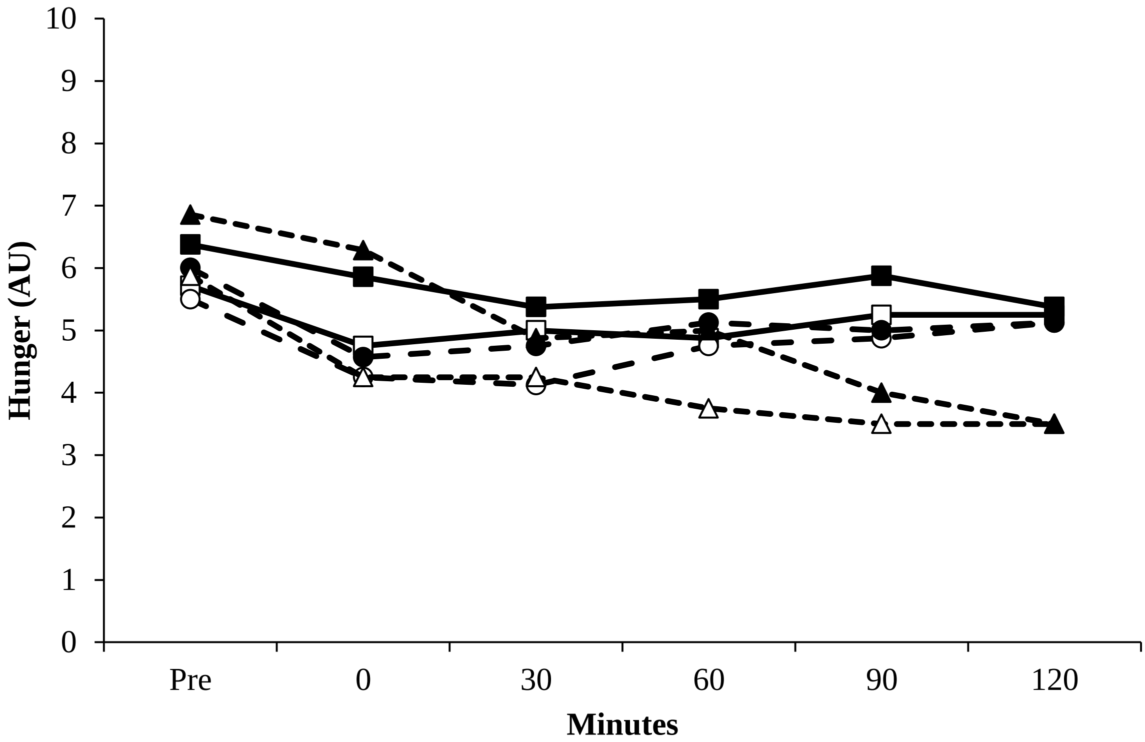

Fig. 14. Feelings of hunger that the subjects expressed at each time point throughout the trials, with subjects divided into groups dependant on aerobic fitness levels. 1 = very hungry, 10 = not hungry at all. □ – coconut water (group 1), ■– coconut water (group 2), ○– sports drink (group 1), ● – sports drink (group 2), △ – plain water (group 1), ▲ – plain water (group 2).

No significance was found at any time point throughout all the trials between groups 1 and 2 ($P > 0.05$) for ratings of feeling hungry. Medium effect sizes were seen immediately after exercise during the coconut water ($d = 0.41$) and plain water ($d = 0.77$) trials, with the fitter individuals reporting larger values i.e. feeling less hungry.

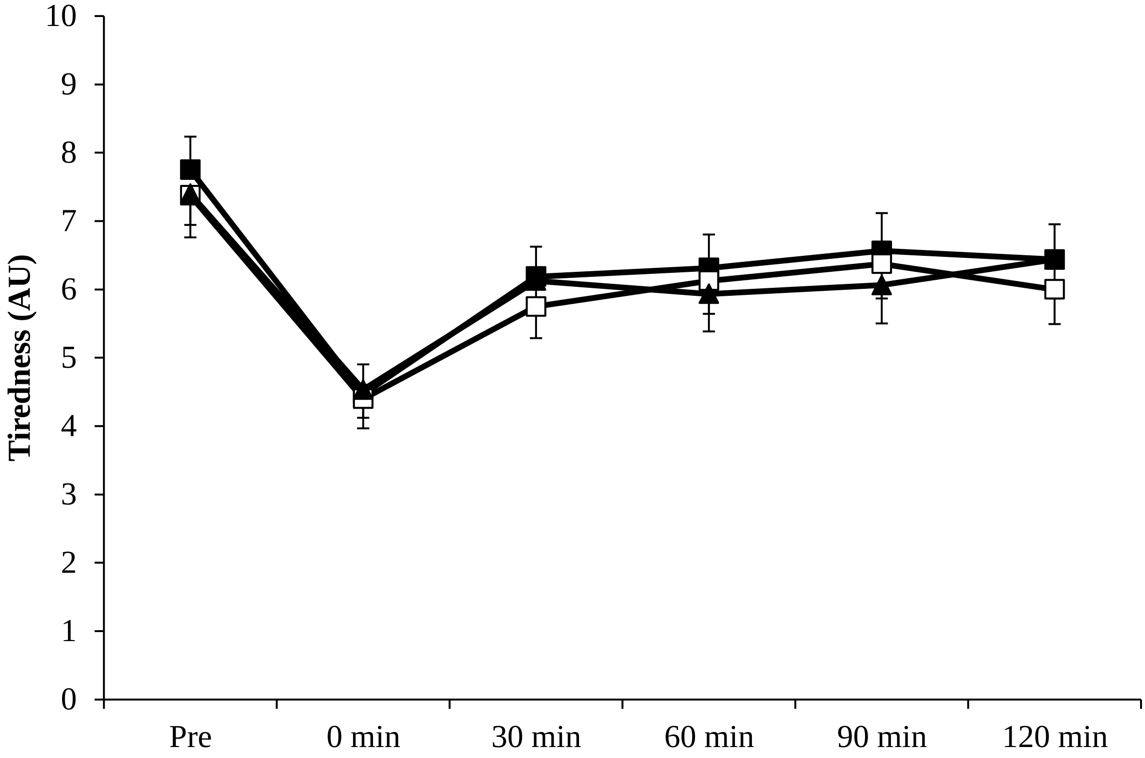

Fig. 15. Feelings of tiredness that the subjects expressed at each time point throughout the trials. 1 = very tired, 10 = not tired at all. Closed Squares – Coconut Water, Open Squares – Sports Drink, Closed Triangles – Plain Water.

Similar trends can be seen in figure 8 for subjects' reported feeling of tiredness throughout each of the trials. Subjects initially scored 7.8 ± 1.9, 7.4 ± 2.2 and 7.4 ± 1.8 for the coconut water, sports drink and plain water trials respectively. As expected, subjects felt most tired immediately post exercise (4.5 ± 1.7, 4.4 ± 1.7 and 4.5 ± 1.6 for the coconut water, sports drink and plain water trials respectively). Over the course of the rehydration phase, feelings of tiredness began to recover however they failed to be returned to pre exercise values by the end of the 120 minutes (6.4 ± 2.1, 6.0 ± 2.0 and 6.4 ± 2.3 for the coconut water, sports drink and plain water trials respectively). No significant differences were found between any of the trials, P = 0.764, 0.871, 0.805 and 0.799 for time points 30, 60, 90 and 120 minutes during rehydration.

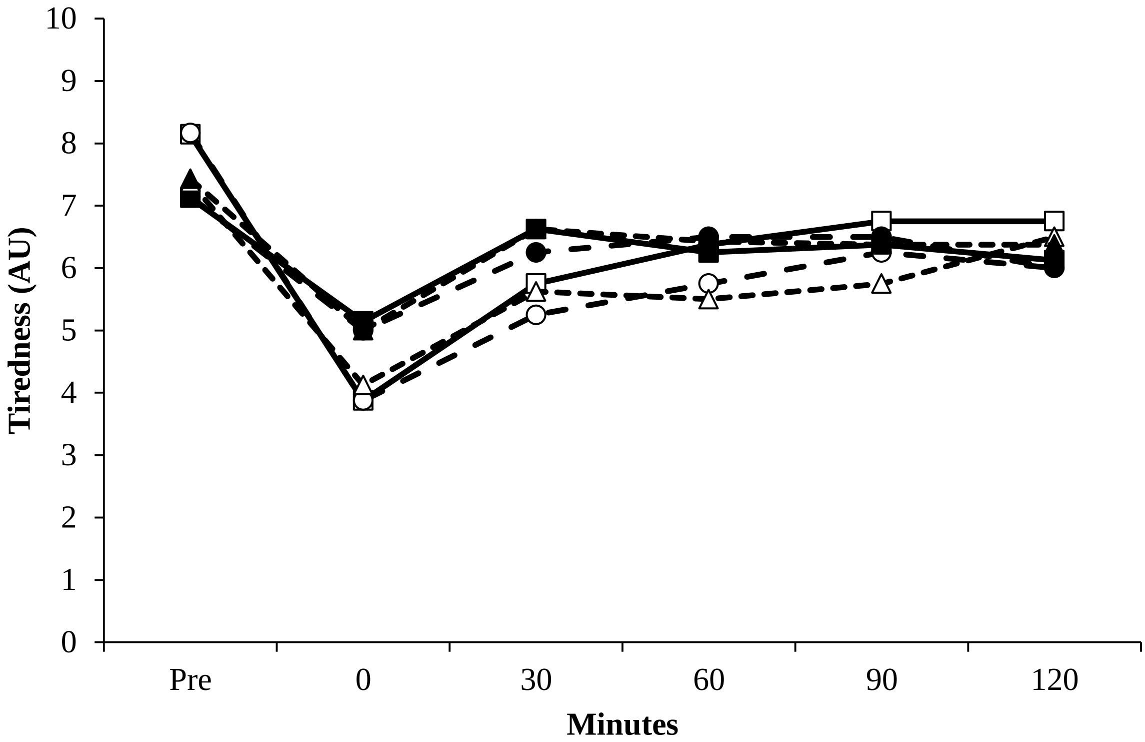

Fig. 16. Feelings of tiredness that the subjects expressed at each time point throughout the trials, with subjects divided into groups dependant on aerobic fitness levels. 1 = very tired, 10 = not tired at all. □ – coconut water (group 1), ■ – coconut water (group 2), ○ – sports drink (group 1), ● – sports drink (group 2), △ – plain water (group 1), ▲ – plain water (group 2).

