

22 June 2022
206-22

Supporting document 1

Risk Assessment Proposal P1030: Carbohydrate Composition

Executive summary

Intense physical exercise leads to sweating in order to dissipate heat and reduce body temperature to normal levels. Sweating results in a loss of body water, sodium and to a lesser extent other minerals including potassium, calcium and magnesium. Physiological responses to dehydration include increased cardiovascular strain, an inability to thermoregulate and at high levels results in impaired mental function.

Dehydration as well as a decrease in the body's carbohydrate reserves can impair physical performance. Consumption of electrolyte drinks during and after intense exercise is one way to aid in rehydration and maintain physical performance. Research on electrolyte drinks has primarily focused on those with a carbohydrate content of 6 to 18% (g per 100 ml), and Standard 2.6.2 of the Australia New Zealand Food Standards Code (the Code) currently requires an electrolyte drink to contain 5 to 10% carbohydrate.

The purpose of this review is to determine if electrolyte drinks with a carbohydrate concentration below the 5% lower limit that is currently permitted in the Code, referred to here-in as lower carbohydrate electrolyte drinks, have a similar effect on rehydration and exercise performance compared with the higher carbohydrate electrolyte drinks that are currently permitted in the Code.

Seven randomised crossover studies were included in the body of evidence for the effect of lower carbohydrate electrolyte drinks on rehydration compared to electrolyte drinks with the currently permitted levels of carbohydrate. Participants in the trials undertook strenuous physical activity for approximately 1 hour or until a body weight loss of approximately 2% was achieved. In general, electrolyte drinks were consumed following exercise and the effects on recovery from dehydration were considered. However one study observed the effects of electrolyte drinks on preventing dehydration when drinks were consumed during exercise.

Four randomised crossover studies were considered as evidence for the effect of lower carbohydrate electrolyte drinks on physical performance compared to electrolyte drinks with higher carbohydrate concentrations. Participants exercised for between 60 and 120 min while consuming electrolyte drinks with a carbohydrate content ranging from 2 to 10%. Exercise performance was measured as time to exhaustion or fixed distance time trials. A number of limitations in study design were identified in the body of evidence including the lack of blinding of participants and investigators, small sample size, as well as the insensitivity of hydration markers which may have made differences in drink composition difficult to detect.

This qualitative and narrative assessment concluded that based on the available evidence no clear difference between lower carbohydrate electrolyte drinks and those that are currently permitted in the Code are observed in terms of benefit on rehydration or on exercise performance when consumed during or on completion of sustained exercise (at least 60 min or resulting in a 2% body weight loss).

Table of Contents

EXECUTIVE SUMMARY	1
1. INTRODUCTION.....	4
1.1 PHYSIOLOGY OF HYDRATION.....	4
2. RISK ASSESSMENT.....	5
2.1 ASSESSMENT OF HYDRATION STATUS	6
2.2 REHYDRATION STUDIES.....	7
2.3 PERFORMANCE STUDIES	12
3. DISCUSSION	14
4. CONCLUSION	16
5. REFERENCES.....	16
APPENDIX 1. INCLUDED STUDIES THAT INVESTIGATE THE EFFECT OF LOWER CARBOHYDRATE ELECTROLYTE DRINKS (LESS THAN 5% CARBOHYDRATE) ON REHYDRATION OR PERFORMANCE.	20
APPENDIX 2 EXCLUDED STUDIES THAT INVESTIGATE THE EFFECT OF LOWER CARBOHYDRATE ELECTROLYTE DRINKS (LESS THAN 5% CARBOHYDRATE) ON REHYDRATION OR PERFORMANCE.	26
APPENDIX 3 GLOSSARY OF ABBREVIATIONS AND DEFINITIONS.....	31

1. Introduction

An electrolyte drink is defined in Standard 2.6.2 of the Food Standards Code as a drink formulated and represented as suitable for the rapid replacement of fluid, carbohydrates and minerals.

According to Clause 9 of Standard 2.6.2 a food sold as an electrolyte drink or electrolyte drink base must be an electrolyte drink or an electrolyte drink base and contain:

- (i) no less than 10 mmol/L of sodium; and
- (ii) no less than 50 g/L and no more than 100 g/L in total of dextrose, fructose, glucose syrup, maltodextrin and sucrose; and
- (iii) no more than 50 g/L fructose.

For an electrolyte drink base, the amounts apply to the electrolyte drink base as ready to drink.

The purpose of this assessment is to establish the minimum effective carbohydrate concentration (dextrose, fructose, glucose syrup, maltodextrin, sucrose) in electrolyte drinks. Specifically to determine whether, compared to electrolyte drinks containing 5 to 10% carbohydrate, lower carbohydrate electrolyte drinks (less than 5%) have a similar effect on rehydration and on physical performance as measured by decreased time to completion or improved endurance.

1.1 Physiology of Hydration

Physical activity leads to sweating in order to dissipate heat and return body temperature to within normal ranges. The level of sweating is dependent on a range of factors including individual responses to exercise based on physical characteristics (body weight, metabolism, heat acclimatisation and genetic pre-disposition), intensity and duration of exercise, clothing worn and environmental conditions such as temperature, humidity and altitude. Variability across types of exercise also impacts levels of sweating, for example, constant load exercise versus intermittent exercise during team sports.

Sweating results in a loss of body water. Sodium and to a lesser extent potassium, calcium and magnesium levels are also depleted from the body (Sawka et al. 2007).

Exercise-induced dehydration of at least 2% body mass is generally considered to impair exercise performance (Casa et al. 2005; Sawka et al. 2007). Physiological responses to dehydration include an inability to thermoregulate, increased cardiovascular strain and in severe cases of dehydration can lead to impaired mental function. Fatigue during exercise can also arise from a reduction in the body's carbohydrate reserves (EFSA, 2015).

Consumption of electrolyte drinks during and after intense exercise aids in maintaining physical performance and rehydration. The European Food Safety Authority (EFSA) Panel on Dietetic Products, Nutrition and Allergies assessed health claims on carbohydrate-electrolyte solutions and a reduction in the rate of perceived effort during exercise, enhancement of water absorption during exercise and maintenance of endurance performance. The Panel concluded that consuming drinks with electrolytes (particularly sodium) and carbohydrate helps maintain physical performance during prolonged exercise and contributes to the maintenance of fluid and electrolyte balance compared to water (EFSA, 2011).

In 2015, EFSA published scientific advice on food intended for sportspeople. The Panel concluded that drinks containing both electrolytes (particularly sodium) and carbohydrate contribute to the maintenance of physical performance during endurance exercise and that drinks with electrolytes and carbohydrate help maintain fluid and electrolyte balance during prolonged exercise (EFSA, 2015).

The American College of Sports Medicine's position statement on exercise and fluid replacement states that consumption of drinks containing electrolytes and carbohydrates can help sustain fluid electrolyte balance and exercise performance (Sawka et al. 2007). It indicates that "carbohydrate consumption can be beneficial to sustain exercise intensity during high-intensity exercise events of approximately 1 hour or longer as well as less intense exercise events sustained for longer periods". It also states "that consuming normal meals and drinks will restore hydration. Individuals needing rapid and complete recovery from excessive dehydration can drink approximately 1.5 L of fluid for each kilogram of body weight lost. Consuming drinks and snacks with sodium will help expedite rapid and complete recovery by stimulating thirst and fluid retention".

A systematic review studied the effect of carbohydrate supplementation compared with placebo (i.e. no carbohydrate) on exercise performance of different durations in 61 separate studies. The review found statistically significant higher performance with carbohydrate supplementation in 82% of the studies while the remaining studies showed no improvement (Stellingwerff et al. 2014).

These statements and reviews have covered the literature available at the time, however the majority of these studies used carbohydrate concentrations in the range of 6 to 18% and a limited number of studies investigated hydration parameters or exercise performance using drinks with carbohydrate content below 5%. Consequently, regulations concerning the composition of products sold as electrolyte drinks set 5% as the minimum carbohydrate content; currently, most commercially available electrolyte drinks contain 6 to 7.4% carbohydrate (Sports Dieticians Australia, 2018). However, it has been suggested that drinks with lower carbohydrate concentrations may result in increased rates of gastric emptying (Vist et al. 1995) and water absorption (Rehrer et al. 1992).

2. Risk Assessment

A literature search was conducted in PubMed and Cochrane Central on 9/1/2018 and repeated on 7 January 2021, to identify studies that compared the effects of electrolyte drinks on rehydration or performance. Eligibility criteria for inclusion in the review were as follows:

Participants: healthy individuals

Intervention: Studies with a trial drink that fulfilled the current definition of an electrolyte drink in the Code with the exception that the carbohydrate content was less than 5% instead of 5 – 10%.

Control: Studies with a trial drink that met the current definition of electrolyte drink (5 to 10% carbohydrate with a minimum sodium content of 10 mmol/L) and an electrolyte content that matched the intervention trial. Water placebos with similar electrolyte composition and flavour to the test drinks were also considered as part of the assessment.

Outcomes: Hydration status and/or exercise performance. Defined methods were not determined for rehydration *a priori*. Studies in which exercise performance was measured by fixed distance time trial or time to exhaustion were included.

Study design: parallel and crossover randomised controlled trials (RCTs) and non-randomised trials (if RCTs are not available).

Time: individuals undertaking strenuous physical activity of approximately 1 hour or more or leading to approximately 2% or greater dehydration as estimated by decrease in body mass.

Non-randomised studies were included in the initial searches however as several randomised studies were identified these were not included in the body of evidence that informed the judgement of effect of lower carbohydrate electrolyte drinks. Only crossover studies and studies with at least 7 days between trial arms were identified. Included studies consisted of intermittent exercise (e.g. team sports) or continuous exercise such as cycle ergometer, running, elliptical exercise, striding and stretching. Some studies did not specify the mode of exercise undertaken. All hydration studies measured serum osmolality and change in plasma volume.

Where required data were only presented in graphs values were extracted using WebPlotDigitizer Version 4.12 (<https://automeris.io/WebPlotDigitizer>)

2.1 Assessment of hydration status

Water balance in the human body is constantly in flux as water is lost from the skin, lungs and kidneys and gained through food and water. Several methods have been developed to study hydration status with varying degrees of accuracy and precision, however consensus on a gold standard has not been reached (Armstrong 2007; Cheuvront et al. 2010; Villiger et al. 2018).

Acute change in body mass can accurately measure hydration status and is often used in sports nutrition studies (Armstrong et al. 2007; Cheuvront et al. 2010). Measurements of total body water including isotope dilution and neutron activation analysis are highly accurate when undertaken in controlled laboratory settings, however these methods are expensive and require a high degree of technical expertise and specialised equipment and therefore are not widely used.

Plasma osmolality is a measure of the body's water electrolyte balance and is determined by freezing point depression. Plasma osmolality increases during dehydration and decreases when overhydrated. It is considered to be an effective marker of hydration status when measured under controlled laboratory conditions (Popowski et al. 2001; Armstrong 2007; Cheuvront et al. 2010). However, as blood glucose levels directly affect serum osmolality the effect of consumption of varying carbohydrate concentrations on serum osmolality should also be taken into account (Evans et al. 2008).

