THE SCIENCE BEHIND

HYDRA FUEL

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PRACTICAL IMPLICATIONS

- Carbohydrate ingestion during exercise has a beneficial effect on prolonged performance possibly by preventing hypoglycemia or enhancing carbohydrate oxidation late in exercise or attenuating muscle glycogen use.
- Most forms of carbohydrate are suitable and give similar results with regard to performance and oxidation, although fructose may prove problematic.
- Factors that affect the availability of ingested carbohydrate during exercise include gastric emptying, intestinal absorption, primary liver use, as well as transport to and across muscle.
- The likely maximal rates of carbohydrate oxidation from ingested carbohydrate are 1.0g/min.
- Carbohydrate ingestion is unlikely to be beneficial for bouts of exercise of about 60 minutes or less although some benefits have been seen with a carbohydrate mouth rinse.
- Skill, decision making, cognitive function, reaction time, and rating of perceived exertion benefit from carbohydrate ingestion during exercise – particularly in the later stages i.e. after 60 minutes.
- The addition of key electrolytes such as sodium and magnesium are beneficial for carbohydrate availability and hydration.

INTRODUCTION

Carbohydrates and fats are the two major energy sources that fuel muscle during prolonged steady state as well as intermittent exercise. The fatigue associated with prolonged performance has been reported to coincide with the depletion of muscle and/or liver glycogen, the latter leading to disturbances in the level of circulating plasma glucose and resulting in hypoglycaemia (Cermak & van Loon, 2013). Significant improvements in endurance performance and capacity are well established when carbohydrates are ingested before and/or during activity (Stellingwerff & Cox, 2014). These improvements could be due to a number of factors such as stimulation of carbohydrate receptors in the oral cavity which directly affect the brain and reduce perceived exertion (Carter et al., 2004) and/or maintenance of plasma glucose concentration leading to an increase in carbohydrate oxidation late in exercise (Coggan & Coyle, 1989). In addition, it has been demonstrated that carbohydrate intake during exercise not only increases oxidation of carbohydrate but may spare use of muscle glycogen and so improve performance or time to fatigue (Stellingwerff et al., 2007).

Stellingwerff & Cox (2014) proposed a likelihood of performance benefits with carbohydrate ingestion when exercise was longer than 1-h but not necessarily if the bout was less than 1-h. They concluded that the primary mechanism by which carbohydrates enhance endurance performance was due to a high rate of carbohydrate delivery resulting in elevated rates of carbohydrate oxidation. Consequently, many investigations have explored the promotion of carbohydrate delivery to muscle by using high levels of a single source of carbohydrate (Newell et al., 2018). The issue with ingesting large amounts of carbohydrate during performance (particularly running) is that the gastrointestinal system is compromised and may lead to unwarranted symptoms such as gut pain, flatulence, diarrhoea, and vomiting. Even so, it appears that the maximum rate of exogenous carbohydrate is achieved when ingesting around 60g/h. Amounts of ingested carbohydrate at these levels results in a maximal rate of exogenous carbohydrate oxidation of ~1.0g/min (Jeukendrup, 2010).

CARBOHYDRATES AND GASTRIC EMPTYING

Previous research has demonstrated that the energy content and osmolality of the ingested solution plays a key role in the rate of gastric emptying (Vist & Maughan, 1994). Solutions of low osmolality (effectively low concentration) empty from the stomach at a faster rate than those with a high osmolality. Drinks with as little as 2.5% carbohydrate have been shown to empty more slowly than water. Figure 1 illustrates the gastric emptying of fluid or glucose based on the concentration of an ingested glucose solution. The amount of carbohydrate delivery to the intestine and the rate of exogenous carbohydrate oxidation increases linearly with increasing carbohydrate concentration despite the decrease in gastric emptying. Only solutions with low or isotonic carbohydrate should be ingested during prolonged exercise as they are emptied rapidly and help hydrate. When the requirement is for greater amount of carbohydrate during strenuous exercise, this can be achieved with a more concentrated carbohydrate source irrespective of the reduced gastric emptying (Foster, 1990). The type of carbohydrate ingested appears immaterial for gastric emptying since osmolality appears to be more important (El-Sayed & MacLaren, 1997), although some studies have shown a higher concentration of maltodextrin can empty at the same rate as a lower concentration of glucose because the osmolality of maltodextrin is lower (MacLaren et al, 1996). Having said that, it appears that a carbohydrate concentration of 6-8% is ideal in so far as it helps hydrate and promotes glucose availability to muscle and brain. If the emphasis is for hydration (due to exercise in a hot and humid environment) then water or a solution of around 2-3% carbohydrate is preferable.