No significance was found at any time point throughout all the trials between groups 1 and 2 ($P > 0.05$) for ratings of feeling tired. Medium effect sizes were seen immediately after exercise during all 3 trials (d = 0.65, 0.62 and 0.46 for coconut water, sports drink and plain water trials respectively), with the fitter individuals reporting larger values i.e. feeling less tired. Medium effect sizes were again found 30 minutes into the rehydration phase during all 3 trials (d = 0.42, 0.49 and 0.46 for coconut water, sports drink and plain water trials respectively).

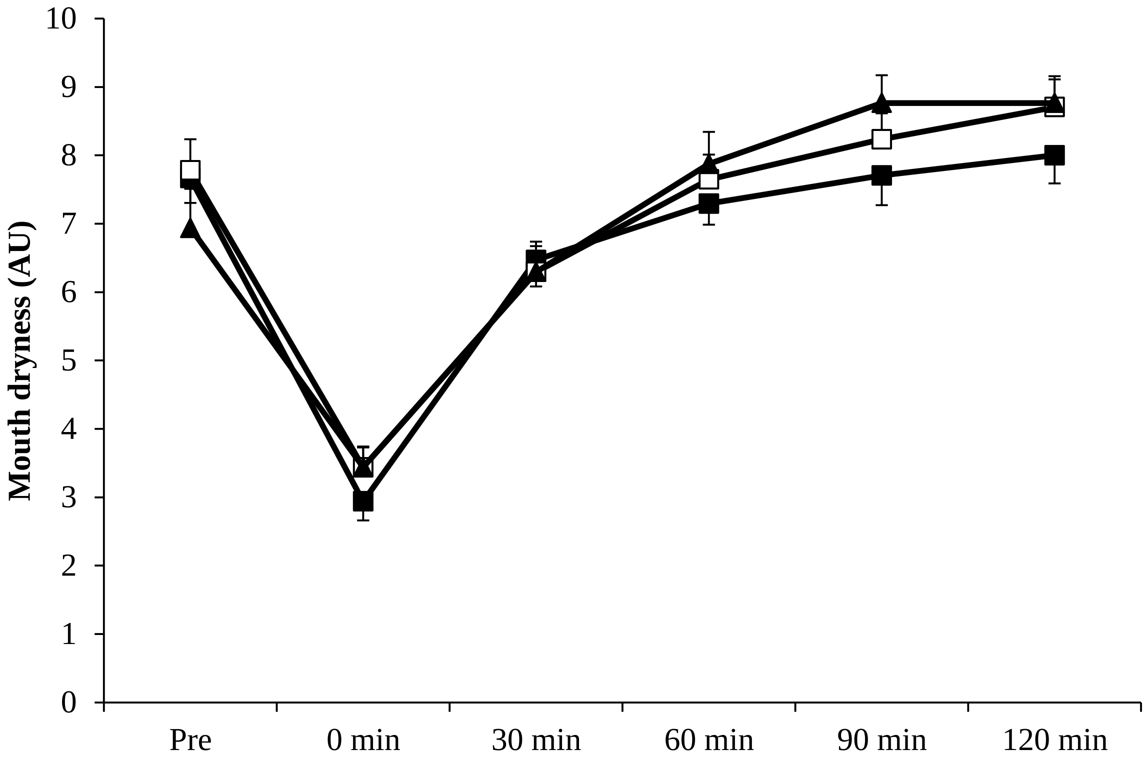

Fig. 17. How dry the subjects thought their mouths felt at each time point throughout the trials. 1 = mouth felt very dry, 10 = mouth did not feel dry at all. Closed Squares – Coconut Water, Open Squares – Sports Drink, Closed Triangles – Plain Water.

Subjects initially scored 7.5 ± 1.4, 7.5 ± 1.7 and 6.7 ± 2.2 for the coconut water, sports drink and plain water trials respectively. Subjects felt that their mouths felt most dry immediately after the dehydrating exercise, as should be expected, in all trials (3.0 ± 1.1, 3.5 ± 1.2 and 3.35 ± 1.1 for the coconut water, sports drink and plain water trials respectively). No significant differences were found between any of the trials, P = 0.902, 0.530, 0.232 and 0.419 for time points 30, 60, 90 and 120 minutes during rehydration. Feelings of mouth dryness were recovered to values greater than pre exercise values by the end of the rehydration phase during all trials (8.0 ± 1.6, 8.6 ± 1.6 and 8.7 ± 1.6 for the coconut water, sports drink and plain water trials respectively).

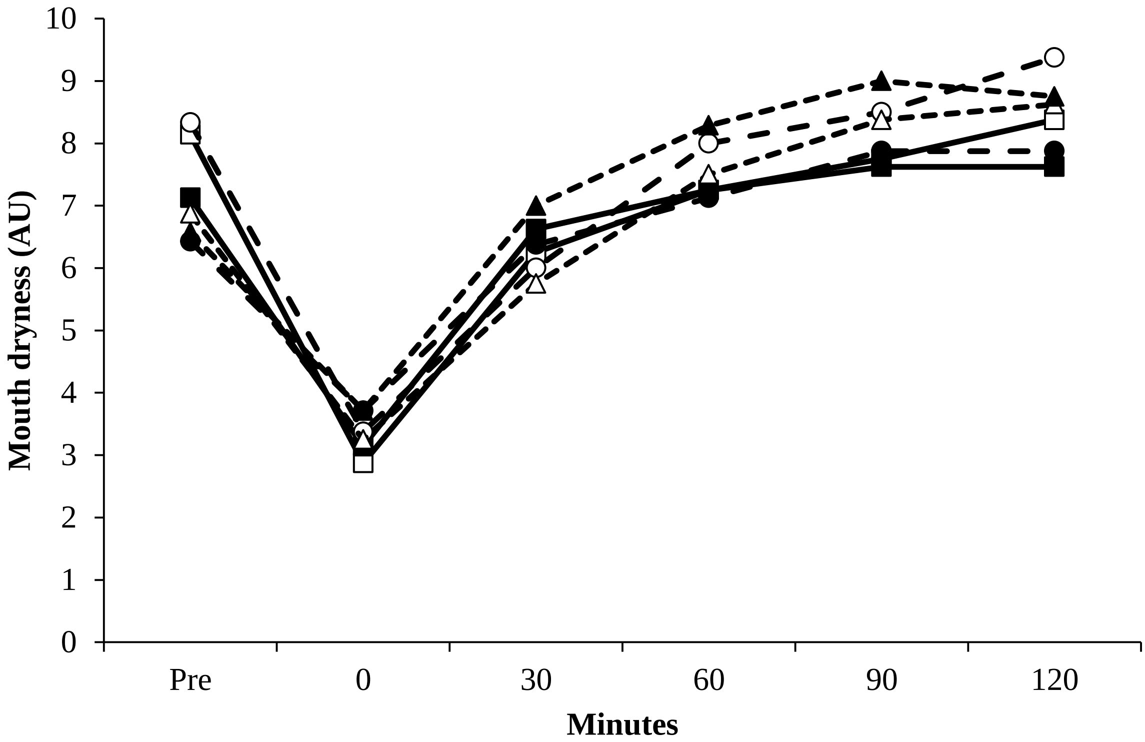

Fig. 18. How dry the subjects thought their mouths felt at each time point throughout the trials, with subjects divided into groups dependant on aerobic fitness levels. 1 = mouth felt very dry, 10 = mouth did not feel dry at all. □– coconut water (group 1), ■– coconut water (group 2), ○ – sports drink (group 1), ● – sports drink (group 2), △– plain water (group 1), ▲ – plain water (group 2).

There were no significant differences found in mouth dryness throughout each trial between group 1 and group 2. At time point 60 minutes a medium effect size was found between group 1 and group 2 during the sports drink trial (*d* = 0.50). Medium effect sizes were also seen at 120 minutes into rehydration during the coconut water (*d* = 0.41) and sports drink (*d* = 0.90) trials, with the fitter subjects (group 2) reporting that their mouth felt drier than the group 1 subjects.