Plasma volume calculated from haemoglobin and haematocrit (Dill and Costill, 1974) can vary during and after acute changes in body hydration levels. Urinary markers and plasma volume changes are considered to be less effective markers for measuring acute changes in hydration status as they do not measure intracellular or extracellular fluid (Armstrong, 2007).

Urine samples consist of urine produced since the previous void which may not coincide with the time elapsed between drink consumption in experiments. When a large bolus of fluid is consumed in a short period diuresis is promoted thereby producing a large volume of urine. Urinary markers can therefore be influenced greatly by the volume of fluid consumed rather than indicate hydration status (Kovacs et al. 2002; Armstrong 2007).

Net fluid balance is calculated from sweat loss during exercise, estimated from body mass loss, drink volume ingested during rehydration and urine output. However corrected net fluid

balance accounts for the volume of fluid remaining in the stomach, providing a more accurate estimate of hydration status.

Therefore, most studies that assess hydration status following exercise use several hydration markers.

2.2 Rehydration Studies

FSANZ identified seven suitably designed studies that compared the effect of electrolyte drinks with different carbohydrate content on rehydration when consumed during or after exercise (Rogers et al. 2005; Evans et al. 2009a; Evans et al. 2009b; Osterberg et al. 2010; Kamijo et al. 2012; Clayton et al. 2014; Li et al. 2018). The studies were randomised crossover trials of between 5 and 15 healthy participants. Three of the studies compared drinks with 2% and 10% carbohydrate (Evans et al. 2009a; Evans et al. 2009b; Clayton et al. 2014) and four studies tested drinks with carbohydrate concentrations of approximately 3% and 6% (Rogers et al. 2005; Osterberg et al. 2009; Kamijo et al. 2012; Li et al. 2018). Four studies included a carbohydrate-free placebo containing electrolytes; one study included a carbohydrate-free placebo with no added electrolytes (Rogers et al. 2005) and two studies did not include a placebo (Clayton et al. 2014; Li et al. 2018) (Table 1).

Rogers et al. (2005)

Rogers et al. (2005) studied the effects of three drinks, 3% carbohydrate (1% glucose, 2% sucrose, 3.1 mmol/L potassium and 17.2 mmol/L sodium), 6% carbohydrate (2% glucose, 4% sucrose, 3.1 mmol/L potassium and 17.2 mmol/L sodium), or water placebo (matched in colour and flavour but no electrolytes added) on rehydration and performance in subjects that completed a 3 mile time trial on a cycle ergometer following 85 min moderate intensity exercise on a cycle ergometer at ambient temperature (22°C). Five healthy individuals (4 male, 1 female, age 25 ± 1 year, weight 70.2 ± 3.6 kg, VO_{2max} 61.5 ± 2.1 mL/kg/min) completed the randomised controlled double-blinded crossover study in which they consumed a total volume of 23 mL/kg body weight, with 10% of total volume consumed every 10 min during the 85 minute exercise session.

Plasma osmolality and percentage change in plasma volume was measured at the start of exercise and at 20 minute intervals during the exercise period. Data was analysed using a linear mixed model with post-hoc comparisons using the Tukey method. Plasma osmolality increased compared to baseline on completion of the time trial (~ 300 mOsm/kg vs 287 for 3% trial, 289 for water placebo and 291 for 6% trial as estimated from graph; statistics not provided). No statistically significant differences in plasma osmolality or plasma volume were observed between trials before exercise or during the exercise/hydration period ($P > 0.05$) however it was noted that the study was underpowered.

Evans et al. (2009a)

A study by Evans et al. (2009a) evaluated the effect of consuming three drinks containing varying glucose concentrations (0%, 2% or 10% glucose) with electrolytes (31 mmol/L sodium, 27 mmol/L chloride and 0.6 mmol/L potassium ions) on rehydration following exercise-induced dehydration of $1.99 \pm 0.07\%$ of body mass in 6 male and 3 female subjects (age 23 ± 2 yr, body mass 76.8 ± 8.3 kg and VO_{2max} 3.7 ± 0.8 L/min) in a randomised single-blinded crossover design. Subjects undertook intermittent exercise on a cycle ergometer in the heat ($35.3 \text{ }^\circ\text{C} \pm 0.3 \text{ }^\circ\text{C}$) at $58 \pm 3\%$ VO_{2max} prior to consuming test drinks *ad libitum* for two hours post-exercise. Sugar-free sweetener and flavour was added to the 0% and 2% drinks in order to mask differences in carbohydrate content. Average exercise time to achieve the required weight loss was 50 ± 16 min. Data was analysed using repeated measures analysis of variance (ANOVA) with Tukey's or Dunnett's post-hoc pairwise comparisons.

Fluid intake was not statistically different between trials, equivalent to $150 \pm 36\%$, $165 \pm 26\%$, and $143 \pm 21\%$ of the body mass lost for the 0%, 2% and 10% trials respectively ($P = 0.173$) however *ad libitum* consumption resulted in an average difference of 22% of lost body mass between the 2% and 10% drink trials.

Statistically significant increases in serum osmolality were observed in all trials following exercise compared to pre-exercise levels (0% trial: 285.4 vs 277.9 mOsm/kg; 2% trial: 287.5 vs 280.0 mOsm/kg; 10% trial: 285.1 vs 277.1 mOsm/kg as estimated from graph; $P < 0.05$). The 10% glucose trial resulted in significantly higher serum osmolality midway through the rehydration period compared to both pre-exercise levels and the 0% and 2% glucose trials (284.54 mOsm/kg vs 277.11, 277.4 and 279.4 mOsm/kg respectively as estimated from graph; $P < 0.05$). This may be due to a decreased rate of gastric emptying for the higher glucose content drink as reported elsewhere (Dill et al. 1990). On completion of the rehydration period, the 10% trial had significantly higher serum osmolality compared to the 0% and 2% glucose trials (282.4 vs 276.9 and 274.8 mOsm/kg respectively, as estimated from graph; $P < 0.05$). Furthermore the 2% trial had significantly lower serum osmolality than pre-exercise levels on completion of the rehydration period. No statistically significant difference was observed between the three trials at 1, 2, 3, or 5 hr post-hydration.

The percentage decrease in plasma volume immediately following exercise compared to pre-exercise levels was not statistically significant in any trials. Plasma volume was significantly greater than pre-exercise levels in the 2% trial midway through the rehydration period ($9.2 \pm 5.9\%$); at the end of the rehydration period ($11.7 \pm 4.9\%$) and at 1 hr ($8.7 \pm 4.9\%$), 2 hr ($8.2 \pm 5\%$) and 3 hr ($6.6 \pm 2.6\%$) following rehydration. Plasma volume was also significantly greater in the 0% trial at the end of the rehydration period ($6.3 \pm 4.6\%$) and 1 hr ($8.8 \pm 6.5\%$), 2 hr ($8.6 \pm 6.6\%$) following rehydration. However, no statistically significant differences from pre-exercise levels were observed for the 10% trial at any time point.

Net fluid balance was significantly lower than pre-exercise levels immediately following exercise ($P < 0.05$). No statistically significant difference in net fluid balance compared to pre-exercise levels was observed at any other time point. Net fluid balance was calculated from sweat loss, drink volume and urine volume data, however, gastric volume was not measured in the calculation and therefore net fluid balance may not accurately estimate hydration status (Maughan et al. 2007).

Urine osmolality decreased from pre-exercise levels 1 hr after consuming the 2% glucose drink but was not significantly different from pre-exercise levels in the 0% or 10% trials. No other details of urine osmolality were provided.

The findings of this study indicate that the 2% drink resulted in more rapid rehydration following exercise induced dehydration compared to the 10% drink as measured by serum osmolality and plasma volume however *ad libitum* consumption of test drinks means that variations in fluid intake may have affected study outcomes .

Evans et al. (2009b)

A similarly designed study by the same authors investigated the effects of ingestion of drinks with electrolytes (32 mmol/L sodium, 27 mmol/L chlorine and ~0.4 mmol/L potassium ions) and different carbohydrate concentrations (0%, 2% or 10% glucose) on rehydration in six healthy young male volunteers (age 26 ± 5 year, body mass 72.1 ± 5.5 kg and VO_{2max} 3.6 ± 0.7 L/min) following exercise-induced dehydration (Evans et al. 2009b).

Participants exercised by intermittent cycle ergometer at $58 \pm 2\%$ VO_{2max} at 35.3 ± 0.2 °C and a relative humidity of $59 \pm 2\%$ resulting in dehydration of $1.9\% \pm 0.1\%$ in 45 ± 8 min. One of three test drinks was then consumed in four equal volumes over a one hour period following exercise, equivalent to 150% of body mass lost. Although randomisation of study arms was

not discussed in the paper the author confirmed by personal communication that study arms were randomised. Data was analysed using repeated measures ANOVA followed by suitable pairwise testing.

Serum osmolality was higher than pre-exercise levels in all trials following exercise but only reached statistical significance in the 2% trial (0% trial: 283 ± 6 mOsm/kg vs 277 ± 5 mOsm/kg; 2%: 285 ± 3 mOsm/kg vs 279 ± 3 mOsm/kg ($P = 0.042$); 10% trial: 285 ± 3 mOsm/kg vs 278 ± 4 mOsm/kg). Serum osmolality was significantly higher than pre-exercise levels in the 10% glucose trial on completion of the rehydration period (284.52 vs 277.67 mOsm/kg as estimated from graph; $P = 0.045$) and was significantly higher than the 0% trial on completion (284.52 vs 273.17 mOsm/kg as estimated from graph) and 1 hr after rehydration (282.46 vs 272.78 mOsm/kg as estimated from graph). No other statistically significant differences compared to pre-exercise levels was observed in any trials 2- 6 hr post-rehydration.

Percentage decrease in plasma volume following exercise compared to pre-exercise levels was non-significant in all trials. Plasma volume was significantly higher than pre-exercise levels in the 2% glucose trial at the end of the rehydration period ($9\% \pm 4.9\%$; $P < 0.001$) and 1hr following rehydration ($P = 0.031$). Plasma volume was not significantly different to pre-exercise levels at any time point in the 0% or 10% glucose trials. Changes in urine osmolality were the same in all trials. Net fluid balance did not account for volume of gastric contents and therefore was not used as part of the assessment.

The evidence provided in this study indicates that the 2% glucose drink was superior to the 10% drink in aiding rapid rehydration as indicated by lower serum osmolality and higher plasma volume on completion of the rehydration period.

Osterberg et al. (2010)

Osterberg et al. (2010) studied the effects of electrolyte drinks with varying concentrations of carbohydrate on rehydration following exercise in hot and humid conditions in a randomised double-blind crossover study. Fifteen recreationally competitive male runners and triathletes that trained all year round participated in the study (mean age 34.4 ± 10 yr with a mean body mass of 77.8 ± 6.7 kg and VO_{2max} of 56.2 ± 6.3 mL/kg/min). Prior to testing, subjects were fasted for 3 hr, heat-acclimatised and confirmed as being hydrated with a urine specific gravity of below 1.02. Data was analysed using ANOVA, with repeated measures for time-based assessment.