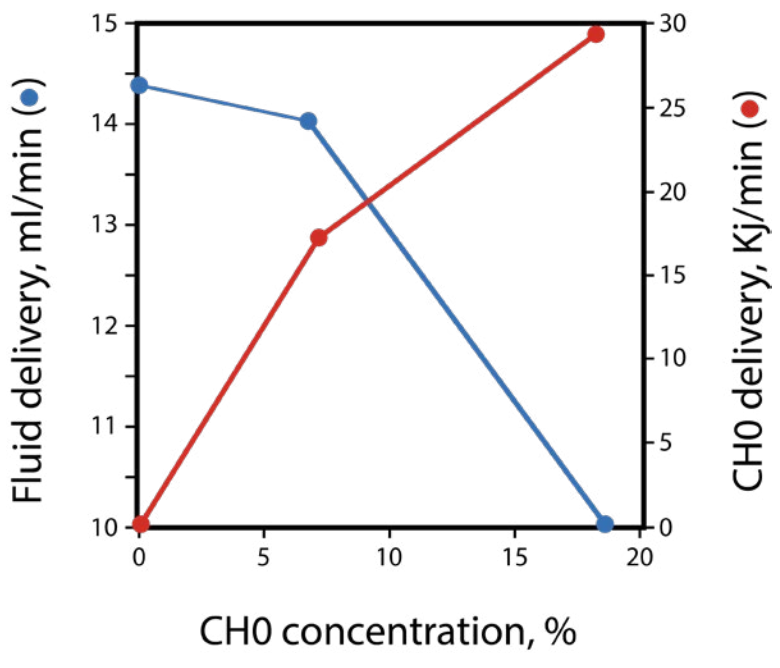

Figure 1. Fluid delivery and carbohydrate delivery across the gut in relation to increasing carbohydrate concentration ingested. Note that as the carbohydrate concentration is increased there is an initial gradual reduction in fluid delivery with a concomitant increase in carbohydrate delivery. After a concentration of about 8% carbohydrate the fluid delivery is markedly reduced whereas the carbohydrate delivery is enhanced significantly.

CARBOHYDRATE SOURCES, ABSORPTION, AND OXIDATION

The majority of carbohydrate drinks ingested during exercise are monosaccharides or so-called simple sugars such as glucose, fructose, and galactose, although disaccharides such as sucrose (table sugar) and polysaccharides such as maltodextrins and even starch have been employed. The disaccharides and polysaccharides have to be digested to their respective monosaccharides before being absorbed across the gut in the small intestine. Figure 2 highlights how glucose, fructose and galactose are absorbed. It is evident that a sodium-dependent glucose transporter (SGLT1) and a glucose transporter (GLUT 5) are required for glucose/galactose and fructose uptake respectively across the brush border, and that GLUT2 or GLUT5 are required to transport the monosaccharides into the portal blood vessels. The fact that glucose and fructose employ different gut transporters is probably the reason why so-called multiple carbohydrate drinks have been used by some. Evidence is available that the number of SGLT1 transporters are in abundance when compared with GLUT5 transporters, and is a factor as to why glucose uptake across the intestine is greater (and faster) than fructose. Indeed, high concentrations of fructose ingested during running-based activities in particular have been reported to contribute to increases in gastrointestinal problems – notably diarrhea, pain, and flatulence (Prado de Oliveira et al., 2014).