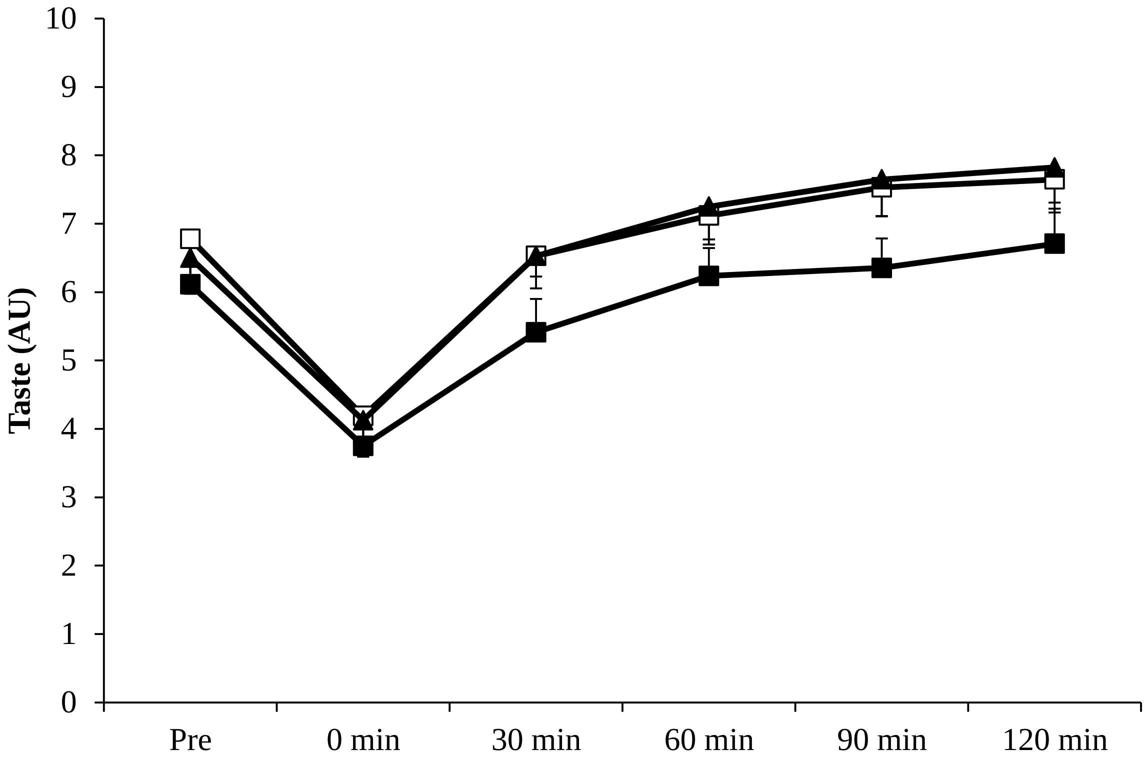

Fig. 19. How subjects felt the taste in their mouths was at each time point throughout the trials. 1 = bad taste in the mouth, 10 = excellent taste in the mouth. Closed Squares – Coconut Water, Open Squares – Sports Drink, Closed Triangles – Plain Water.

Pre-exercise (6.3 ± 2.1, 6.8 ± 2.2 and 6.4 ± 2.0 for the coconut water, sports drink and plain water trials respectively) and immediately post exercise (3.8 ± 1.3, 4.3 ± 1.4 and 4.1 ± 2.1 for the coconut water, sports drink and plain water trials respectively) there was found to be no significant differences in the subjective feelings of taste within the subjects' mouths for all the trials. However, throughout the rehydration phase when subjects were given the beverages to consume, there appeared to be differences between the coconut water and the other two beverages. Although not significant (P = 0.076, 0.221, 0.092 and 0.320 for 30, 60, 90 and 120 minutes respectively) subjects reported the taste in their mouth to be worse while drinking coconut water. Cohen's effect sizes were found to be medium effects, d = 0.5, 0.5, 0.6 and 0.4 when coconut water was compared to the sports drink at 30, 60, 90 and 120 minutes into rehydration respectively. Similar results were seen when coconut water was compared to plain water, medium effect sizes, d = 0.6, 0.5, 0.6 and 0.4 for 30, 60, 90 and 120 minutes into rehydration respectively. When sports drink was compared to plain water d = 0.1, 0.1, 0.0 and 0.1 at 30, 60, 90 and 120 minutes into rehydration respectively, all of which are trivial differences.

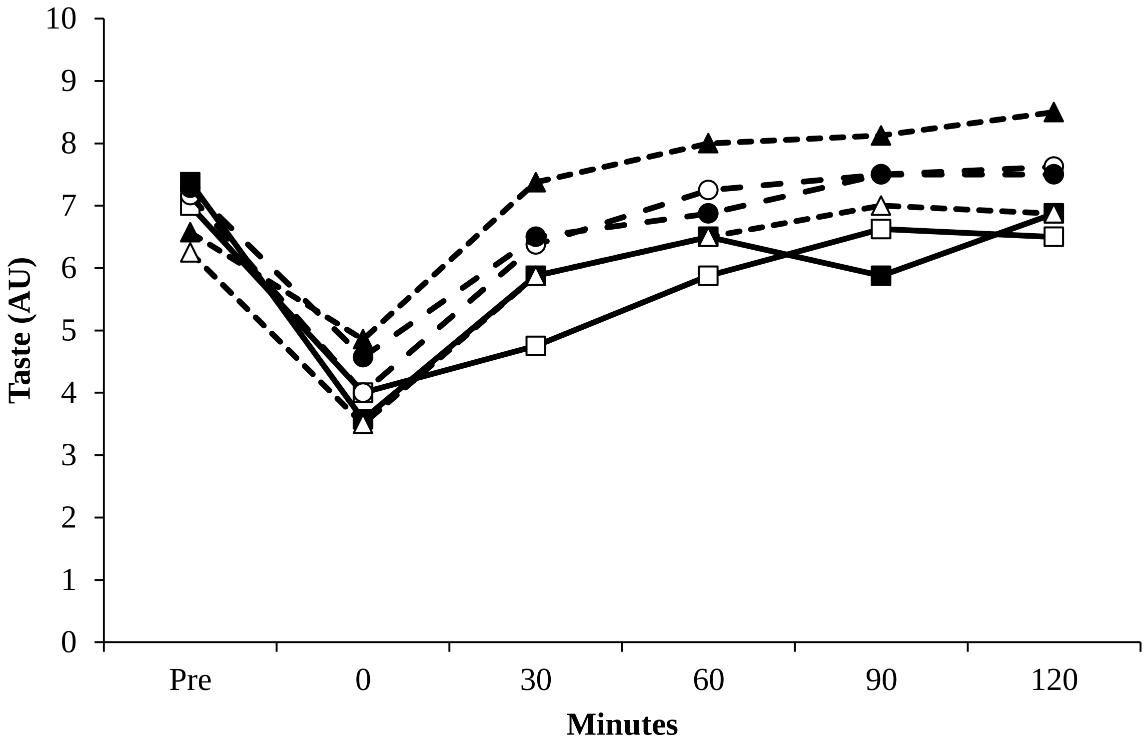

Fig. 20. How subjects felt the taste in their mouths was at each time point throughout the trials, with subjects divided into groups dependant on aerobic fitness levels. 1 = bad taste in the mouth, 10 = excellent taste in the mouth. □– coconut water (group 1), ■– coconut water (group 2), ○ – sports drink (group 1), ● – sports drink (group 2), △ – plain water (group 1), ▲ – plain water (group 2).

No significant differences were seen at any time point throughout all 3 trials between group 1 and group 2 subjects. Immediately following exercise the fitter subjects in group 2 reported the taste of plain water to be greater than the group 1 subjects did (d = 0.60). The fitter subjects also reported the taste of coconut water (d = 0.50) and plain water (d = 0.74) to be greater than the group 1 subjects at 30 minutes into rehydration. Plain water continued to be reported as tasting better by the fitter subjects at time points 60, 90 and 120 minutes into rehydration, d = 0.62, 0.45 and 0.69 respectively.

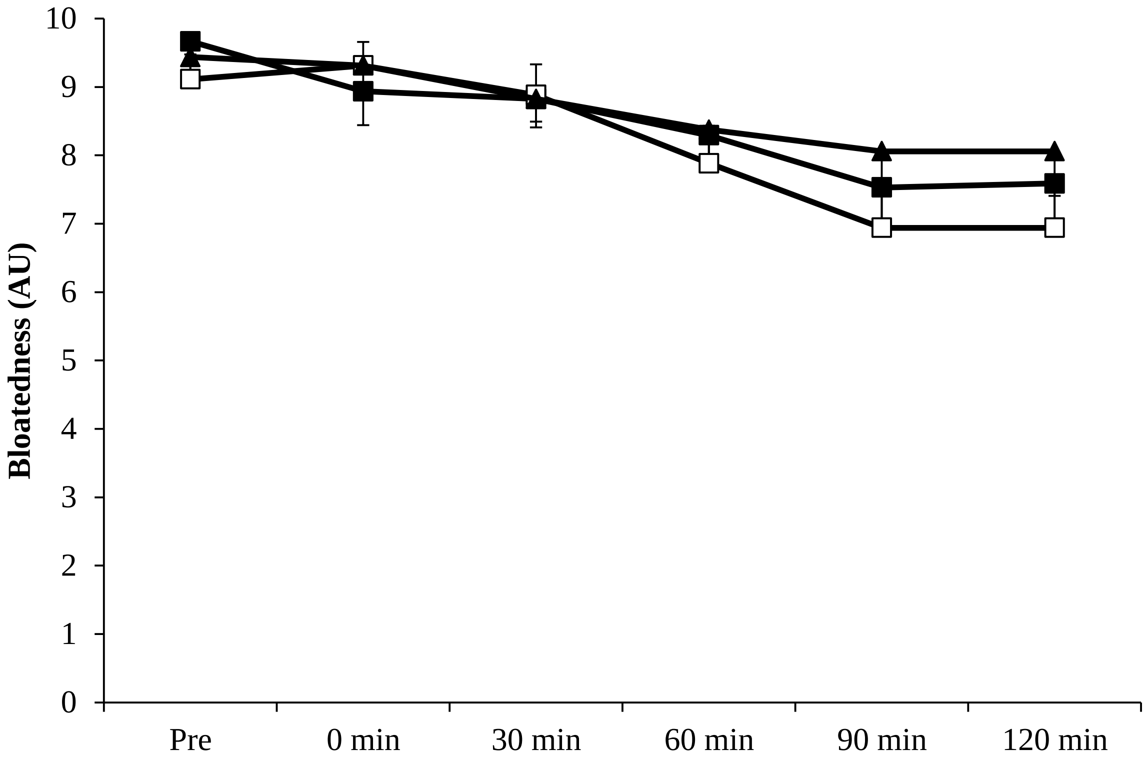

Fig. 21. How bloated the subjects felt at each time point throughout the trials. 1 = very bloated, 10 = not bloated at all. Closed Squares – Coconut Water, Open Squares – Sports Drink, Closed Triangles – Plain Water.