Each trial consisted of 90 min exercise (running, stationary cycling and elliptical exercise) at 70 – 75% maximal heart rate without fluid consumption in 30 °C and 50% relative humidity resulting in body mass loss of 2 - 3%. Subjects replaced 100% of body mass loss with one of five drinks containing either 0%, 3%, 6% or 12% carbohydrate (sucrose and high fructose corn syrup – 58% glucose, 42% fructose) with standardised electrolyte concentrations (18 mmol/L sodium, 3 mmol/L potassium) or flavoured placebo with no added electrolytes, in 60 min following a 30 min equilibration period. All drinks were matched for taste (aspartame) and flavour (lemon lime) and were served chilled (3.3 °C). Although the focus of the study was the relative fluid retention properties of different drinks, several markers of hydration were recorded following consumption of electrolyte drinks.

Serum osmolality was not significantly different post exercise for any trials compared to pre exercise levels however it was significantly higher in the 12% trial compared to other trials following the rehydration period (90 min post-exercise) (values not provided; $P < 0.001$). No other statistically significant differences were observed at any time point.

The relative plasma volume decreased in all trials by an average of $7.1\% \pm 4.3\%$ following exercise but did not reach statistical significance. At 90 min (immediately following the

rehydration period) the group that received the 3% drink had significantly higher relative plasma volume than all other drinks compared to pre-exercise levels (+ 2.22% vs - 4.0, - 4.3, -4.8, -7.9% for 3%, placebo with electrolytes, 6%, placebo and 12% electrolyte drink respectively as estimated from graph; $P < 0.034$).

A non-statistically significant increase in urine specific gravity (USG) compared to pre-exercise levels was observed in all trials following the exercise period but was not measured at the start of the rehydration period. At 90 min (on completion of the rehydration period) the 6% and 12% trials had significantly higher USG than both placebo trials and the 12% trial had a higher USG than the 3% trial ($P < 0.05$). USG was significantly higher in the 6% trial compared to 3% or electrolyte placebo trials at 60 min ($P < 0.05$). At 120 min the 6% and 12% trials had higher USG than both placebo trials and the 3% trial was less than the 12% trial ($P < 0.05$). At 180 min the USG of the 6% and 12% trials was higher than both placebos and the 12% trial was higher than both the 3% or 6% trials ($P < 0.05$). At 240 min the USG of the 6% and 12% trials was higher than both placebos ($P < 0.05$).

The study by Osterberg et al. (2010) indicates that the presence of higher carbohydrate content (6% or 12% carbohydrate) in drinks did not improve the rate of rehydration following exercise induced dehydration in the heat compared to the 3% drink as measured by serum osmolality, percentage change in plasma volume and urine specific gravity.

Kamijo et al. (2012)

A study by Kamijo et al. (2012) investigated the effects of two carbohydrate electrolyte drinks (3.3% carbohydrate: 1.7% glucose and 1.6% fructose; 6.5% carbohydrate: 3.4% glucose and 3.1% fructose, both with 21 mmol/L sodium, 5 mmol/L potassium, 16.5 mmol/L chloride, 3.33 mmol/L citrate) and a carbohydrate-free drink with the same electrolytes on rehydration following exercise in the heat. Seven recreationally active male participants (age 25 ± 6 years, weight 65.37 ± 10.83 kg, VO_{2peak} 3081 ± 592 mL) followed a standardised diet the day before testing, consumed a light breakfast following an overnight fast and exercised on a cycle ergometer at 50% VO_{2peak} in the heat until approximately 2.3% of body weight was lost. Following a 2 hour recovery period subjects consumed drinks equivalent to 100% of body weight loss in a 30 min period. Two way ANOVA for repeated measures was used to determine the differences in hydration parameters following dehydration with post-hoc tests using the Tukey-Kramer method.

Plasma osmolality increased by approximately 6 mOsm/kg following dehydration in each trial, with no statistically significant difference between trials. Plasma osmolality was not significantly different between carbohydrate-containing trials following rehydration, except at 75 min (45 min after the rehydration period) in which plasma osmolality was higher in the group that received the 6.5% drink compared to the 3.3% drink (294 vs 289 mOsm/kg; $P < 0.05$). Plasma osmolality was significantly higher in the 6.5% drink trial compared to control at 15 min (297 vs 290 mOsm/kg), 45 min (294 vs 289 mOsm/kg), and 75 min after rehydration (291 vs 287 mOsm/kg; $P < 0.05$) and in the 3.3% trial 15 min after rehydration (295 vs 290 mOsm/kg; $P < 0.05$).

Plasma volume decreased following exercise in all trials compared to pre-exercise levels however statistical significance was not provided. The percentage increase in plasma volume following rehydration compared to dehydrated levels was significantly greater in the 6.5% trial compared to the 3.3% trial at 105 min (9.9% vs 6.9% as estimated from graph; $P < 0.05$) and 135 min post-rehydration (9.6% vs 6.1% as estimated from graph; $P < 0.05$) but was not significantly different at any other time point. Compared to the 0% trial a statistically significant increase in plasma volume was observed in the 3.3% trial at 15 and 45 min post-rehydration ($P < 0.05$) and in the 6.5% trial at 45, 75 and 105 min post-rehydration.

Study design was limited by the lack of blinding. Furthermore, rehydration did not commence until 2 hr after completion of exercise.

Clayton et al. (2014)

A randomised crossover study by Clayton et al. (2014) investigated the effects of consuming drinks with different carbohydrate concentrations on rehydration of 8 healthy males (age 24 ± 3 years; weight 79.5 ± 9.3 kg) following exercise in heat ($35 \text{ }^\circ\text{C} \pm 0.2 \text{ }^\circ\text{C}$) and high humidity ($68.4\% \pm 6.1\%$ relative humidity) at $50\% \text{ VO}_{2\text{max}}$ that resulted in loss of $\sim 1.8\%$ of total body mass from dehydration in ~ 57 min. Drinks consisted of 2% or 10% glucose, 30 mmol/L sodium, and sugar-free squash for taste and were consumed in four equal volumes over a 1 hour period, commencing 15 min following dehydration. Data were analysed using repeated measures ANOVA with Bonferroni adjustment.

Serum osmolality increased in both trials following exercise but reached statistical significance only in the 2% trial (2% trial: 294 vs 290 mOsm/kg, $P < 0.05$; 10% trial: 292 vs 290 mOsm/kg). A statistically significant increase in serum osmolality was observed in the 10% trial compared to the 2% trial immediately following rehydration (296 vs 287 mOsm/kg; $P < 0.05$) and 60 min after rehydration (292 vs 285 mOsm/kg; $P < 0.05$) but was not significantly different at any other time points.

Plasma volume was reduced compared to pre-exercise levels in both trials following exercise (3.8% in 2% trial and 4.3% in 10% trial; $P < 0.001$). Restoration of plasma volume was faster in the 2% trial compared to the 10% trial immediately following rehydration (6.7% increase compared to pre-exercise levels vs 5.9% decrease; $P < 0.015$) and 60 min after rehydration (4.2% increase compared to pre-exercise levels vs 1.9% decrease; $P < 0.05$).

A statistically significant increase in urine osmolality was observed following exercise in both trials (2% trial: 770 vs 377 mOsm/kg; 10% trial: 770 vs 414 mOsm/kg; $P < 0.05$). Urine osmolality was significantly lower in the 2% trial compared to pre-exercise levels 60 min after rehydration (81 vs 377 mOsm/kg; $P = 0.002$) and tended to be lower in the 10% trial (192 vs 414 mOsm/kg; $P = 0.054$). Urine osmolality was also greater in the 10% trial compared to the 2% trial immediately following rehydration (554 vs 383 mOsm/kg; $P = 0.015$) but no other statistically significant differences were observed at any other times.

A statistically significant decrease in corrected net fluid balance in which remaining gastric fluid was measured was observed compared to pre-exercise levels in all trials following exercise (-1478 mL as estimated from graph, $P < 0.001$). A statistically significant decrease in corrected net fluid balance was observed in the 10% trial immediately after and 60 min after rehydration (-918 mL and -883 mL respectively as estimated from graph, $P < 0.001$) compared to pre-exercise levels. Corrected net fluid balance was significantly lower in the 10% compared to 2% trials immediately following (-918 vs 0 mL) and 60 min (-883 mL vs -174 mL) after rehydration, as estimated from graph ($P < 0.001$). In the 2% trial the corrected net fluid balance was similar to pre-exercise levels immediately following and 1 hr after rehydration ($P > 0.05$).

Overall, the 2% glucose drink resulted in more rapid rehydration compared to the 10% glucose drink as measured by serum osmolality, plasma volume, urine osmolality and corrected net fluid balance following exercise induced dehydration in the heat.

Li et al. 2018

A randomised single-blinded 5-arm crossover study by Li et al. (2018) examined the effects of electrolyte drinks containing sodium (21 mmol/L), potassium (3.3 mmol/L), carbohydrate (3.3% or 6.6%), or carbohydrate and whey protein, on post-exercise rehydration following exercise at $65\% \text{ VO}_{2\text{peak}}$. Ten male adults (mean age 22 ± 0.7 years; weight 64.5 ± 1.9 kg; $\text{VO}_{2\text{peak}} 59.8 \pm 1.9$ mL/kg/min) completed a 60 minute run on five occasions resulting in an

average body mass loss of $2.15 \pm 0.05\%$, with a one week washout between trials. Drinks were consumed within 150 minutes following each trial in 6 boluses in a volume equivalent to 150% of body mass loss and hydration parameters were measured prior to exercise and at 0, 1, 2, 3 and 4 hours post-exercise.

No significant difference in plasma osmolality was observed in the 6.6 % carbohydrate compared to the 3.3% carbohydrate group at any measured timepoint (pre-exercise: 277 ± 5 vs 279 ± 3 mmol/kg; 2 hours: 285 ± 6 vs 277 ± 7 mmol/kg; 4 hours: 288 ± 7 vs 277 ± 5 mmol/kg; $P > 0.05$). Similarly, no significant difference in urine osmolality (pre-exercise: 498 ± 49 vs 478 ± 85 mmol/kg; 299 ± 72 vs 137 ± 36 mmol/kg; 4 hours: 126 ± 15 vs 89 ± 9 mmol/L), or urine specific gravity (pre-exercise: 1.01 ± 0.001 vs 1.01 ± 0.002 g/mL; 2 hours: 1.01 ± 0.002 vs 1.00 ± 0.00 g/mL; 4 hours: 1.00 ± 0.00 g/mL each) was observed between the 6.6% and 3.3% carbohydrate drink groups at any time point ($P > 0.05$).

2.3 Performance Studies

FSANZ identified five studies that investigated the effects of electrolyte drinks with carbohydrate concentrations lower than 5% on exercise performance using a randomised crossover design (Rogers et al. 2005; Phillips et al. 2012; Watson et al. 2012; Smith et al. 2013; Newell et al. 2014 (Table 1)). The range of carbohydrate concentrations in the drinks used in these studies was 2–10%. An additional study was identified, however the authors did not state if treatments were randomised across study arms (Smith et al. 2010). Studies that were considered to have unsuitable study design and therefore not used as part of the body of evidence are outlined in Table 2.