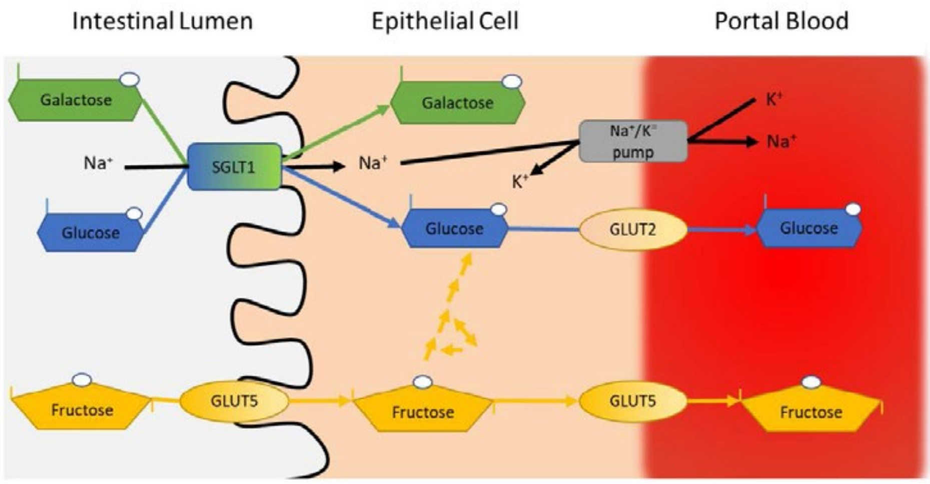

Figure 2. Transport of monosaccharides across the gut wall. SGLT1 is sodium dependent glucose transporter; GLUT5 and GLUT2 are glucose transporters.

Once glucose is dispersed into the portal system most of it by-passes the liver and is transported to muscle for oxidation (at least during exercise) whereas fructose is taken up by liver and undergoes either oxidation or is converted to glucose and lactate, which are then transported out of the liver for muscle and other tissue to utilize. The consequence of carbohydrate ingestion during exercise is that plasma glucose and insulin levels increase and so drive carbohydrate and attenuate fat oxidation.

During exercise there is a reduction in blood flow to and from the gut and so, in general, the availability of absorbed nutrient sources may be compromised. So once the glucose is in the general circulation, it can then be taken up into muscle for oxidation. Glucose does not freely diffuse into muscle, rather it is taken across the plasma membrane using a glucose transporter (GLUT4). GLUT4 normally resides in intracellular vesicles and is translocated to the plasma membrane due to signaling mechanisms. Figure 3 illustrates that insulin provides one such mechanism in so far as plasma insulin levels are promoted due to increasing concentration of glucose, and that the insulin binds to its cell membrane receptor causing changes within the muscle cell. One of the molecules 'turned on' by insulin is Akt, which drives the translocation of GLUT4 to the surface of the cell membrane and promotes uptake of glucose. Incidentally, the other key 'driver' for GLUT4 translocation is AMPK, which is elevated due to an increase in calcium ions resulting from the muscle activity.