There were no significant differences found in the subjective feelings of bloatedness throughout all the trials (*P* = 0.992, 0.790, 0.582 and 0.658 for 30, 60, 90 and 120 minutes respectively). The same trend was found throughout all trials (can be seen in figure 11) that over the course of time bloatedness values decreased from initial scores of 9.6 ± 0.7, 9.1 ± 1.7 and 9.4 ± 1.1 to 7.8 ± 2.3, 7.2 ± 2.9 and 8.0 ± 2.6 at the end of the rehydration phase for the coconut water, sports drink and plain water trials respectively, meaning subjects were becoming increasingly bloated over time.

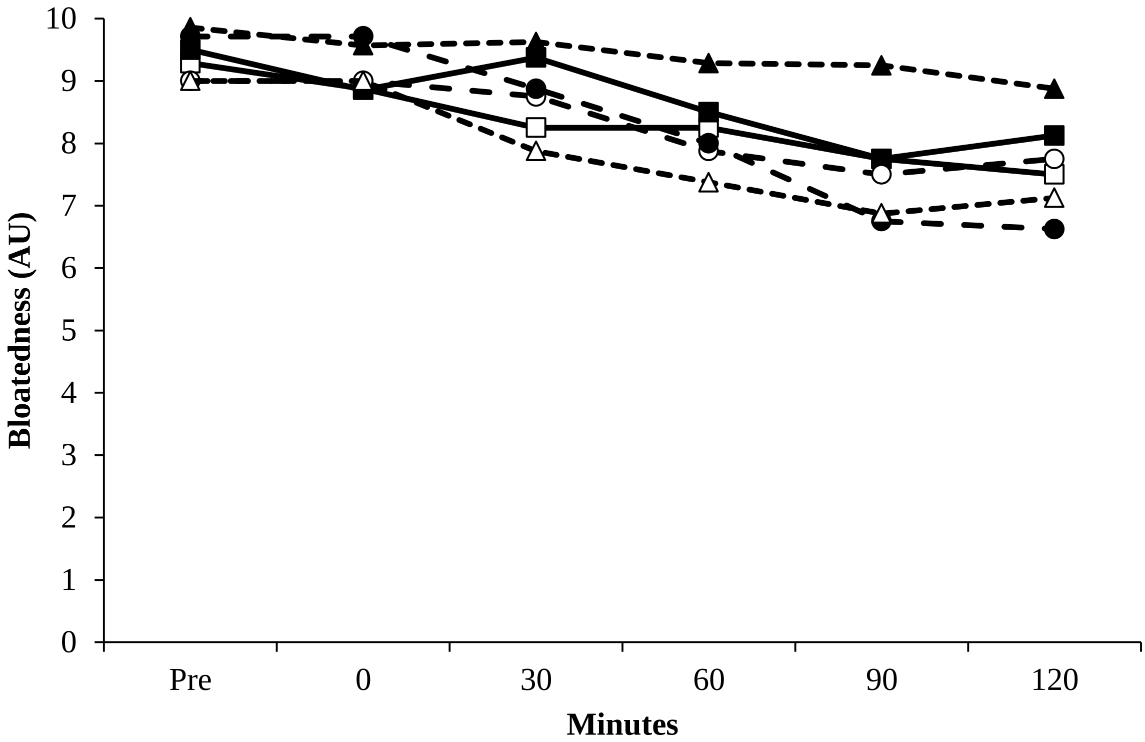

Fig. 22. How bloated the subjects felt at each time point throughout the trials, with subjects divided into groups dependant on aerobic fitness levels. 1 = very bloated, 10 = not bloated at all. □ – coconut water (group 1), ■– coconut water (group 2), ○– sports drink (group 1), ● – sports drink (group 2), △ – plain water (group 1), ▲ – plain water (group 2).

The fitter subjects (group 2) consistently reported feeling less bloated at time points 30, 60, 90 and 120 minutes into rehydration during the plain water trial. A large effect size was seen at 30 minutes (d = 0.88, P < 0.05), 60 minutes (d = 0.81) and 90 minutes (d = 0.88, P < 0.05). A medium effect size was seen at 120 minutes between groups 1 and 2 during the plain water trial (d = 0.56). A medium effect size was also seen during the coconut water trial at the first time point during rehydration (30 minutes), d = 0.68 with fitter subjects reporting feeling less bloated than the subjects in group 1.

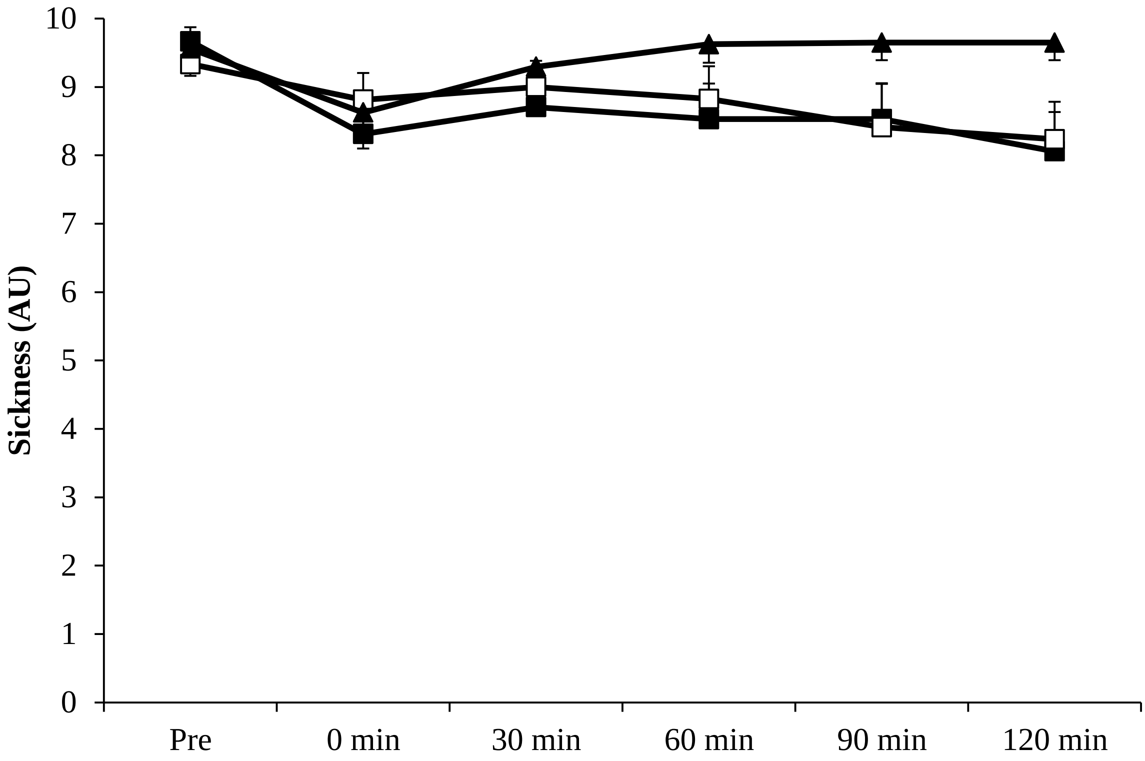

Fig. 23. How sick the subjects felt at each time point throughout the trials. 1 = feeling very sick, 10 = not feeling sick at all. Closed Squares – Coconut Water, Open Squares – Sports Drink, Closed Triangles – Plain Water.

Pre exercise (9.6 ± 0.8, 9.4 ± 1.4 and 9.5 ± 1.6) and immediately post exercise (8.2 ± 2.2, 8.8 ± 1.5 and 8.5 ± 2.0) for the coconut water, sports drink and plain water trials respectively there was found to be no significant differences in the subjective feelings of sickness for all the trials (*P* = 0.570, 0.404, 0.266 and 0.118 for 30, 60, 90 and 120 minutes respectively). However, throughout the rehydration phase when subjects were given the beverages to consume, there appeared to be differences between the plain water and the other two beverages. Scores were recovered at the end of the rehydration phase in only the plain water trial 9.7 ± 1.0, compared to the coconut water trial and sports drink trial 8.3 ± 2.3 and 8.6 ± 2.2 respectively. Figure 12 shows that subjects reported they felt less sick while drinking plain water at time points 60, 90 and 120 minutes into rehydration, compared to drinking coconut water or the sports drink, however further analysis found there to be no significant differences. Cohen's effect sizes were found to be d = 0.2, 0.4, 0.5 and 0.6 when the plain water was compared to the coconut water at 30, 60, 90 and 120 minutes into rehydration respectively. These results represent a small effect size at 30 minutes and medium effects at 60, 90 and 120 minutes into rehydration. Similar results were seen when plain water was compared to the sports drink, a trivial effect was found at 30 minutes, small effect size at 60 minutes and medium effects at both 90 and 120 minutes into rehydration (d = 0.0, 0.3, 0.4 and 0.5 for 30, 60, 90 and 120 minutes into rehydration respectively). When the coconut water was compared to sports drink a small effect was seen after 30 minutes of the rehydration phase, at all other time points effect sizes were found to be trivial (d = 0.2, 0.1, 0.0 and 0.1 at 30, 60, 90 and 120 minutes into rehydration respectively).