Rogers et al. (2005)

The study by Rogers et al. (2005) has been described previously. Briefly, five healthy individuals undertook an 85 minute moderate intensity cycle followed by a 3 mile time trial at ambient temperature (22°C) during which time 23 mL/kg body weight of a 3% carbohydrate, 6% carbohydrate electrolyte drink or water placebo without added electrolytes was consumed.

A decrease in trial times was observed with increased carbohydrate content, however this was not statistically significant between trials ($8:25 \pm 0:29$ min for water placebo, $8:13 \pm 0:25$ min for 3% carbohydrate, $7:58 \pm 0:33$ min for 6% carbohydrate). The study was underpowered and included only five participants.

Phillips et al. (2012)

A study by Phillips et al. (2012) looked at the effects of consuming electrolyte drinks with a range of carbohydrate concentrations on intermittent endurance capacity during prolonged intermittent running in seven adolescent team sport players at ambient temperature (18°C). A randomised controlled double-blinded crossover trial was undertaken with varying carbohydrate concentrations (2%, 6% or 10% maltodextrin) prior to and during exercise. Subjects exercised for 4 x 15 min sessions followed by a time to exhaustion (TTE) running trial. Data were analysed using repeated measures ANOVA with Bonferroni adjustment.

While the greatest intermittent endurance capacity was achieved in the 6% trial, it was not significantly different to the 2% trial (5.5 ± 0.8 min vs 4.8 ± 1.2 min, $P = 0.10$). Time to exhaustion was not significantly different between the 2% trial and the 10% trial (4.8 ± 1.2 min vs 4.1 ± 1.5 , $P = 0.09$). Distance covered was not significantly different in the 2% compared to the 6% trial ($P = 0.09$) or the 2% compared to the 10% trial ($P = 0.11$).

Watson et al. (2012)

Watson et al. (2012) studied the effect of electrolyte drinks with standardised electrolytes and differing concentrations of carbohydrate (0, 2, 4, 6% sucrose, glucose, fructose in ratio

50:25:25 with 18 mmol/L Na⁺ and 2mmol/L K⁺) in cool and warm conditions on performance measured as TTE in a randomised crossover study. Blinding was not discussed in the study. Two groups of twelve healthy males performed exercise on a cycle ergometer while consuming one of four electrolyte drinks. Participants exercised at 70% VO_{2max} in cool conditions (10°C) and 60% VO_{2max} in warm conditions (30 °C) until the point of volitional exhaustion. Data were analysed using repeated measures ANOVA with Bonferroni adjustment.

In the cool conditions study TTE was significantly longer than control in both the 4% trial (mean difference from control and standard deviation 19.4 ± 19.5 min, P = 0.032) and 6% trial (21.5 ± 24.2 min, P = 0.044) but not in the 2% trial (8.4 ± 25.8 min, P = 0.427). TTE was longer in the 6% trial than the 2% trial (21.5 ± 25.2 min, P = 0.025) but no other statistically significant differences in TTE were observed between carbohydrate-containing trials (P > 0.05).

In the warm conditions study, TTE increased as carbohydrate concentration increased (mean difference of 9.6 ± 16.0 min for 2%; 10.9 ± 12.1 min for 4%) although a significant difference was only observed for the 6% trial compared to water placebo (mean difference 17.6 ± 21.3 min, P < 0.045). However no statistical difference was observed in TTE between any of the carbohydrate-containing drinks in warm conditions (P > 0.05).

Smith et al. (2013)

Another study consisted of four separate randomised, double-blind crossover trials involving fifty one individuals (Smith et al. 2013). Thirteen different test drinks were prepared: water placebo and 12 electrolyte drinks containing 1-12% carbohydrate in 1% increments (1:1:1 glucose: fructose: maltose); all of which contained 18mmol/L Na⁺, 3 mmol/L K⁺ and 11 mmol/L Cl⁻. Each group of participants undertook four trial arms in which a placebo and three electrolyte glucose drinks were consumed on different occasions (Table 1). Following a 2 hour cycle a TTE trial was undertaken. The authors reported an optimal carbohydrate dose rate of 78 g/hr for performance during the time trial. However the effects of low versus high carbohydrate concentrations was unclear from the statistical analysis undertaken and therefore no conclusion could be drawn from this work.

Smith et al. (2010)

Previously, the same authors compared the effects of either 0%, 1.5%, 3%, or 6% glucose electrolyte drinks on performance in twelve recreationally-trained healthy male cyclists in a similarly designed study (Smith et al. 2010). No significant improvement in power output was observed between the 6% and either the 1.5% (P = 0.299) or 3% drinks (P= 0.413), although improvements were observed in carbohydrate containing drinks compared to placebo (1.5% electrolyte drink: 7.4% improvement, P=0.014; 3% electrolyte drink: 8.3% improvement, P=0.009; 6% electrolyte drink: 10.7% improvement, P=0.001). The study used a crossover design, however it was not stated if treatments were randomised. Attempts to contact the authors for clarification failed. Therefore the results of this study were not used in the body of evidence.

Newall et al. (2014)

In a similar study by Newall et al. (2014), twenty trained male cyclists (mean age 34 ± 10.2 yr body mass 74.6 ± 7.9 kg, VO_{2max} 62 ± 9 mL.kg⁻¹min⁻¹ that trained for > 6 hr/wk for > 3 yr) were recruited from regional cycling and triathlon clubs to determine the dose-response relationship between carbohydrate feeding and exercise performance. Participants completed a time trial following a 2-hr cycle in which three different commercially available drinks and water placebo were consumed: 2%, 3.9% or 6.4% glucose drink with added sodium (2%: 370 mg/L; 3.9% and 6.4% glucose: 500 mg/L), in an investigator-blinded placebo-controlled randomised crossover study. It was noted that the lack of participant-

blinding was a limitation of the study. Data were analysed using one-way ANOVA with Dunnett's post hoc comparisons with the control.

The 2% glucose trial resulted in a non-significant increase in performance compared to the water control trial ($P = 0.13$). However, the 2% drink contained a different sodium concentration to the other electrolyte drinks and therefore could not be considered with the other results. The 3.9% and 6.4% carbohydrate electrolyte drink trials resulted in improved time to completion compared to water placebo (6.1%; $P = 0.02$ and 7%; $P = 0.01$ respectively) as well as an increased power output of 8% ($P = 0.02$) and 9% ($P = 0.01$) for the 3.6% and 6.4% drinks respectively.

3. Discussion

The assessment considered data from human studies comparing the effect of consuming electrolyte drinks with different carbohydrate concentration during and after exercise in aiding rehydration and enhancing exercise performance.

Seven randomised crossover studies were considered in the body of evidence for the effect of electrolyte drinks on rehydration following exercise. All of these studies examined the effect of electrolyte drinks with different carbohydrate content on serum or plasma osmolality and six observed changes in plasma volume following exercise. In six studies participants consumed electrolyte drinks with different carbohydrate content following exercise that resulted in dehydration of approximately 2 to 3% of body weight. In six studies serum or plasma osmolality in the high-carbohydrate electrolyte drink trial was either greater than or similar to the lower carbohydrate electrolyte drink trials (10% vs 2%: Evans et al. 2009a, Evans et al. 2009b, Clayton et al. 2014; 12% vs 6% and 3% Osterberg et al. 2010; ~6% vs ~3% Kamijo et al. 2012; Li et al. 2018) at each measured time point following rehydration. A non-statistically significant difference in serum osmolality was observed in the study by Rogers et al. (2005) in which participants consumed test drinks during the exercise protocol.

Six of the studies reviewed in this assessment considered the effect of electrolyte drinks on changes in plasma volume following exercise. Three of the studies reported a statistically significant percentage increase in plasma volume following rehydration in trials with 2% carbohydrate but not with 10% carbohydrate trials compared to pre-exercise levels (Evans et al. 2009a; Evans et al. 2009b; Clayton et al. 2014). Three other studies reported either similar or increased plasma volume in lower carbohydrate drinks compared to high carbohydrate drinks soon after rehydration. Osterberg et al. (2010) reported that the 3% drink resulted in significantly higher plasma volume compared to either the 0%, 6% or 12% drink trials on completion of the rehydration period. Kamijo et al. (2012) did not observe a significant difference in plasma volume between 3.3% and 6.5% drinks at 15, 45 or 75 min post-rehydration although it was significantly higher in the 6.5% drink at 105 min and 135 min post-rehydration. In Rogers et al. (2005) no significant percentage change in plasma volume was observed between the 3%, 6% or placebo drinks following rehydration although it was noted that this study was underpowered. However, compared to pre-exercise levels, a significant difference in plasma volume following dehydration was observed in only one study (Clayton et al. 2014), thereby questioning the validity of change in plasma volume in measuring hydration status when dehydrated by 2-3%.

Three studies assessed the effects of 2% or 10% electrolyte drinks on urine osmolality. Evans et al. (2009a) found that compared to pre-exercise levels, urine osmolality was significantly lower in the 2% drink trial at 1 hr post-rehydration compared to pre-exercise levels but was not significantly different in the 0% or 10% drink trials. Clayton et al. (2014) reported that urine osmolality was significantly higher in the 10% drink compared to the 2%

drink immediately following rehydration and Evans et al. (2009b) did not observe a significant difference in urine osmolality between drinks at any time point.

Four studies were considered in the body of evidence for the effect of lower carbohydrate electrolyte drinks (less than 5%) on exercise performance compared to drinks with higher carbohydrate concentrations (greater than 5%). All studies were randomised crossover design with participants exercising for 70 min (Phillips et al. 2012), 85 min (Rogers et al. 2005) to approximately 120 min (Watson et al. 2012; Newall et al. 2014) in each experimental arm. All studies were undertaken in a climate-controlled environment of 18 to 23° C except for the two studies by Watson et al. (10° C and 30° C), as previously described. One study involved intermittent exercise (Phillips et al. 2012), with the remaining studies involving constant exercise.

In a randomised, investigator-blinded study of 20 trained cyclists Newall et al. (2014) found that the 3.9% or 6.4% carbohydrate trials had a similar effect on performance in a time trial following a 2hr ride. Two similarly designed studies by Watson et al. (2012) that measured the effect of four drinks (0%, 2%, 4% and 6% carbohydrate electrolyte drinks) found that in cool conditions (10°C) the 4% and 6% trial, but not the 2% trial had significantly longer TTE than control. Of the carbohydrate trials only the 2% and 6% electrolyte drinks had a significantly different TTE to each other. In warm conditions (30°C) the 6% trial had significantly greater TTE than control although no significant difference in TTE between carbohydrate- containing drinks was observed. Phillips et al. (2012) did not find a significant difference in time trial performance when participants consumed a 2% or 6% carbohydrate drink however the 6% drink trial had improved performance compared to the 10% trial (Phillips et al. 2012). Similarly, Rogers et al. (2005) did not observe a significant difference in exercise performance when participants consumed either the 3% or 6% carbohydrate electrolyte drinks or water placebo. However the lack of statistical significance in this study may be a consequence of the small study size (5 individuals).