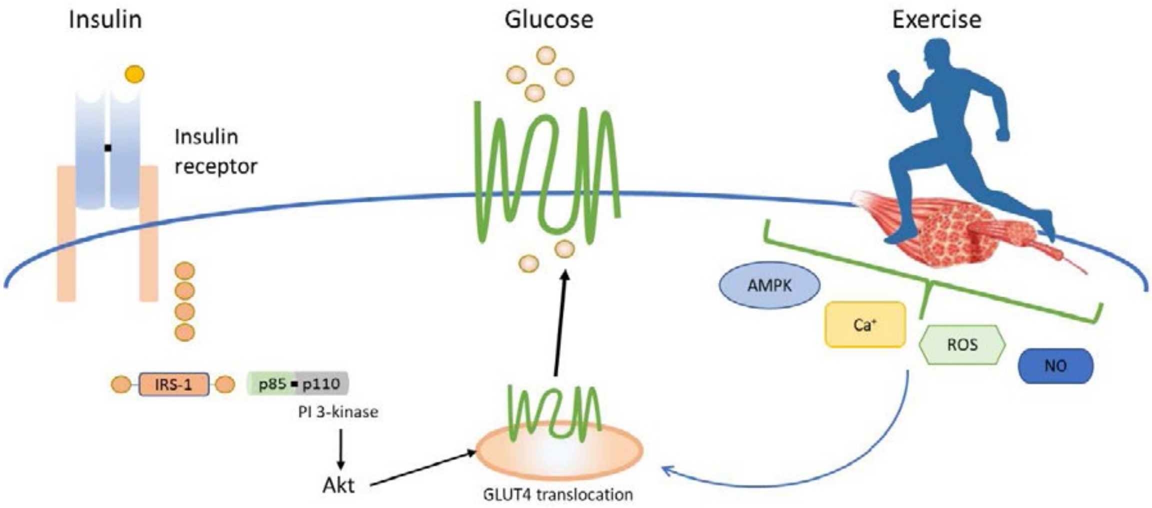

Figure 3. Insulin stimulation of GLUT4 translocation to the cell membrane via promotion of Akt.

So, on reflection, the carbohydrate ingested has to empty from the stomach rapidly, be digested if in a complex form, get absorbed across the gut wall, pass into the body circulatory system, and then get transported across the muscle membrane before oxidation is possible. This series of processes are potential limiting factors for carbohydrate use during exercise (Rosset et al., 2017)

LIMITATIONS OF EXOGENOUS CARBOHYDRATE USE

The maximal rates of exogenous glucose oxidation during exercise have consistently observed to be around 1.0g/min irrespective of the dose ingested (Jeukendrup, 2010). Ingestion of short-chain glucose polysaccharides such as maltose and maltodextrins result in similar maximal oxidation rates as glucose. Since such glucose polysaccharides are required to be digested before absorption and yet maximal rates of oxidation are similar to glucose would indicate that pre-absorptive factors are not limiting. Consequently, the limitation of carbohydrate oxidation maybe considered to be at the level of intestinal absorption, with the ≈1 g/min plateau being consistent with intestinal glucose absorption kinetics (Shi et al., 1995). Another physiological effect of exercise, decreased splanchnic blood flow, may also limit intestinal absorption capacity.

LIKELY BENEFITS OF CARBOHYDRATE INGESTION DURING EXERCISE

Carbohydrate ingestion during exercise has been consistently shown to improve prolonged exercise performance, and typical guidelines recommend ingesting 30–60 g carbohydrate per hour (American Dietetic et al., 2009).
To undertake a comprehensive treatise on the reported benefits of carbohydrate ingestion during exercise on performance or capacity is beyond the scope of this article. It is unquestionable that carbohydrates of varying types and doses present a positive beneficial effect on performance or capacity as well as improvements in skill, attenuation of ratings of perceived exertion, and maintenance of blood glucose concentrations when compared with placebo. To this end, it would be useful to examine some more detailed review articles (Jeukendrup, 2014; Williams & Rollo, 2015) or to note the conclusions from a recent meta-analysis of the benefits of carbohydrate intake during exercise on performance (Pochmuller et al., 2016). In the latter review and meta-analysis, the authors concluded that (a) there was a performance benefit of carbohydrate ingestion during exercise, (b) that this benefit was greatest for

exercise durations of around or greater than 90 minutes and that there were no significant benefits when exercise was 60 minutes or less in duration, and (c) that doses in the range of 6-9% carbohydrate were most beneficial.

It is worth considering that some recent findings have promoted the concept that carbohydrate feeding during exercise is beneficial in prolonged intermittent sporting activities such as soccer, and not merely extended bouts of cycling or running. To this end the use of the Loughborough Intermittent Shuttle Test (LIST) has proved worthwhile. In one study, games players exhibited a 33% increase in part B of the test when ingesting a 6.5% carbohydrate-electrolyte drink than placebo (Nicolas et al., 1995). In a similar type of investigation using the LIST, professional rugby league referees were found to significantly increase distance covered in part B of the test by 280-m, to have a faster mean 20-m sprint speed of 3%, and a 5% lower rating of perceived exertion when ingesting a 6% maltodextrin drink compared with placebo (MacLaren & Close, 2000). More recently, use has been made of simulating soccer activity on a computerised-driven treadmill. Twelve soccer players underwent 90 minutes of intermittent running on the treadmill in the heat and ingested carbohydrate electrolyte drinks or placebo during the bouts. An uphill high intense bout of running to fatigue after the 90minute simulation resulted in a longer time to fatigue with carbohydrate (Clarke et al., 2011).