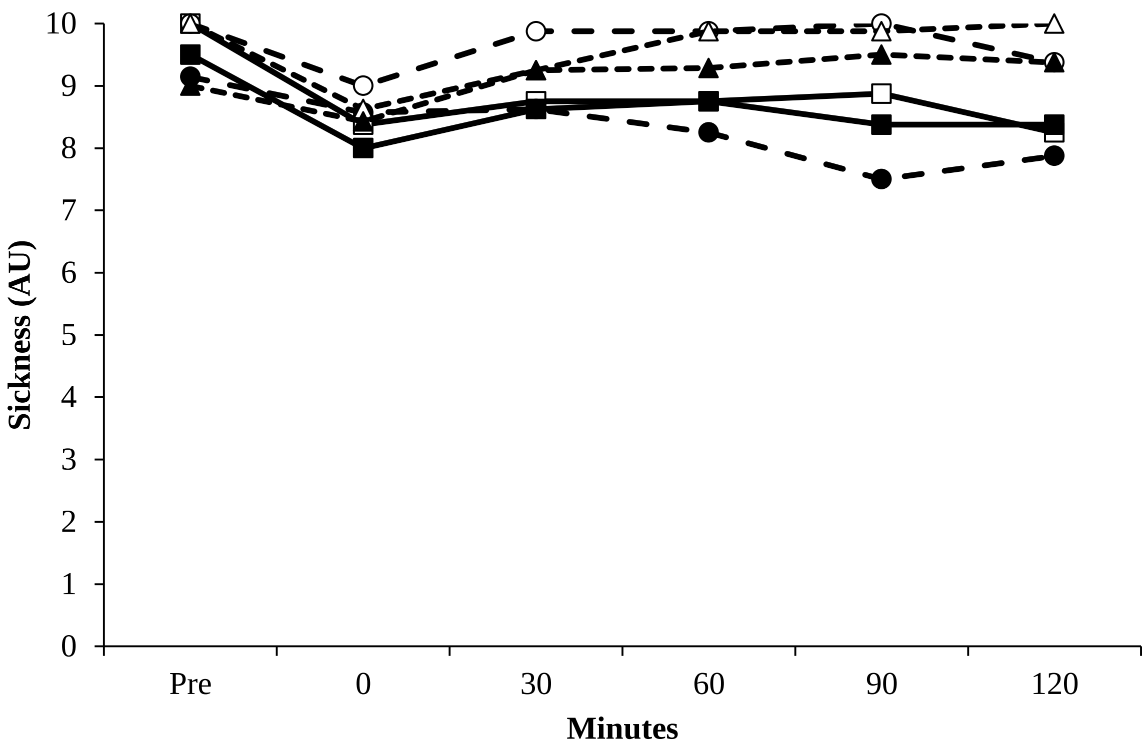

Fig. 24. How sick the subjects felt at each time point throughout the trials, with subjects divided into groups dependant on aerobic fitness levels. 1 = feeling very sick, 10 = not feeling sick at all. □ – coconut water (group 1), ■– coconut water (group 2), ○– sports drink (group 1), ● – sports drink (group 2), △ – plain water (group 1), ▲ – plain water (group 2).

Throughout the rehydration phase the fitter subjects reported feeling more sick during the sports drink trial compared to group 1 subjects, *d* = 0.86, 0.90, 1.10 and 0.69 for time points 30, 60, 90 and 120 minutes respectively. Medium effect sizes were also found during the plain water trial at time points 60 (*d* = 0.53) and 120 minutes (*d* = 0.63) into rehydration, with the fitter subjects again reporting greater feelings of sickness. No significant differences were seen between the groups during the coconut water trial.

Discussion

As previously mentioned, dehydration by as little as a 2% body mass loss can have a detrimental effect on exercise performance. Following the exercise protocol subjects lost on average 2.36 ± 0.45% which indicates that the protocol was successful in dehydrating the subjects by a suitable amount so that subsequent rehydration was required.

After completion of the rehydration phase subjects were found to have restored body mass to 100.4 ± 0.3; 100.4 ± 0.6 and 100.3 ± 0.5% of their initial pre exercise body mass, following the coconut water, sports drink and water trials respectively. These results were in line with those found by Kalman *et al* (2012), who reported subjects restoring body mass by on average 99.49, 99.49 and 99.49% following a rehydration phase using coconut water, sports drink and plain water respectively.

Initially 36 subjects had been intended to be recruited based on the power calculation. This proved to be unfeasible as the expectations on subjects to give up their time was too much. The use of meta-analysis data was explored but was also found to be not feasible as no access to raw data could be obtained. As the main body of the research study was under powered it was decided that to add novelty to the study that the 16 subjects obtained could be split to investigate potential differences in rehydration capacity depending on aerobic fitness levels. Subjects were split into two group dependant on their maximum oxygen uptake to allow investigation of a fitness effect on rehydration. The criteria used to split the groups (group 1 < 50 $ml \cdot kg^{-1} \cdot min^{-1}$, group 2 > 50 $ml \cdot kg^{-1} \cdot min^{-1}$) is lower than previous studies, however this gave a perfect 50/50 split in the groups.

The fitter individuals in group 2 (31.7 ± 9.9 g/min) were found to produce greater estimated sweat rates compared to the individuals in group 1 (25.7 ± 6.1 g/min). This is what was expected to been seen and was similar to what has been reported in previous studies (Ichinose-Kuwahara *et al*, 2010).

Percentage rehydration and rehydration index

The percentage rehydration calculation is a simple tool to use to assess rehydration. The equation used to calculate percentage rehydration is as follows:

$$\% \text{ Rehydration} = \frac{(\text{Body Mass Lost (kg)} - (\text{Initial Body Mass (kg)} - \text{End Body Mass (kg)}))}{\text{Volume of Fluid Consumed (kg)}}$$

Where,

- 'Body Mass Lost' refers to the mass lost as a result of dehydration
- 'Initial Body Mass' is the body mass recorded when subjects first arrive
- 'End Body Mass' is the body mass recorded at the end of the protocol before the subjects leave
- 'Volume of Fluid Consumed' is the amount of fluid ingested during the rehydration period

Following the 2 hour rehydration period we found percentage rehydration to be not significantly different between the different fluids, 76.4 ± 11.0; 78.0 ± 17.3; 74.6 ± 13.0% for coconut water, sports drink and plain water respectively. The measurement of percentage rehydration reflects the amount of fluid that remains within the body following rehydration, by assumption that body weight is restored purely from the fluid that is consumed. Our percentage rehydration values were greater than the values achieved by Gonzalez-Alonso *et al* (1992) who found that rehydrating with a volume equivalent to 100% of the body mass lost during exercise produced percentage rehydration values between 54 - 69%. Our results were also higher than the results found by Ismail *et al* (2007) who rehydrated subjects with the equivalent volume to 120% of the body mass lost and reported percentage rehydration values with the range of 58.9 - 68.1%. Our results therefore justify the rehydration strategy used, feeding subjects with fluid equating to 150% of the body mass they had lost during exercise. Ismail *et al* added sodium to their coconut water to try and bring the concentration in line with sports drinks, however our study still produced better percentage rehydration values than what was reported in their study. It would therefore appear to be more important to rehydrate with a greater volume of fluid rather than comprising volume and increasing the salt content. In a sporting context, athletes may have to compete for long durations on consecutive days therefore recovering hydration status between bouts becomes vitally important for optimal performance to continue.

There were no significant differences found when the subjects were divided dependant on aerobic fitness for percentage rehydration. Even though the fitter individuals sweat at a higher rate and lost more body mass during exercise there appears to be no upregulation of the ability to rehydrate.

Percentage rehydration was not seen to be near 100% in any of the trials. The environment that the subjects were in during the rehydration phase was not closely monitored and therefore may not have remained constant throughout the study. During the rehydration phase subjects would still be losing water through respiration and perspiration both of which could be effected by the environment the subjects were in. As this study ran all year round atmospheric conditions in regards to temperature and humidity would have differed throughout. Although no significant differences were seen between the fluids, we cannot say for certain that differences may have been seen had the environment been kept constant throughout.

Rehydration index is a measurement derived by Mitchell *et al* (1994) as an alternative to percentage rehydration to assess the effectiveness of a rehydration beverage. RI gives an estimation of the amount of rehydration fluid that is used by the body to restore the body mass lost following dehydration. Mitchell *et al* state that the optimum value for RI is 1.0 with values recorded higher than this indicating that the rehydration fluid is not being used effectively by the body to restore body mass.

The following formula shows how RI is calculated:

$$RI = \frac{\left(\dfrac{\text{Volume of Fluid Consumed (ml)}}{\text{Body Mass Regained (g)}}\right)}{\left(\dfrac{\text{\% Rehydration}}{100}\right)}$$

Where,

- 'Volume of Fluid Consumed' is the amount of fluid ingested during the rehydration period
- 'Body Mass Regained' is the amount of body mass regained during a rehydration period following dehydration
- '% Rehydration' is percentage rehydration, calculated using the equation previously mentioned

Rehydration Index ranges 1.80 - 2.60 have been reported with sodium levels of 20 mmol/l typical of most sports drinks (Ismail *et al*, 2007). Saat *et al* (2002) found that percent rehydration was higher with a sports drink (80 ± 4%) compared to coconut water (75 ± 5%) and water (73 ± 5%). In the same study Saat *et al* reported RI values of 1.56, 1.36 and 1.71 for coconut water, sports drink and water respectively. The lower value of percentage rehydration and larger RI values were perhaps due to the lower sodium content of the coconut water. This was then further investigated by Ismail *et al* (2007) who added sodium to coconut water and saw similar results in percent rehydration and rehydration index when compared to a sports drink. The sports drink used in Ismail's study had a rehydration index of 1.80 which falls within the range of typical RI values. However, the rehydration index seen following rehydration with sodium enriched coconut water was 1.75 which is better than that reported in studies using sports drinks, which may be due to the increased potassium content of the coconut water.