A number of limitations in study design were identified in the body of evidence. Blinding of both participants and investigator is important in order to minimise performance bias, particularly in studies in which exercise performance is measured. Blinding was not discussed in one performance study (Watson et al. 2012) and participants were not blinded in a study by Newall et al. (2014). Rogers et al. (2005) suggested that small sample size (n=5) may have resulted in insufficient study power. Small samples sizes were noted in other studies that did not discuss study power (Evans et al. (2009b): n=6; Kamijo et al. (2012): n=7; Phillips et al. (2012): n=7). Furthermore, some subjects were tested after overnight fasting in order to standardise metabolic status of participants during each trial arm (Rogers et al. 2005; Newall et al. 2014; Li et al. 2018) which results in depleted glycogen storage that is used to maintain overnight blood glucose levels, potentially inflating the positive effects on performance.

Variations in study designs were also noted including measurement of differences in performance that included time to exhaustion and time trials as well as differences in exercise intensity and duration, and laboratory temperature. Furthermore, a lack of consensus exists regarding the optimal measurement of changes in hydration status. Serum osmolality is generally considered a suitable marker for hydration status in short-term laboratory controlled studies. It was noted that serum/plasma osmolality did not significantly increase from baseline levels immediately following exercise in some trial arms (Evans et al 2009a; Osterberg et al. 2012; Clayton et al. 2014; Li et al. 2018) despite the loss of body weight indicating loss of body fluid. Similarly, of the studies that assessed plasma volume only one study observed a significant decrease in plasma volume following exercise-induced dehydration compared to pre-exercise levels (Clayton et al. 2014) which are presumably due to other compensatory metabolic changes. Therefore, the reliability of serum osmolality and

change in plasma volume as measures of dehydration and rehydration in these studies is uncertain.

4. Conclusion

The assessment considered data from human studies that compared the effect of consuming electrolyte drinks with different carbohydrate content during and after exercise on rehydration and performance. All reviewed studies found that serum osmolality in lower carbohydrate electrolyte drink trials was lower than or similar to levels found in high carbohydrate electrolyte drink trials when consumed either during or after exercise. In general, plasma volume in lower carbohydrate electrolyte drinks was greater than or similar to levels found after consuming high carbohydrate electrolyte drinks.

In terms of exercise performance, four studies did not find a significant difference in performance between the lower or high carbohydrate drink trials. One study found no difference between the 4% and 6% carbohydrate trial at 10°C but that performance improved in the 6% trial compared to the 2% trial at 10°C. However, when the same study was undertaken at 30°C a significant difference in performance was not observed between carbohydrate trials.

The available evidence indicated no clear difference between lower and high carbohydrate electrolyte drinks with regard to hydration parameters and exercise performance. However several limitations in studies were noted including blinding of participants and investigators, sample size, differences in volume of test drinks consumed and reliability of hydration markers that would tend to make any differences difficult to detect. Other variations in study procedures including type and intensity of exercise, temperature and the outcomes measured decreased the comparability of studies and therefore further research is required in this area. Based on these considerations it was concluded that electrolyte drinks containing 2 to 4% carbohydrate have a similar effect on rehydration or enhancing performance when consumed during or on completion of sustained exercise (at least 60 min or 2% body weight loss) to electrolyte drinks containing 5 to 10% carbohydrate.

5. References

- Armstrong LE, Soto JA, Hacker FT, Casa DJ, Kavouras SA, Maresh CM (1998) Urinary Indices during dehydration, exercise, and rehydration. *International journal of sport nutrition* 8(4):345–55
- Armstrong LE (2007) Assessing hydration status: The elusive gold standard. *Journal of the American College of Nutrition* 26(5 Suppl):575S-584S
- Casa DJ, Clarkson PM, Roberts WO (2005) American College of Sports Medicine roundtable on hydration and physical activity: consensus statements. *Current sports medicine reports* 4(3):115–27
- Casey A, Mann R, Banister K, Fox J, Morris PG, Macdonald IA, Greenhaff PL (2000) Effect of carbohydrate ingestion on glycogen resynthesis in human liver and skeletal muscle, measured by (13)C MRS. *American journal of physiology, endocrinology and metabolism* 278(1):E65-75, doi:10.1152/ajpendo.2000.278.1.E65
- Cheuvront SN, Ely BR, Kenefick RW, Sawka MN (2010) Biological variation and diagnostic accuracy of dehydration assessment markers. *The American journal of clinical nutrition* 92(3):565–73, doi:10.3945/ajcn.2010.29490

- Clayton DJ, Evans GH, James LJ (2014) Effect of drink carbohydrate content on postexercise gastric emptying, rehydration, and the calculation of net fluid balance. *International journal of sport nutrition and exercise metabolism* 24(1):79–89
- Coombes JS, Hamilton KL (2000) The effectiveness of commercially available sports drinks. *Sports medicine (Auckland, N.Z.)* 29(3):181–209
- Currell K, Jeukendrup AE (2008) Superior endurance performance with ingestion of multiple transportable carbohydrates. *Medicine and science in sports and exercise* 40(2):275–81, doi:10.1249/mss.0b013e31815adf19
- Davis JM, Lamb DR, Pate RR, Slentz CA, Burgess WA, Bartoli WP (1988) Carbohydrate-electrolyte drinks: Effects on endurance cycling in the heat. *The American journal of clinical nutrition* 48(4):1023–30, doi:10.1093/ajcn/48.4.1023
- Davis JM, Burgess WA, Slentz CA, Bartoli WP (1990) Fluid availability of sports drinks differing in carbohydrate type and concentration. *American Journal of Clinical Nutrition* 51:1054:1057
- Dill DB, Costill DL (1974) Calculation of percentage changes in volumes of blood, plasma, and red cells in dehydration. *Journal of applied physiology* 37(2):247–8, doi:10.1152/jappl.1974.37.2.247.
- EFSA (2011) Scientific Opinion on the substantiation of health claims related to carbohydrate-electrolyte solutions and reduction in rated perceived exertion/effort during exercise (ID 460,466, 467, 468), enhancement of water absorption during exercise (ID 314, 315, 316, 317,319, 322, 325, 332, 408, 465, 473, 1168, 1574, 1593, 1618, 4302, 4309), and maintenance of endurance performance (ID 466, 469) pursuant to Article 13(1) of Regulation (EC) No 1924/2006. *EFSA Journal* 2011; 9(6):2211. doi: 10.2903/j.efsa.2011.2211
- EFSA (2015) Scientific and technical assistance on food intended for sportspeople. *EFSA Journal* 12(9):18. doi:10.2903/sp.efsa.2015.EN-871
- Evans GH, Shirreffs SM, Maughan RJ (2008) Acute effects of ingesting glucose solutions on blood and plasma volume. *British Journal of Nutrition* 101(10):1503-1508
- Evans GH, Shirreffs SM, Maughan RJ (2009a) Postexercise rehydration in man: The effects of carbohydrate content and osmolality of drinks ingested ad libitum (2009a). *Applied physiology, nutrition, and metabolism* 34(4):785–93, doi:10.1139/H09-065
- Evans GH, Shirreffs SM, Maughan RJ (2009b) Postexercise rehydration in man: The effects of osmolality and carbohydrate content of ingested drinks. *Nutrition* 25(9):905–13, doi:10.1016/j.nut.2008.12.014
- Goulet electrolyte drinkB (2013) Effect of exercise-induced dehydration on endurance performance: Evaluating the impact of exercise protocols on outcomes using a meta-analytic procedure. *British journal of sports medicine* 2013; 47(11):679–86, doi:10.1136/bjsports-2012-090958
- Kamijo Y-I, Ikegawa S, Okada Y, Masuki S, Okazaki K, Uchida K, Sakurai M, Nose H (2012) Enhanced renal Na⁺ reabsorption by carbohydrate in drinks during restitution from thermal and exercise-induced dehydration in men. *American journal of physiology. Regulatory, integrative and comparative physiology* 303(8):R824-33, doi:10.1152/ajpregu.00588.2011
- Kovacs EM, Senden JM, Brouns F (1999) Urine color, osmolality and specific electrical

conductance are not accurate measures of hydration status during postexercise rehydration. *The Journal of sports medicine and physical fitness* 39(1):47–53

Kovacs EMR, Schmahl RM, Senden JMG, 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(1):14–23

Li L, Sun FH, Huang WYJ, Wong SHS (2018). Effects of whey protein in carbohydrate-electrolyte drinks on post-exercise rehydration. *European journal of sport science* 18(5) 685-694.

Maughan RJ, Bethell LR, Leiper JB (1996) Effects of ingested fluids on exercise capacity and on cardiovascular and metabolic responses to prolonged exercise in man. *Experimental physiology* 81(5):847–59

Maughan RJ, Fenn CE, Leiper JB (1989) Effects of fluid, electrolyte and substrate ingestion on endurance capacity. *European journal of applied physiology and occupational physiology* 58(5):481–6

Maughan RJ, Shirreffs SM, Leiper JB (2007) Errors in the estimation of hydration status from changes in body mass. *Journal of sports sciences* 25(7):797–804, doi: 10.1080/02640410600875143

Minehan MR, Riley MD, Burke LM (2002) Effect of flavor and awareness of kilojoule content of drinks on preference and fluid balance in team sports. *International journal of sport nutrition and exercise metabolism* 12(1):81–92

Phillips SM, Turner AP, Sanderson MF, Sproule J (2012) Beverage carbohydrate concentration influences the intermittent endurance capacity of adolescent team games players during prolonged intermittent running. *European journal of applied physiology* 112(3):1107–16, doi:10.1007/s00421-011-2065-2

Popowski LA, Oppliger RA, Patrick Lambert G, Johnson RF, Kim Johnson A, Gisolfi CV (2001) Blood and urinary measures of hydration status during progressive acute dehydration. *Medicine and science in sports and exercise* 33(5):747–53

Rehrer NJ, Wagenmakers AJ, Beckers EJ, Halliday D, Leiper JB, Brouns F, Maughan RJ, Westerterp K, Saris WH (1992) Gastric emptying, absorption, and carbohydrate oxidation during prolonged exercise. *Journal of applied physiology* 72(2):468–75, doi: 10.1152/jappl.1992.72.2.468

Rogers J, Summers RW, Lambert GP (2005) Gastric emptying and intestinal absorption of a low-carbohydrate sport drink during exercise. *International journal of sport nutrition and exercise metabolism* 15(3):220–35

Rowlands DS, Bonetti DL, Hopkins WG (2011) Unilateral fluid absorption and effects on peak power after ingestion of commercially available hypotonic, isotonic, and hypertonic sports drinks. *International journal of sport nutrition and exercise metabolism* 21(6):480–91

Sawka MN, Burke LM, Eichner ER, Maughan RJ, Montain SJ, Stachenfeld NS (2007) American College of Sports Medicine position stand. Exercise and fluid replacement. *Medicine and science in sports and exercise* 2007; 39(2):377–90, doi:10.1249/mss.0b013e31802ca597.