Most sporting activities require some element of skill and decision making: think of soccer, rugby, hockey, basketball, volleyball, netball and so on. It is evident that at some later stages in these sports there are elements of fatigue which manifest themselves in slower decision making, slower reaction times, and general impaired cognitive function. Ingesting carbohydrates during such sporting activities invariably results in an attenuation of the rating of perceived exertion (RPE) and of maintenance of skill compared with a placebo. Currell et al. (2009) observed a significant improvement in soccer dribbling, agility, and shooting during a 90-minute protocol with 7.5% maltodextrin compared with placebo. In a further study, a modified LIST protocol to mimic basketball play was employed with participants undertaking 20-m sprints in each of the four 15minute blocks as well as tests of motor skills and mood state (Winnick et al., 2005). Six percent carbohydrate electrolyte drinks or placebo were ingested, with the result that significant improvements were noted for sprints, motor skill, and mood states in the fourth quarter. A consistent finding in most research is that there are no beneficial effects of carbohydrate drinks in the first 60-minutes, but thereafter the carbohydrate drinks have a beneficial effect.

VALUE OF ELECTROLYTES

Carbohydrates are not the only component of most sports drinks ingested during activities. Most commercial sports drinks also include electrolytes; notably sodium. The reason for this is threefold:

1. Sodium (Na^+) is important to promote glucose uptake across the intestine (see figure 2), where it also helps 'drive' water across the gut wall. The greater the gut lumen Na^+ concentration the faster the uptake of glucose and fluid.

2. Sodium helps retain fluids in the body rather than aid elimination via urine. It has been well established that lack of sodium in drinks causes greater fluid loss through urine production. So, sodium as an electrolyte in a drink helps fluid retention at a time when it is required.

3. Sodium in electrolyte drinks rather than plain water prevents hyponatremia (low blood sodium), which is a causative factor in cardiac-related deaths during long distance events

Magnesium (Mg) is the second most abundant intracellular cation and serves as a co-factor in more than 300 enzymatic reactions, including energy production. Magnesium is involved in glucose metabolism and enhances exercise performance. In general, prolonged exercise increases Mg excretion through sweat and urine and could result in Mg deficiency. Therefore, exercise performance is highly dependent on the regulation and maintenance of Mg homeostasis. Moreover, exercise performance appears to be impaired under Mg deficiency conditions. Supplementation with Mg improves exercise performance in forced swimming and treadmill exercises in rats. Therefore, the enhancement of exercise performance by Mg could be related to glucose availability and regulation, and this has been shown (in rats) by Chen et al. (2014). More recently, a metanalysis of studies on magnesium and exercise concluded that (a) most athletes do not consume adequate amounts of Mg in their diets, and (b) there is some evidence that magnesium supplementation may enhance athletic performance in individuals of all ages (Volpe, 2015).

CONCLUSION

There is a wealth of research literature on the positive beneficial effects of carbohydrate ingestion during exercise as long as the exercise/performance period is longer than 60 minutes. These include enhanced capacity, maintenance of power and speed during the activity, as well as improved cognition and skill performance. Carbohydrate drink concentrations of up to 9% for single sugars are advisable, as is the use of carbohydrate gels. The amount of carbohydrate consumed within an hour in order to satisfy both the carbohydrate and fluid needs of the athlete as well as avoidance of gastrointestinal problems should be about 60g/h for activities lasting up to 2-h. Furthermore, the addition of electrolytes such as sodium and magnesium to a carbohydrate drink are beneficial.

HydraFuel – is a carbohydrate-electrolyte product that contains key components for availability of glucose and fluids during exercise. The correct balance of carbohydrates as well as sodium and magnesium are likely to prove beneficial to athletes engaging in exercise lasting more than 60-minutes. It is likely to be of greatest benefit in the second half of football and rugby matches as well as later stages of most team sports. The benefits may be realised not just for maintaining high exercise intensity but also for aspects such as skill, decision making, concentration, perceived exertion, and reaction times. Additionally, HydraFuel can be taken with foods and protein supplements to aid recovery and hydration.

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