The RI values obtained from our study were 1.7 ± 0.4; 2.4 ± 2.9; 1.9 ± 0.7 for coconut water, sports drink and water respectively. Again our results show Go Coco coconut water rehydrated subjects better than Ismail *et al* managed even when adding sodium to the coconut water. This further strengthens the suggestion that increasing volume of fluid consumed during rehydration is more important than altering the contents, as Go Coco coconut water has very low levels of sodium (11.6 mmol/l) yet % rehydration and RI values were still found to be better.

To maintain exercise capacity, blood flow to the muscles as well as to the skin surface must be maintained. However, with dehydration comes a decrease in exercise performance, which is believed to be due to the reduction in plasma volume (Maughan, 1999). This reduction in plasma volume means that there must be a comprise in blood flow to the working muscles or to the skin surface. Therefore, the major target during exercise is to remain in a hydrated state allowing plasma volume to be maintained, circulation and sweating can then continue optimally (Leiper and Maughan, 1986). Previous studies suggest high potassium content of drinks, as seen in coconut water, may delay recovery of plasma volume due to increased intracellular fluid restoration instead of extracellular.

Again, no significant differences were found between the subjects in group 1 and group 2 for rehydration index. This measurement along with the percentage rehydration values suggest that the fitter individuals show no upregulation of their ability to rehydrate.

Urine osmolality

Urine osmolality was used as it is a relatively inexpensive and simple measurement of hydration. Although we recognise that this may not be best marker for hydration status within a research laboratory, it is a measurement that is reflective of real life practice within elite sports, where cost and time may be constrained. Urine samples were collected throughout the rehydration phase, however once analysed for urine osmolality these samples were discarded. Subjects were only given a small container to provide a sample and all other urine produced at that time point was simply voided into the lavatory. To understand fluid balance in more detail each urine sample should have been fully collected within a larger container and total volume produced recorded as well as urine osmolality at each time point.

We found that during the coconut water trial a significant difference was seen at end of the rehydration phase, compared to the plain water trial. Coconut water produced significantly higher values of urine osmolality. Nose *et al* (1988b) suggested that when a large volume of fluid is consumed that contains low sodium levels, that there is an acute hyponatremic response, plasma osmolality falls and the body increases urine output.

Our results found that at the end of the plain water trial urine osmolality was very low 158.1 ± 144.1, compared to the coconut water trial 325.4 ± 242.1, a significant difference (P < 0.05). These results favour plain water as a more suitable rehydration fluid. However, % rehydration and RI values, although not significantly different, would favour coconut water as a more suitable fluid for rehydration. These differences may be explained by the theory, suggested by Nose *et al*, that as plain water (a hypotonic solution) is consumed in large volumes, plasma osmolality will fall increasing urine production by the kidneys, the fluid being consumed is passed right through. Coconut water may contain low levels of sodium, but it contains large amounts of potassium. Therefore, as coconut water is consumed in large volumes for rehydration the fluid can be retained within the body more effectively. When our subjects were asked to produce a urine sample during the coconut water trial, their bodies had retained the fluid they had consumed, urine production was reduced as the body tried to rehydrate, urine therefore required to be forced resulting in the sample being more concentrated. During the plain water trial, the body increased production of urine and the fluid consumed passed straight through, resulting in the subjects’ samples being measured with low osmolality.

As previously seen with percentage rehydration and rehydration index, there were no differences found between the fitter individuals compared to the less fit individuals throughout all 3 trials.

Blood glucose

It has been long since known that many nutritional strategies have beneficial effects for athletes during exercise (Coyle *et al*, 83 & 86). For endurance athletes carbohydrate is the most important substrate as it is carbohydrates that will be fuelling the body to complete the exercise. Carbohydrates are progressively depleted during endurance exercise, to the point where fatigue sets in and work rate can no longer be maintained. Therefore the most notable nutritional strategy for endurance performance is carbohydrate ingestion during the exercise period.

However, when high glycaemic index fluids are consumed there is a rapid rise in the circulating blood glucose, to combat this rise there is an accompanying rise in circulating insulin. The circulating insulin is responsible for the clearance of glucose from the blood, however in some individuals the decrease in blood glucose can surpass resting levels (3.5 mM), making these individuals hypoglycaemic (Martini and Nath, 2009). Hypoglycaemia is associated with several symptoms including feelings of fatigue. Sapata *et al* (2006) found that subjects fed with a high glycaemic meal prior to exercise had a higher heart rate during the exercise trial compared to when they were fed with a low glycaemic meal. The hypoglycaemic response following the high glycaemic meal demanded the heart to work harder to sustain the same work load. Also in 2006, Stevenson *et al* found that during exercise fat oxidation was lower when a prior high glycaemic meal had been consumed compared to a low glycaemic meal. During endurance sporting performance higher fat oxidation helps constraint the depletion of glycogen stores, which will allow work rate to be sustained for longer, therefore enhancing sporting performance.

We found medium effect sizes in blood glucose values between coconut water and the sports drink at 30, 60 and 90 minutes (d = 0.44, 0.40 and 0.41 respectively) into the rehydration phase. Coconut water was found to produce a lower blood glucose response compared to the sports drink.

The Go Coco coconut water used in this study contains 4.4g per 100ml sugars of which approximately 70% is glucose and the remaining 30% is made up of fructose. The sports drink contained 3.6g per 100ml but was 100% glucose. A study by Currell and Jeukendrup (2008) was the first to demonstrate beneficial performance effects from consumption of a mixed carbohydrate beverage in the ratio 2:1 of glucose to fructose. Their study involved 8 subjects over 3 experimental trials, using plain water, a glucose only beverage and a beverage containing glucose and fructose (2:1 ratio) during exercise testing. Exercise testing consisted of subjects cycling for a fixed 2 hour period while being fed the experimental beverage in 15 minute intervals. At the end of the 2 hour period, subjects immediately began a time trial to complete a set amount of work in the quickest time possible. They were given the test beverage to consume during the time trial, on completion of 25, 50 and 75% of the work set. The results found that the glucose alone beverage improved performance (mean power output and time to completion) by 10% compared to the water trial. However, the performance improvement effects of the glucose:fructose beverage surpassed this by a further 8%. This improvement during the glucose:fructose trial is due to the increased rate of absorption. Glucose can only be transported through a sodium dependant glucose transporter called SGLT1 which can become saturated, slowing absorption. Fructose, however, is transported through the GLUT5 transporter which can work simultaneously with the SGLT1 transporter to increase absorption (Martini and Nath, 2009).

In our study the sports drink used contained glucose alone. Therefore, due to the properties contained within the Go Coco coconut water, it is being suggested that coconut water could potentially be consumed during endurance sport, as an alternative to man-made sports drinks. Coconut water naturally contains sugars and electrolytes as well as having antioxidant properties as well. If athletes switched to coconut water use then it would cut down the number of additives consumed in the athlete's diet. This may also, in turn, lead to children choosing a more natural, healthier option to sports drinks.

During endurance exercise the use of carbohydrates is essential for performance. Therefore, since we found no significant differences between coconut water and the sports drink throughout the rehydration phase in blood glucose values (6.8 ± 1.6 vs. 7.7 ± 1.9, 7.6 ± 1.3 vs. 8.2 ± 1.5, 5.9 ± 1.6 vs. 6.6 ± 1.0, 6.2 ± 1.0 vs. 6.0 ± 0.7 mM, for coconut water vs. sports drink at each time point duration rehydration 30, 60, 90 and 120 minutes respectively). However, Cohen's effect sizes were found to be medium at 30, 60 and 90 minutes into rehydration. This coupled with the glucose:fructose contents of the coconut water suggest that there is a potential for the use of coconut water during endurance exercise to have a benefit to performance.

Subjective questionnaire

Subjectively there was found to be no difference in the feeling of thirst between any of the three beverages. Subjects therefore did not have a preference of rehydration beverage based solely on its ability to quench their feelings of thirst. However, further subjective questionnaire results show that significance was almost reached with subjects rating the taste of the coconut water lower than the sports drink and plain water, Cohen's effect sizes found medium effects between coconut water and both the sports drink and plain water. Coconut water was obviously adequate enough to quench the subjects' feelings of thirst when they were in a dehydrated state but would appear not to be the selected drink of choice based on the taste. This is also reflected in the feeling of sickness question where subjects reported lower values meaning they felt more nauseous during the coconut water trial compared to the water trial (medium effect sizes seen at 60, 90 and 120 minutes into rehydration). Some subjects struggled to consume the required volume of coconut water. Coconut water companies have started flavouring their drinks which may get round the taste issue for some subjects. However one of the main attractions towards the use of coconut water is that it is natural, adding flavourings would make the coconut water more man-made like sports drinks that are already highly popular within the market.

The greatest difference detected between the subjects when they were split based on aerobic fitness was in the subjective questionnaire measurement of sickness. Consistently throughout the rehydration phase the fitter individuals reported feeling more sick than the less fit subjects during the sports drink trial. There was no significant difference found between the fitness group during the coconut water trial at any of the time points. This is an interesting finding as elite level athletes have to consume rehydration beverages frequently after hard training sessions or competition, potentially in large volumes. The fitter subjects reported greater feelings of sickness during the sports drink trial compared to the coconut water trial which may indicate that for elite athletes it might feel easier on the stomach to consume coconut water as a rehydration beverage compared to a sports drink.

There are still many unanswered questions with regards to the use of coconut water as a rehydration beverage and its potential use as an ergogenic aid during exercise performance. Future research in this field should aim to investigate the mechanisms involved in the results seen in our study with upregulation of sweat rates by fitter individuals but with no difference in rehydration capacity, is there a ceiling effect? There also requires to be investigation into whether Go Coco coconut water may be used by athletes exercising for long periods of time on a regular basis during training and competition.