Shi X, Summers RW, Schedl HP, Chang RT, Lambert GP, Gisolfi CV (1994) Effects of

solution osmolality on absorption of select fluid replacement solutions in human duodenojejunum. *Journal of applied physiology* 77(3):1178–84, doi: 10.1152/jappl.1994.77.3.1178

Smith JW, Pascoe DD, Passe DH, Ruby BC, Stewart LK, Baker LB, Zachwieja JJ (2013) Curvilinear dose-response relationship of carbohydrate (0-120 g·h⁻¹) and performance. *Medicine and science in sports and exercise* 45(2):336–41, doi:10.1249/MSS.0b013e31827205d1

Smith JW, Zachwieja JJ, Péronnet F, Passe DH, Massicotte D, Lavoie C, Pascoe DD (2010) Fuel selection and cycling endurance performance with ingestion of ¹³Cglucose: Evidence for a carbohydrate dose response. *Journal of applied physiology* 108(6):1520–9, doi:10.1152/japplphysiol.91394.2008

Sports Dietitians Australia (2018) Sports Drinks Factsheet 2018 <https://www.sportsdietitians.com.au/factsheets/fuelling-recovery/sports-drinks/> Accessed 5 September 2018

Thomas DT, Erdman KA, Burke LM (2016) American College of Sports Medicine Joint Position Statement. Nutrition and Athletic Performance. *Medicine and science in sports and Exercise* 48(3):543–68, doi:10.1249/MSS.0000000000000852

Villiger M, Stoop R, Vetsch T, Hohenauer E, Pini M, Clarys P, Pereira F, Clijsen R (2018) Evaluation and review of body fluids saliva, sweat and tear compared to biochemical hydration assessment markers within blood and urine. *European journal of clinical nutrition* 72(1):69–76, doi:10.1038/ejcn.2017.136

Vist GE, Maughan RJ (1995) The effect of osmolality and carbohydrate content on the rate of gastric emptying of liquids in man. *The Journal of physiology* 486 (Pt 2):523–31

Watson P, Shirreffs SM, Maughan RJ (2012) Effect of dilute carbohydrate drinks on performance in cool and warm environments. *Medicine and science in sports and exercise* 44(2):336 – 43, doi:10.1249/MSS.0b013e31822dc5ed

Yaspelkis BB, Ivy JL (1991) Effect of carbohydrate supplements and water on exercise metabolism in the heat. *Journal of applied physiology* 71(2):680–7, doi:10.1152/jappl.1991.71.2.680

Appendix 1. Included studies that investigate the effect of lower carbohydrate electrolyte drinks (less than 5% carbohydrate) on rehydration or performance.

Reference and study details	Outcome parameters measured*	Results
<p>Rogers et al. (2005)</p> <p>Randomised controlled double-blinded crossover trial of five healthy volunteers (4 male, 1 female, age 25 ± 1 year, weight 70.2 ± 3.6 kg, VO_{2max} 61.5 ± 2.1 mL/kg/min).</p> <p>Subjects requested to refrain from physical activity and maintain the same diet for 24 hr prior to each trial arm.</p> <p>Subjects undertook 85 min moderate intensity exercise (60% VO_{2max} on cycle ergometer) followed by a 3 mile time trial.</p> <p>0% carbohydrate, 3% carbohydrate (1% glucose, 2% sucrose) or 6% carbohydrate (2% glucose, 4% sucrose) drink with matched colour and flavour. The 3% and 6% carbohydrate drinks contained 3.1 mmol/L potassium and 17.2 and 17.6 mmol/L sodium respectively. The use of artificial sweeteners in test drinks was not discussed.</p> <p>Drink volume was calculated as 23 mL/kg body weight, with 10% of total volume consumed every 10 min during exercise.</p> <p>Trials were conducted at least one week apart; participants fasted overnight before testing.</p>	<p>Rehydration</p> <p>Serum osmolality % change in plasma volume</p> <p>Performance</p> <p>Cycling time trial performance</p>	<p>No significant difference in plasma osmolality or percentage change in plasma volume were observed between trials either before exercise or during the exercise/hydration period ($P > 0.05$).</p> <p>Time trial performance was not significantly different between trials: water placebo: $8:25 \pm 0:29$ min, 3% carbohydrate drink $8:13 \pm 0:25$ min , 6% carbohydrate drink $7:58 \pm 0:33$ min ($P > 0.05$).</p>
<p>Evans et al. (2009a)</p> <p>Nine subjects, 6 male and 3 female (age 23 ± 2 yr, body mass 76.8 ± 8.3 kg and VO_{2max} 3.7 ± 0.8 L/min) participated in a randomised single blinded study with crossover design.</p> <p>Intermittent exercise (cycle ergometer) in heat ($35.3 \text{ }^\circ\text{C} \pm 0.3 \text{ }^\circ\text{C}$) at $58 \pm 3\%$ VO_{2max} resulted in $1.99 \pm 0.07\%$ loss of body weight. Mean exercise time was 50 ± 16 min.</p>	<p>Rehydration</p> <p>Serum osmolality Percentage change in plasma volume Net fluid balance Urine osmolality</p>	<p>Serum osmolality was significantly higher than pre-exercise levels immediately after the dehydration period for all trials (0% trial: 285.4 vs 277.9 mOsm/kg; 2% trial: 287.5 vs 280.0 mOsm/kg; 10% trial: 285.1 vs 277.1 mOsm/kg as estimated from graph; $P < 0.05$). Serum osmolality was significantly higher in the 10% glucose trial compared to either the 0 or 2% glucose trial midway through and on completion of the 2 hr rehydration period. Also serum osmolality in the 2% trial was significantly lower than pre-exercise levels on completion of the rehydration period. No significant differences were observed between trials at 1, 2, 3 or 5 hr post-rehydration.</p>

Reference and study details	Outcome parameters measured*	Results
<p>Electrolyte drinks with 0, 2, or 10% glucose and 31 mmol/L sodium, 27 mmol/L chlorine and 0.6 mmol/L potassium consumed <i>ad libitum</i> during 120 min rehydration period. Fluid intake was not significantly different between trials ($P = 0.173$); equivalent to $150 \pm 36\%$, $165 \pm 26\%$, and $143 \pm 21\%$ of body mass lost.</p> <p>Low energy lemon flavour and aspartame was added to the 0% and 2% glucose trials so that the sweetness of all drinks was comparable.</p> <p>Similar physical activity and nutritional intake patterns were followed for 24 hr before the experimental trial. Subjects fasted overnight prior to testing and consumed 500 mL water 1 hr before arrival at laboratory. Tests were conducted at least 7 days apart. Bladders were voided before commencement of trials.</p>		<p>The percentage decrease in plasma volume following exercise compared to pre-exercise levels was non-significant in all trials. Percentage change in plasma volume compared to pre-exercise levels was significantly greater in the 2% glucose trial midway through the rehydration period ($9.2 \pm 5.9\%$); at the end of the rehydration period ($11.7 \pm 4.9\%$) and at 1 hr ($8.7 \pm 4.9\%$), 2 hr ($8.2 \pm 5\%$) and 3 hr ($6.6 \pm 2.6\%$) following rehydration. Percentage change in plasma volume was not significantly different than pre-exercise levels for the 10% trial but significantly greater for 0% at the end of the rehydration period ($6.3 \pm 4.6\%$), and 1 hr ($8.8 \pm 6.5\%$) and 2 hr ($8.6 \pm 6.6\%$) post hydration.</p> <p>Net fluid balance was significantly lower than pre-exercise levels following dehydration in all trials however no other significant difference was observed at any other time point. Net fluid balance was not considered a suitable marker for hydration status as volume of gastric contents were not included in calculations.</p> <p>Urine osmolality decreased from pre-exercise levels 1 hr after consuming the 2% glucose solution but was not significantly different from pre-exercise levels in the 0% or 10% drink trials.</p>
<p>Evans et al. (2009b)</p> <p>Six healthy young male subjects (age 26 ± 5 yr, body mass 72.1 ± 5.5 kg and VO_{2max} 3.6 ± 0.7 L/min) participated in a crossover study. Randomisation was not mentioned but was confirmed by the author in a personal communication.</p> <p>Subjected exercised intermittently on cycle ergometer at an intensity of $58 \pm 2\%$ VO_{2max} at 35.3 ± 0.2 °C and a relative humidity of $59 \pm 2\%$ until a body mass loss of $1.9 \pm 0.1\%$ was achieved (mean exercise time of 45 ± 8 min).</p> <p>Electrolyte drinks: 0%, 2%, or 10% glucose; ~32 mmol/L sodium, ~27 mmol/L chlorine and ~ 0.4 mmol/L potassium ions; consumed in the 60 min post-exercise rehydration period in 4 equal aliquots equivalent to 150% (130% for one subject) of body mass lost.</p> <p>Similar physical activity and nutritional intake for 24 hr before the experimental trial was requested. Participants fasted overnight with 500 mL water consumed 1 hr before arrival at laboratory. Tests were conducted at least 7 days apart.</p>	<p>Rehydration</p> <p>Serum osmolality % Change in plasma volume Urine osmolality Net fluid balance</p>	<p>Serum osmolality was higher than pre-exercise levels in all trials following exercise but only reached statistical significance in the 2% trial (0% trial: 283 ± 6 mOsm/kg vs 277 ± 5 mOsm/kg; 2%: 285 ± 3 mOsm/kg vs 279 ± 3 mOsm/kg ($P = 0.042$); 10% trial: 285 ± 3 mOsm/kg vs 278 ± 4 mOsm/kg).</p> <p>Serum osmolality was significantly higher in the 10% glucose trial compared to the 0% glucose trial on completion of and 1 hr after the rehydration period. Serum osmolality was also significantly higher in the 10% trial compared to pre-exercise levels on completion of the rehydration period. No significant difference in serum osmolality was observed between trials at 2, 3, 4 or 6 hr post-rehydration.</p> <p>Percentage decrease in plasma volume following exercise compared to pre-exercise levels was non-significant in all trials. Plasma volume was significantly higher than pre-exercise values in the 2% glucose trial at the end of the rehydration period ($9\% \pm 4.9\%$; $P < 0.001$) and 1hr following rehydration ($P = 0.031$). Plasma volume was not significantly different to baseline levels at any time point in the 0% or 10% glucose trials.</p> <p>Changes in urine osmolality were similar in all trials.</p>