Limitations

Maughan and Leiper (1995), Maughan (1994) and Kovacs (2002) followed a rehydration period for 5-6 hours which obviously provides a much more complete overview of the effect that a fluid consumed has on kidney function and the restoration of euhydration. We did not believe that this would be feasible to follow and therefore tried to shorten the rehydration time. We found no significant differences between any of the rehydration beverages at the end of the 2 hour rehydration phase, however our rehydration strategy may have affected the final measurements. Our protocol involved providing the subjects with fluid at regular 40 minute intervals during the rehydration phase. This was to avoid excessive consumption which would not be reflective of rehydration strategies employed by professional athletes. However, as the process of maintaining fluid balance via osmotic movements within the kidneys is a slow process, we feel that a full picture of the rehydration process was not seen within the 2 hour rehydration period used in our protocol.

Conclusion

In light of our findings, primarily that there is no significant difference between Go Coco coconut water and a commercially available sports drink when comparing their ability to rehydrate following dehydrating exercise and that fitter individuals rated feeling more sick while consuming a sports drink compared to coconut water, it is recommended that the naturally occurring coconut water would make an ideal alternative to the manufactured sports drink. These sports drinks are used during sporting endurance performance, our early indications suggest that Go Coco coconut water produces a similar blood glucose response to the sports drink, as well as a mixture of glucose and fructose sugars, and could therefore produce similar benefits to endurance performance. Future research should aim to investigate whether Go Coco coconut water may be used by athletes exercising for long periods of time on a regular basis during training and competition.

References

Aragon-Vargas, L.F. and Madriz-Davila, K. (2000) Incomplete warm-climate, post-exercise rehydration with water, coconut water or a sports drink. *Medicine and Science in Sports and Exercise* 32(5): S238.

Armstrong, L.E., Costill, D.L. and Fink, W.J. (1985) Influence of diuretic induced dehydration on competitive running performance. *Medicine and Science in Sports and Exercise* 17(4): 456-461.

Beltrami, F.G., Hew-Butler, T. and Noakes, T.D. (2008) Drinking policies and exercise-associated hyponatraemia: is anyone still promoting overdrinking? *Br J Sports Med* 42: 796-
801.

Bhagya, D., Prema, L. and Rajamohan, T. (2010) Beneficial effects of tender coconut water on blood pressure and lipid levels in experimental hypertension. *Journal of Cell and Tissue Research* 10(1): 2139-2144.

Convertino, V.A., Armstrong, L.E., Coyle, E.F., Mack, G.W., Sawka, M.N., Senay, L.C. Jr. and Sherman, W.M. (1996) American college of sports medicine position stand. Exercise and fluid replacement. *Med Sci Sports Exerc* 28(1): 1-7.

Costill, D.L. and Sparks, K.E. (1973) Rapid fluid replacement following thermal dehydration. *J Appl Physiol* 34: 299-303.

Costill, D.L., Coté, R. and Fink, W. (1976) Muscle water and electrolytes following varied levels of dehydration in man. *Journal of Applied Physiology* 40(1): 6-11.

Coyle, E.F., Coggan, A.R., Hemmert, M.K. and Ivy, J.L. (1986) Muscle glycogen utilization during prolonged strenuous exercise when fed carbohydrate. *Journal of Applied Physiology* 61(1): 165-172.

Coyle, E.F., Hagberg, J.M., Hurley, B.F., Martin, W.H., Ehsani, A.A. and Holloszy, J.O (1983) Carbohydrate feeding during prolonged strenuous exercise can delay fatigue. *Journal of Applied Physiology* 55(1): 230-235.

Currell, K. and Jeukendrup, A.E. (2008) Superior endurance performance with ingestion of multiple transportable carbohydrates. *Med Sci Sports Exerc* 40(2): 275-281.

Gonzalez-Alonzo, J., Heaps, C.L. and Coyle, E.F. (1992) Rehydration after exercise with common beverages and water. *Int J Sports Med* 13: 399-406.

Ichinose-Kuwahara T, Inoue Y, Iseki Y, Hara S, Ogura Y & Kondo N (2010). Sex differences in the effects of physical training on sweat gland responses during a graded exercise. *Exp Physiol* **95**, 1026-1032.

Ismail, R., Singh, R. and Sirisinghe, R.G. (2007) Rehydration with sodium-enriched coconut water after exercise-induced dehydration. *Southeast Asian J Trop Med Public Health* 38(4): 769-785.

Kalman, D.S., Feldman, S., Krieger, D.R. and Bloomer, R.J. (2012) Comparison of coconut water and an electrolyte sports drink on measures of hydration and physical performance in exercise-trained men. *Journal of the International Society of Sports Nutrition* 9(1): 1.

Kovacs, E.M., Schmahl, R.M., Senden, J.M. and Brouns, F. (2002) Effect of high and low rates of fluid intake on post-exercise rehydration. *International Journal of Sport Nutrition and Exercise Metabolism* 12: 14-23.

Laitano, O., Trangmar, S.J., Marins, D.M., Menezes, E.S. and da Silva Reis, G. (2014) Improved exercise capacity in the heat followed by coconut water consumption. *Motriz Rio Claro* 20(1): 107-111.

Lambert, C.P., Costill, D.L., McConell, G.K., Benedict, M.A., Lambert, G.P., Robergs, R.A. and Fink, W.J. (1992) Fluid replacement after dehydration: influence of beverage carbonation
and carbohydrate content. *Int J Sports Med* 13: 285-292.

Leiper, J.B. and Maughan, R.J. (1986) Absorption of water and electrolytes from hypotonic, isotonic and hypertonic solutions. *J Physiol* 373: 90-102.

Manna, K., Khan, A., Das, D.K., Kesh, S.B., Das, U., Ghosh, S., Dey, R.S., Saha, K.D., Chakraborty, A., Chattopadhyay, S., Dey, S. and Chattopadhyay, D. (2014) Protective effect of coconut water concentrate and its active component shikimic acid against hydroperoxide mediated oxidative stress. *Journal of Ethnopharmacology* In Press

Martini, F.H. and Nath, J.L. (2009) *Fundamentals of Anatomy and Physiology*. 8th Ed. San Francisco: Pearson.

Maughan R.J. and Leiper, J.B. (1995) Sodium intake and post-exercise rehydration in man. *European Journal of Applied Physiology* 71: 311-319.

Maughan, R.J. (1999) Nutritional ergogenic aids and exercise performance. *Nutrition Research Reviews* 12: 255-280.

Maughan, R.J. and Shirreffs, S.M. (1997) Recovery from prolonged exercise: restoration of water and electrolyte balance. *Journal of Sports Sciences* 15(3): 297-303.

Maughan, R.J., Owen, J.H., Shirreffs, S.M. and Leiper, J.B. (1994) Post-exercise rehydration in man: effects of electrolyte addition to ingested fluids. *European Journal of Applied Physiology* 69: 209-215.

Mitchell, J.B., Grandjean, P.W., Pizza, F.X., Starling, R.D. and Holtz, R.W. (1994) The effect of volume ingested on rehydration and gastric emptying following exercise induced dehydration. *Med Sci Sports Exerc* 26: 1135-1143.

Nadel, E.R., Mack, G.W. and Nose, H. (1990) Influence of fluid replacement beverages on body fluid homeostasis during exercise and recovery. *Fluid Homeostasis During Exercise*. *Carmel, IN: Cooper Publishing*: 181-198.

Nielsen, B., Sjogaard, G., Ugelvig, J., Knudsen, B. and Dohlmann, B. (1986) Fluid balance in exercise dehydration and rehydration with different glucose-electrolyte drinks. *Eur J Appl Physiol* 55: 318-323.

Nielsen B, Hales JRS, Strange S, Christensen NJ, Warberg J, Saltin B (1993) Human circulatory and thermoregulatory adaptations with heat acclimation and exercise in a hot, dry environment. *J Physiol* **460**: 467-485.

Noakes, T.D. (2007) Drinking guidelines for exercise: what evidence is there that athletes should drink "as much as tolerable", "to replace the weight lost during exercise" or "ad libitum"? *Journal of Sports Sciences* 25(7): 781-796.

Nose, H., Mack, G.W., Shi, X.R. and Nadel, E.R. (1988a) Role of osmolality and plasma volume during rehydration in humans. *J Appl Physiol* 65: 325-331.

Nose, H., Mack, G.W., Shi, X.R. and Nadel, E.R. (1988b) Shift in body fluid compartments after dehydration in human. *J Appl Physiol* 65: 318-324.

Saat, M., Singh, R., Sirisinghe, R.G. and Nawawi, M. (2002) Rehydration after exercise with fresh young coconut water, carbohydrate-electrolyte beverage and plain water. *Journal of Physiological Anthropology and Applied Human Science* 21(2): 93-104.

Sapata, K.B., Fayh, A.P.T. and Oliveira, A.R. (2006) Effect of prior consumption of carbohydrate on the glycaemia and performance. *Rev Bras Med Esporte* 12(4): 189 – 194.

Sawka, M.N., Burke, L.M., Eichner, E.R., Maughan, R.J., Montain, S.J. and Stachenfeld, N.S. (2007) American college of sports medicine position stand. Exercise and fluid replacement. *Med Sci Sports Exerc* 39: 377-390.

Shirreffs, S.M., Taylor, A.J., Leiper, J.B. and Maughan, R.J. (1996) Post-exercise rehydration in man: effects of volume consumed and drink sodium content. *Medicine & Science in Sports & Exercise* 28(10): 1260-1271.