Reference and study details	Outcome parameters measured*	Results
<p>Osterberg et al. (2010)</p> <p>Randomised controlled double blind crossover trial of 15 recreationally competitive male runners or triathletes mean age 34.4 ± 10 yr with a mean body mass of 77.8 ± 6.7 kg and VO_{2max} of 56.2 ± 6.3 mL/kg/min.</p> <p>2 - 3% body mass loss from 90 min exercise at 70-75%_{max} heart rate in hot humid conditions (30°C and 50% relative humidity)</p> <p>0, 3, 6, 12% carbohydrate (sucrose and high fructose corn syrup – 58% glucose, 42% fructose) with standardised electrolyte concentrations (18 mmol/L sodium, 3 mmol/L potassium or flavoured placebo with no added electrolytes replaced 100% fluid lost in 60 min after 30 min equilibration period. All drinks were matched for taste (aspartame) and flavour (lemon lime) and were served chilled (3.3°C).</p> <p>Participants consumed a standardised diet for 24 hr before each trial with no other food allowed; Sodium, caffeine and alcohol were restricted; subjects were fasted for 3 hr before commencement of trials. Urine SG was less than 1.02 before commencement of trial; no difference in mean sweat loss was observed between trials. Serum osmolality was not different pre- or post-exercise for any trials.</p>	<p>Rehydration</p> <p>Serum osmolality % change in plasma volume Urine specific gravity</p>	<p>Net fluid balance was not considered as gastric contents were not included in calculations.</p> <p>Serum osmolality was not significantly different post exercise for any trials compared to pre-exercise levels however it was significantly higher in the 12% trial compared to other trials at 90 min ($P < 0.001$) but not significantly different at any other time point.</p> <p>Plasma volume decreased by an average of $7.1\% \pm 4.3\%$ following exercise in all trials but did not reach statistical significance. Plasma volume was significantly higher in the 3% trial than in any other trials at 90 min post-exercise (on completion of the rehydration period) ($P = 0.034$).</p> <p>A non-statistically significant increase in urine specific gravity (USG) compared to pre-exercise levels was observed in all trials following the exercise period but was not measured at the start of the rehydration period. USG was significantly higher in the 6% trial compared to 3% or electrolyte placebo trials at 60 min ($P < 0.05$); At 90 min the 6% and 12% trials had significantly greater USG than both placebo trials and the 12% trial had a greater USG than 3% trial ($P < 0.05$). At 120 min the 6% and 12% trials had greater USG than both placebo trials and the 3% trial was lower than the 12% trial ($P < 0.05$). At 180 min the USG of the 6% and 12% trials was higher than both placebos and the 12% trial was higher than both the 3% or 6% trials ($P < 0.05$). At 240 min the USG of the 6% and 12% trials was higher than both placebos ($P < 0.05$).</p>
<p>Kamijo et al. (2012)</p> <p>Randomised crossover designed study with 7 recreationally active men (age 25 ± 6 years, weight 65.37 ± 10.83 kg, VO_{2max} 3081 ± 592 mL). Blinding of participants was not discussed.</p> <p>Standardised meals based on recommended daily allowances were consumed the day before each trial. Subjects were also requested to avoid strenuous exercise, caffeine and alcohol the day before each trial. A light breakfast (200kcal, 0.4 g salt and 500mL water) was consumed prior to testing.</p> <p>Approximately 2.3% of body weight was lost through intermittent exercise on a cycle ergometer at 50% VO_{2max} in a hot environment (36°C). One hundred percent of body weight loss was consumed.</p>	<p>Rehydration</p> <p>Plasma osmolality % change plasma volume</p>	<p>Plasma osmolality increased in all trials following dehydration by ~6 mOsm/kg with no statistically significant difference between trials.</p> <p>Plasma osmolality was not significantly different between carbohydrate-containing trials except at 75 min (45 min after the rehydration period) when plasma osmolality was higher in the 6.5% drink compared to the 3.3% drink (294 vs 289 mOsm/kg; $P < 0.05$). Plasma osmolality was significantly higher in the 6.5% drink trial compared to control at 15 min (297 vs 290 mOsm/kg), 45 min (294 vs 289 mOsm/kg), and 75 min after rehydration (291 vs 287 mOsm/kg; $P < 0.05$) and in the 3.3% trial 15 min after rehydration (295 vs 290 mOsm/kg; $P < 0.05$).</p> <p>Plasma volume decreased following exercise in all trials however statistical significance was not provided. Percentage change in plasma volume compared to dehydrated levels was significantly greater in the 6.5% trial</p>

Reference and study details	Outcome parameters measured*	Results
<p>Test drinks (consumed at 14°C) containing 0% carbohydrate, 3.3% carbohydrate (1.7% glucose, 1.6% fructose) or 6.5% carbohydrate (3.4% glucose, 3.1% fructose) with standardised electrolyte composition (21 mmol/L sodium, 5 mmol/L potassium, 16.5 mmol/L chloride, 3.33mmol/L citrate) were consumed in 30 min following a 2 hr rest after completing exercise.</p> <p>Trials were conducted at least 7 day apart.</p>		<p>compared to the 3.3% trial at 105 min (9.9% vs 6.9% as estimated from graph; $P < 0.05$) and 135 min (9.6% vs 6.1% as estimated from graph; $P < 0.05$) post-rehydration but was not significantly different at any other time point.</p> <p>Compared to 0% trial the percentage change in plasma volume was significantly greater in the 3.3% trial at 15 and 45 min post-rehydration ($P < 0.05$) and in the 6.5% trial at 45,75,105 min post-rehydration.</p>
<p>Phillips et al. (2012)</p> <p>Randomised controlled double blinded crossover trial of three electrolyte drinks - 2%, 6%, 10% carbohydrate (maltodextrin) – electrolyte solution: (sodium 250 mg/L, magnesium 60 mg/L, potassium 90 mg/L, calcium 20 mg/L).</p> <p>7 adolescent team sport players that regularly participated in competitive club level (or higher) soccer, rugby or field hockey.</p> <p>Participants refrained from heavy physical activity for 48 hr before each trial, recorded food and drink intake before the first trial and replicated it between subsequent trials.</p> <p>Exercise included a warm-up of jogging, striding and stretching for 10 min. Four 15 min blocks of exercise were undertaken with a 3 minute recovery time in which a bolus of drink (2mL/kg body mass) was consumed. Intermittent run to exhaustion followed.</p> <p>1.6% body weight was lost during exercise.</p> <p>Washout 3-7 days between trials; fasting prior to testing was not discussed.</p>	<p>Performance</p> <p>TTE and distance covered</p>	<p>Time to exhaustion was not significantly different between the 6% solution and the 2% solution (5.5 ± 0.8 min vs 4.8 ± 1.2 min, $P = 0.10$) or between the 2% and 10% trials (4.8 ± 1.2 min vs 4.1 ± 1.5, $P = 0.09$).</p> <p>Distance covered was not significantly different in the 2% compared to the 6% trial ($P = 0.09$) or the 2% compared to the 10% trial ($P = 0.11$).</p>
<p>Watson et al. (2012)</p> <p>Randomised crossover study of 24 healthy males that evaluated the efficacy of drinks containing low concentrations of carbohydrate (2- 6%) on exercise performance in cool (10°C; 12 participants) and warm (30 °C; 12 participants) environments. Blinding was not discussed.</p>	<p>Performance</p> <p>Time to exhaustion (TTE) –fixed intensity exercise to volitional exhaustion at 70% VO_{2max} in cool conditions</p>	<p>TTE increased with increasing carbohydrate content ($P < 0.012$).</p> <p>Compared to control at 10°C TTE was significantly longer in the 4% carbohydrate trial (mean difference: 19.4 ± 19.5 min, $P = 0.032$) and 6% (21.5 ± 24.2 min, $P = 0.044$) but not compared to the 2% trial (mean difference: 6.6 min $P = 0.427$). TTE was longer on 6% trial than 2% trial (13.0 ± 12.5 min, $P = 0.025$). No significant difference was observed between 4% and 6% trials in cool conditions ($P > 0.05$).</p>

Reference and study details	Outcome parameters measured*	Results
<p>0, 2, 4, 6% carbohydrate sols (each with sucrose, glucose, fructose in ratio 50:25:25) containing 18 mM Na⁺ and 2 mM K⁺. The 0% drink consisted of a sugar-free sports drink with sugar added in the case of the other drinks. All drinks were prepared using a sugar-free fruit drink base.</p> <p>Participants followed similar nutritional intake from first trial for 24 hr before. No alcohol was consumed or strenuous exercise undertaken for 24 hr before each trial. Participants fasted for 6 hr before each trial and consumed 500 mL plain water 90 min before exercise</p> <p>Minimum 5 day washout between trials; 6 hour fast before testing</p> <p>Test drinks were consumed immediately before and every 10 min during exercise</p>	<p>and 60% VO_{2max} in warm conditions.</p>	<p>A non-significant increase in TTE was observed between the 0% and 2% or 4% trials at 30 °C (P > 0.05) but TTE was longer in the 6% compared to 0% trial (P = 0.045). No difference in TTE was observed between the carbohydrate trials in warm conditions (P > 0.05).</p>
<p>Clayton et al. (2014)</p> <p>Eight young healthy males (age 24 ± 3 years; weight 79.5 ± 9.3 kg) participated in randomised crossover study. Blinding was not discussed.</p> <p>Dietary and exercise activity preceding the first trial arm was recorded and repeated before the second arm. Subjects were requested to avoid strenuous exercise and alcohol for 24 hr before each trial. 500 mL water was consumed 1.5 hr before arrival.</p> <p>Participants exercised at 50% VO_{2max} in hot (35 ± 0.2° C) and humid (68.4% ± 6.1% relative humidity) conditions until approximately 1.8% of body mass was lost in approx. 57 min.</p> <p>2% or 10% glucose electrolyte drinks containing 30 mmol/L sodium and sugar free squash were consumed equivalent to 150% of body mass loss, commencing 15 min after exercise, over a period of 1 hr, in 4 equal aliquots . Drink temperature was 20°C.</p> <p>At least 7 day washout between trials.</p>	<p>Rehydration</p> <p>Serum osmolality Plasma volume Urine osmolality Corrected net fluid balance</p>	<p>Serum osmolality increased in both trials following exercise but reached statistical significance in the 2% trial (2% trial: 294 vs 290 mOsm/kg, P < 0.05; 10% trial: 292 vs 290 mOsm/kg). Serum osmolality was greater in the 10% trial than in the 2% trial following rehydration (296 vs 287 mOsm/kg;) and 60 min after rehydration (292 vs 285 mOsm/kg) (P < 0.05) but was not significantly different at any other time points.</p> <p>Plasma volume was reduced compared to pre-exercise levels in both trials following exercise (3.8% in 2% trial and 4.3% in 10% trial; P = 0.001). Restoration of plasma volume was faster in the 2% trial compared to the 10% trial immediately following rehydration (6.7% increase vs 5.9% decrease; P < 0.05) and 60 min after rehydration (4.2% increase vs 1.9% decrease; P < 0.05).</p> <p>Urine osmolality was significantly higher following exercise in both trials (770 vs 377 mOsm/kg in 2% trial and 770 vs 414 mOsm/kg in 2% trial; P < 0.05). Urine osmolality was significantly lower in the 2% trial compared to pre-exercise levels 60 min after rehydration (81 vs 377 mOsm/kg; P = 0.002) and greater in the 10% trial compared to the 2% trial immediately following rehydration (554 vs 383 mOsm/kg; P = 0.015) but was not significantly different at any other times.</p> <p>Corrected net fluid balance in which remaining gastric fluid was measured was significantly lower than pre-exercise levels in all trials following exercise (- 1478 mL estimated from graph; P < 0.001). Corrected net fluid balance was</p>

Reference and study details	Outcome parameters measured*	Results
		significantly lower than pre-exercise levels in the 10% trial immediately after and 60 min after rehydration (- 918 mL and -883 mL respectively as estimated from graph, (P < 0.01). Corrected net fluid balance was significantly lower in the 10% compared to 2% trials immediately following and 60 min after rehydration (P < 0.001). In the 2% trial the corrected net fluid balance was similar to pre-exercise levels immediately following and 1 hr after rehydration (P > 0.05).
<p>Newell et al. (2014)</p> <p>Investigator blinded, randomised crossover study of twenty male cyclists (mean age 34 ± 10.2 yr body mass 74.6 ± 7.9 kg, VO_{2max} 62 ± 9 mL.kg⁻¹min⁻¹ that trained for > 6 hr/wk for > 3 yr) testing performance following 2 hr ride, followed by work-matched time trial (70% peak power output) following the consumption of four drinks : 0%; 2% glucose 370 mg/L sodium; 3.9% and 6.4% carbohydrate solution, both with 500 mg/L sodium.</p> <p>Each study arm was completed following a 10 hr overnight fast. Participants replicated dietary intake for 48 hr prior to trials, refrained from intense exercise for 48 hr before trials and rested completely for 24 hr before each laboratory visit.</p> <p>Washout: one week between trials</p>	<p>Performance</p> <p>Time to exhaustion (70% peak power output) and power output</p>	<p>The 0% glucose trial did not contain electrolytes and the 2% trial had a different sodium concentration compared to the other trials. Although an improvement in completion time and power output was observed with the 2% trial compared to water control, neither reached statistical significance (P = 0.13 and P = 0.12 respectively).</p> <p>The 3.9% glucose trial resulted in a 6.1% improvement in task completion time (P = 0.02) compared to water and the 6.4% trial resulted in a 7% improvement (P = 0.01) compared to water.</p> <p>An improvement in power output was observed for the 3.9% and 6.4% trials of 8% (P = 0.02) and 9% (P = 0.01) respectively compared to 0% trial (P < 0.01 for both).</p>
<p>Li et al. (2018)</p> <p>Single blinded randomised crossover study of ten male adults (mean age 22 ± 0.7 years; weight 64.5 ± 1.9 kg; VO_{2peak} 59.8 ± 1.9 mL/kg/min) that examined the effect of 5 drinks containing 3.3% or 6.6% carbohydrate or carbohydrate and whey protein (not assessed here) and standardised electrolytes (21 mmol/L sodium and 3.3 mmol/L potassium) on rehydration following a 60 minute run at 65% VO_{2peak}.</p> <p>Each study arm was completed following a 10-12 hr overnight fast. Participants replicated dietary intake for 24 hr prior to trials and were instructed to abstain from strenuous exercise and alcohol consumption for 24 hr before each trial</p> <p>Washout: one week between trials</p>	<p>Rehydration</p> <p>Plasma osmolality Urine osmolality Urine specific gravity</p>	<p>No significant difference in plasma osmolality, urine osmolality or urine specific gravity was observed between the 3.3% and 6.6% carbohydrate arms at any measured timepoints (pre-exercise, 0, 1, 2, 3, 4 hr post-exercise; P > 0.05).</p>

* Only parameters that were considered relevant to exercise performance and rehydration are reported

Appendix 2 Excluded studies that investigate the effect of lower carbohydrate electrolyte drinks (less than 5% carbohydrate) on rehydration or performance.

Publication	Outcome	Reason for Exclusion
<p>Davis et al. (1988)</p> <p>Double blinded randomised controlled crossover study of nineteen well trained male cyclists</p>	Rehydration and performance	Both carbohydrate and electrolyte concentration varied between trials. The effects of altered carbohydrate content cannot be determined independent of electrolyte content.
<p>Maughan et al. (1989)</p> <p>The effects of six drinks including glucose, fructose, glucose-fructose syrup (36.5%); water or carbohydrate electrolyte drink (4% glucose, 70 mmol/L sodium, 20 mmol/L potassium) or water on endurance performance.</p>	Performance	Concentration of sugar in syrup is above the concentration under consideration.
<p>Yaspelkis and Ivy (1991)</p> <p>Twelve male competitive cyclists completed three randomised trials in which a low carbohydrate (2% maltodextrin, 3.48 mmol/L sodium and 1.53 mmol/L potassium), high carbohydrate (5.75% maltodextrin, 2.75 % fructose, 5.2 mmol/L sodium and 0.51 mmol/L potassium) drink or water placebo was consumed immediately before exercise and every 15 min during exercise that consisted of 120 min of cycling at $48.8 \pm 0.8\%$ VO_{2max}.</p>	Hydration	Both carbohydrate and electrolyte concentration varied between trials. The effects of altered carbohydrate content cannot be determined independent of electrolyte content. Sodium concentration was below 10 mmol/L as required in Standard 2.6.2 – 9 of the Food Standards Code and therefore could not be used as part of the evidence base.

Publication	Outcome	Reason for Exclusion
<p>Maughan et al. (1996)</p> <p>The effects of water and two dilute glucose-electrolyte drinks on exercise performance and cardiovascular and metabolic responses.</p>	<p>Performance and Rehydration</p>	<p>Both carbohydrate and electrolyte concentration varied between trials. The effects of altered carbohydrate content cannot be determined independent of electrolyte content.</p>
<p>Galloway and Maughan (2000)</p> <p>The effects of substrate and fluid (no drink, 2% or 15% electrolyte drink) on thermoregulatory and metabolic responses during prolonged exercise in the heat.</p>	<p>Rehydration</p>	<p>Study does not provide a suitable pair of drinks to compare. Fifteen percent electrolyte drink is above the maximum permitted carbohydrate concentration in the Food Standards Code.</p>
<p>Minehan et al. (2002)</p> <p>Three non-blinded randomised crossover trials of 9 junior, 7 and 8 senior elite sports persons repeated three times each</p> <p>1% or 6.8% carbohydrate 18.7 mmol/L Na, 3 mmol/L potassium electrolyte drinks or water consumed <i>ad libitum</i> during exercise. The two carbohydrate drinks were matched for taste and colour and served at 15 – 16 °C</p> <p>Training sessions were matched for each test.</p>	<p>Rehydration</p>	<p>Accurate rehydration assessment techniques were not used. Net fluid balance calculations did not measure stomach contents or unemptied urine. Hydration status prior to commencement of study was not known.</p>
<p>Saat et al. (2002)</p> <p>Eight recreationally active males consumed water, coconut water (2.5% glucose, 5 mmol/L Na⁺, 52 mmol/L K⁺) or 3.2% glucose electrolyte drink containing 19 mmol/L Na⁺ and 3.75 mmol/L K⁺ following exercise induced dehydration</p>	<p>Rehydration</p>	<p>No conclusions could be drawn from this study as both electrolyte as well as glucose concentrations varied between study arms</p>

Publication	Outcome	Reason for Exclusion
<p>Bonetti and Hopkins (2010)</p> <p>Sixteen well-trained competitive endurance cyclists and triathletes participated in a randomised double-blind crossover designed study.</p> <p>One of four drinks with varying concentrations of simple sugars, sodium chloride and vitamins were consumed at a rate of 250 mL every 15 min during a 2 hr steady ride at constant power (55 – 60% peak power) followed by a continuous incremental test to peak power at room temperature 19 – 21°C.</p>	<p>Performance and Rehydration</p>	<p>No conclusions could be drawn from this study as both electrolyte, vitamin and glucose concentrations varied between study arms</p>
<p>Smith et al. (2010)</p> <p>Crossover study of 12 trained recreational healthy male cyclists or triathletes studying the effect of 1.5%, 3% or 6% glucose electrolyte drink or electrolyte placebo consumed 250 mL test solution at 15 min intervals during a 2 hr ride.</p> <p>Randomisation not mentioned. Uncertain if blinded - drinks provided in opaque bottles.</p>	<p>Performance</p>	<p>Study does not state that it is randomised</p>
<p>Rowlands et al. (2011)</p> <p>Randomised double-blind crossover study of eleven well-trained male cyclists and triathletes who consumed one of four commercial sports drinks (3.9% unspecified carbohydrate, 8 mmol/L sodium; 7.6% carbohydrate, 12 mmol/L sodium or 6% carbohydrate, 21 mmol/L sodium) drinks or flavoured placebo during a 2 hr constant workload ride at 55% max power followed by an incremental exercise test to exhaustion.</p>	<p>Performance and Rehydration</p>	<p>No conclusions could be drawn from this study as electrolyte and carbohydrate concentrations varied between study arms. Sodium concentration was below 10 mmol/L in the low carbohydrate drink as required in Standard 2.6.2 – 9 of the Food Standards Code and therefore could not be used as part of the evidence base.</p>

Publication	Outcome	Reason for Exclusion
<p>Peacock et al. (2012)</p> <p>Randomised crossover study investigating the effects of ad libitum drink consumption on voluntary intake, hydration status and physiological responses in 12 physically active adults following fluid restriction and exercise. Water, 2% carbohydrate electrolyte drink or no fluids were studied in a crossover design</p>	Rehydration	Two percent electrolyte drink was compared to water. The effects of altered carbohydrate content cannot be determined independent of electrolyte content.
<p>Peacock et al. (2013)</p> <p>The effects of ad libitum consumption of water or low carbohydrate electrolyte drink on voluntary fluid intake and hydration status in 10 physically active hypohydrated adults following exercise resulting in 1.2% body mass loss. Water, carbohydrate electrolyte (2% carbohydrate 15 mmol/L sodium) drink or no fluids were studied in a randomised crossover design</p>	Rehydration	Two percent electrolyte drink was compared to water. The effects of altered carbohydrate content cannot be determined independent of electrolyte content.
<p>Smith et al. (2013)</p> <p>Randomised blinded crossover trial that studied the effect of increasing amounts of carbohydrate (0 -12%) in electrolyte drinks on performance on 20 km time trial following a 2hr ride</p> <p>51 male recreationally trained healthy male cyclists or triathletes participated in 4 separate trials at 4 different locations, each of which consisted of 4 study arms</p>	Performance	No conclusions could be drawn from the statistical analysis undertaken.

Publication	Outcome	Reason for Exclusion
<p>13 drinks were tested (0-12% carbohydrate, with 18mmol/L Na⁺, 3 mmol/L K⁺ and 11 mmol/L Cl⁻. The drink was consumed in 250 mL aliquots every 15 min from 15 min after commencement until 120 after commencement. Placebo drink 0% carbohydrate contained non-caloric sweetener. Each carbohydrate drink contained 1:1:1 glucose: fructose: maltose</p> <p>Four test sites were used with 12-15 participants per test site that consumed four different drinks on separate occasions as outlined below:</p> <p>Test site 1: 0, 1, 5, 9% electrolyte drink Test site 2: 0, 2, 6, 10% electrolyte drink Test site 3: 0, 3, 7, 11% electrolyte drink Test site 4: 0, 4, 8, 12% electrolyte drink</p>		

Appendix 3 Glossary of Abbreviations and Definitions.

ANOVA	Analysis of variance
carbohydrate	Carbohydrate
Code	Australia New Zealand Food Standards Code
electrolyte drink	Electrolyte drink
EFSA	European Food Safety Authority
FSANZ	Food Standards Australia New Zealand
mmol/L	Millimoles per litre
mOsm/kg	MilliOsmoles per kilogram
RCT	Randomised controlled trial
Time trial	Fixed distance exercise in which time to completion is measured
TTE	Time to exhaustion
USG	Urine specific gravity
VO _{2peak}	Peak oxygen uptake
VO _{2max}	Maximal oxygen uptake