Singh, R., Brouns, F. and Kovacs, E. (2002) The effect of rehydration on cycling performance after exercise-induced dehydration. *Southeast Asian J Trop Med Public Health* 33: 378-388.

Stevenson, E.J., Williams, C., Mash, L.E., Phillips, B. and Nute, M.L. (2006) Influence of high-carbohydrate mixed meals with different glycemic indexes on substrate utilization during subsequent exercise in women. *Am J Clin Nutr* 84: 354–360.

Yong, J.W.H., Ge, L., Ng, Y.F. and Tan, S.N. (2009) The chemical composition and biological properties of coconut (cocos nucifera L.) water. *Molecules* 14: 5144-5164.

Appendices
Appendix 1

Andrew Leishman & Nairn Scobie

University of Glasgow

Subject Information Sheet for a Research Project

Title of Research Project:

The Comparison of different Hydration Strategies on Rehydration.

The nature of sport in recent years has led to more research into methods to legally enhance athletes' performance. Different nutritional strategies are usually the first to be experimented with for enhancing sporting performance. At the moment the largest area of nutritional supplementation for endurance performance is manufactured sports drinks. This study could open the prospect of using a naturally produced drink as an alternative without comprising the advantageous performance effects of commercially available sports drinks. You have been invited to take part in a research study that will contribute to identifying if the performance benefits of sports drinks can be matched or bettered by the use of coconut water as an alternative.

This information sheet provides you with details of the research project. Please read the information carefully, and ask a member of the research team if you have any questions or need further explanation. If you would like to participate in this research project, it is important that you fully understand what you are volunteering for, and that you are satisfied with the information given to you, before you sign the Informed Consent Form. The form is returned to the research group, whereas you may keep this information sheet and a copy of the signed Informed Consent Form.

What is the purpose of this research project?

These commercially available sports drinks are packed full of sugars and additives. The publicity that sport in the UK is currently getting means that more and more individuals are taking up sport or exercise. These sports drinks are advertised as enhancing performance of the countries sports stars, and are therefore consumed by the public on a mass scale. In most cases, the general public that are exercising regularly only require to remain hydrated during their exercise periods. If these sports drinks are consumed while not participating in long duration sport then the excess sugar contained in the drinks can lead to an increase in body fat.

Can this new more natural alternative, produce the same performance benefits? This new beverage also contains electrolytes and minerals that help keep the body hydrated. In this project we want to investigate whether this new strategy can be used as an alternative to sports drinks for athletic endurance performance.

Why have you been chosen?

You have been selected as a potential participant in this study, because you are male, aged 18-35 years and have a history of physical exercise that enables you to participate in the research project by undertaking repeated exercise sessions. However, inclusion criteria states that you do not smoke, are not on any medication, and do not use drugs, either recreational or performance enhancing. Further, if you have a history of heart or blood vessel disease, metabolic disorder, high blood pressure, or any other related condition, you will not be allowed to participate in this research project.

Do you have to participate?

It is entirely up to you to decide whether or not you want to participate in this research project. If you do not wish to participate, you will not have to give any reason for saying no. If you decide you wish to participate, you will have to sign an Informed Consent Form and return it to the research group, before enrolment. If you decide to participate, you are still free to withdraw from the research project at any time without giving a reason.

What does participation involve?

You will be asked to visit the laboratory on 5 separate days. Each visit will last approximately 3 hours. These visits will be separated by at least 7 days.

On your first visit, you will be introduced to the laboratory personnel and familiarised with the equipment and protocols. You will be asked for your age, height, weight, urine osmolality (which will require you to provide a urine sample which will be analysed to check your hydration status) and bioelectrical impedance will be measured. Bioelectrical impedance involves electrodes being attached at your wrist and ankles and a small electrical current (which cannot be felt) passing through your body. This gives a further measure of your hydration status along with a measure of how much fat your body contains.

The first test involves a maximal oxygen uptake test, which will be carried out on a cycle ergometer. You will be required to wear a heart rate monitor, mouthpiece and nose clip during the test so that measures of heart rate, oxygen uptake and ventilation can be recorded at each step. You will perform a 10 minute warm-up before the test begins, from there the resistance on the bike increases by 15 watts per minute ($W \cdot min^{-1}$) until you can no longer continue or the revolutions per minute drops below 50 (whichever occurs first).

This test will take about 10-20 minutes in total, depending on your fitness, but only the last few minutes of the test are hard and exhaustive.

The final 4 visits to the lab will be completed in an environmental heat chamber heated to a temperature of $30^{o}C$ and 53% humidity. Before these tests get underway, your height, weight, urine osmolality and bioelectrical impedance will be taken. You will also be required to provide a blood sample (5-10ml) which will be analyed for plasma volume which gives us a further marker of your hydration status. You should let the researchers know if you have trouble with needles and blood samples.

You will exercise on a cycle ergometer at 65% VO_{2max} (determined from the VO_{2max} test you performed earlier) for 10 minute intervals (to a maximum of 90 minutes) in order to lose 3% of body weight via sweat loss. The amount of sweat produced during exercise is variable between individuals therefore some subjects will lose 3% body weight quicker than others. Therefore after each 10 minute period of exercise you will be removed from the bike, dried and body weight will be re-measured. The test will be ended if your body weight has decreased by 3%, otherwise you will return to the bike to complete the next exercise interval.

Again these tests will involve a cool down period when the tests are completed, with weight, urine osmolality and bioelectrical impedance being re-measured upon completion. In the 2 hour period following exercise cessation you will rehydrate to the equivalent of 120% of body weight lost. Throughout this 2 hour rehydration phase, your weight, blood sample and bioimpedance will be monitored every 30 minutes. At the end of the 2 hours, urine osmolality will be measured. We will also collect all the urine you produce in this 2 hour period to measure the total volume produced.

For experiments like this carried out in the heat, your body (core) temperature must be monitored throughout. If core temperature rises above a pre-determined level of 40ºC the test is stopped and you will be allowed to cool down. To monitor core temperature you will be required to insert a rectal thermometer 10cm beyond the anal sphincter.

Finally, we ask that you do not drink any alcohol 48 hours prior to each laboratory visit. Also, you will be asked to eat a healthy, normal meal (breakfast or lunch) approximately 3 hours before each laboratory visit, and not eat any chocolate or sugar-rich food during those 3 hours between meals and laboratory visits. You will also be required to refrain from drinking any liquid in this period.

What are the potential disadvantages of the research project for you?

Physical exercise has a negligible risk in healthy adults, although strenuous exercise does carry a small risk of inducing heart attacks. The primary symptom of a heart attack is chest pain. If you experience chest pain, you should stop exercising immediately. Your heart rate will be monitored, and in the unlikely event that you experience serious problems, approved emergency personnel are in the laboratory at all times during the visits and approved emergency procedures are in place.

At the end of the exercise tests you will feel tired and exhausted, your legs will feel heavy, and you may be out of breath and light headed. This is common after strenuous exercise and is harmless to you.

When blood samples are taken, you will feel an initial ‘prick’ from the needle going in. Although slightly discomforting, this is a harmless procedure when performed by experienced personnel.

There are no known side effects of this research project that will affect you.

What are the possible benefits of the research project for you?
The results of the exercise test will tell you how fit you are, and the research team will explain what the results mean for you.

Also, numerous health benefits are associated with physical exercise, such as improved fitness, less risk of disease, and increased well-being.

You will not be paid to participate in this research project.

Confidentiality
All information and results collected during this research project will be kept strictly confidential.

What will happen to the results of the research project?
The results will be used by the students in their respective research project dissertations (Master of Science). The results may also be published in one or more scientific journals after the research project is completed. You will not be identified in any publication.

Disclaimer - What if something goes wrong?
If you are harmed by taking part in this research project, there are no compensation arrangements. If you are harmed due to someone's negligence, then you may have grounds for a legal action but you may have to pay for it.

Further information

You may ask questions about the research project and your rights as a volunteer now or at any time later. You may contact the research team while participating or via the contact details shown below.

Nairn Scobie
E-mail: Nairn.Scobie@glasgow.ac.uk

Andrew Leishman
E-mail: andrew_leishman@hotmail.co.uk

Appendix 2

Ethics Committee for Non Clinical Research Involving Human Subjects, Material or Data

Consent Form

Title of Project: The comparison of commercially available coconut water, sports drink and plain water on rehydration and potential benefit for endurance based performance.

Please initial boxes

I confirm that I have read and understand the information sheet for the above study and have had the opportunity to ask questions ☐

I understand that my participation is voluntary and that I am free to withdraw at any time, without giving any reason and with no consequences ☐

I agree for my samples to be used for future research **YES/NO (delete as appropriate**) ☐

I AGREE TO TAKE PART IN THE ABOVE STUDY.

Name of Volunteer: ______________________________

Signature: ______________________________ Date: __________

____

Name of person taking consent: ______________________________

Signature: ______________________________ Date: __________

Name of Researcher: ______________________________

Signature: ______________________________ Date: __________

Appendix 3

Subjective Feelings Questionnaire

How Thirsty Do You Feel Now?

1 2 3 4 5 6 7 8 9 10

Poor Average Excellent

How Hungry Do You Feel Now?

1 2 3 4 5 6 7 8 9 10

Poor Average Excellent

How Dry Does Your Mouth Feel Now?

1 2 3 4 5 6 7 8 9 10

Poor Average Excellent

How Does Your Mouth Taste Now?

1 2 3 4 5 6 7 8 9 10

Poor Average Excellent

How Tired Do You Feel Now?

1 2 3 4 5 6 7 8 9 10

Poor Average Excellent

How Nauseous (sick) Do You Feel Now?

1 2 3 4 5 6 7 8 9 10

Poor Average Excellent

How Bloated Do You Feel Now?

1 2 3 4 5 6 7 8 9 10

Poor Average Excellent