

The Optimum Composition for Endurance Sports Drinks

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Sports drinks aimed at enhancing endurance performance lasting several hours need to contain ~20 mM salt (sodium chloride) and ~10% carbohydrate in the form of glucose polymers and fructose. The salt and carbohydrate offset the losses of these substances caused by exercise. They also accelerate the uptake of water. Glucose polymers are used instead of glucose to keep the total osmotically active solute concentration (tonicity or osmolarity) of the drink below that of body fluids, because higher concentrations reduce the rate of emptying of the stomach and reduce the rate of uptake of water in the small intestine. KEYWORDS: carbohydrate, energy, hydration, nutrition, salt, water

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This article is an edited version of a literature review commissioned by a drink manufacturer on "the mechanisms... of water uptake in sports drinks of varying carbohydrate content and tonicity... Please explain how carbohydrates, electrolytes and tonicity affect water uptake and hydration in plain English." In our report we placed as much emphasis on the uptake of carbohydrate as of water, for the following reasons. First, in all but the hottest and most humid environments, exercise of duration and intensity sufficient to make dehydration an issue will also make supply of carbohydrate an issue. Secondly, getting the carbohydrate in is more of a challenge than getting the water in. Finally, we assumed that the drink is aimed at optimizing performance of elite endurance athletes and recreational multisport or ultraendurance athletes in competitions. For the mass market of less serious fitness enthusiasts, there is little need to worry about depletion of water, salt and carbohydrate during exercise. Indeed, fitness exercises can be performed without any concern for fluid and carbohydrate uptake.

We performed several searches with SportDiscus and Medline, but we got the best references by using Web of Science to find all the papers that cited a definitive paper by Rehrer et al. (1992). We found reviews by all the major researchers in the field (Brouns and Kovacs, 1997; Coyle, 2004; Jeukendrup, 2004; Jeukendrup et al., 2005; Maughan and Leiper, 1999; Rehrer, 2001).

There has been general agreement for the last decade that sports drinks need to contain salt (sodium chloride, NaCl) and carbohydrate (sugars) at concentrations of around 20 mM and 6% (6 g per 100 ml) respectively. The researchers also agree that at least some of the carbohydrate needs to be in the form of disaccharides (usually sucrose) or glucose polymers (maltodextrins). In the last year or two Jeukendrup and colleagues have found a way to increase the rate of absorption of carbohydrate. This report is mainly a review of the reviews. The only original-research papers we read were the recent ones not covered by the reviews.

The issues with sports-drink composition are as follows...

Exercise Depletes Water and Salt

- Exercise results in loss of water and salt from the body via evaporation of water from the lungs and sweating of water and salt from the skin. For exercise of sufficient duration and intensity, the losses reduce the volume of blood available for the heart to pump to the muscles and skin. Reduction of blood flow to muscles implies less delivery of oxygen to the muscles, so endurance performance declines. Reduction of blood flow to the skin implies less elimination of heat from the body, so the risk of heart stroke (damage to cells and tissues from overheating) increases, especially in a hot or humid environment. The loss of water and salt may also reduce production of sweat, which will

also increase the risk of heat stroke. These effects become substantial for near-maximal exercise lasting an hour in a hot humid environment and two hours in a cool environment.

- In long hard events with excessive sweating, failure to replace the salt lost in sweat, combined with excessive consumption of water or drinks containing no salt, increases the risk of hyponatremia. In hyponatremia the blood becomes more dilute, and as a consequence excess water enters all cells and tissues in the body, including the brain. The brain therefore swells, and because it is encased almost completely by the skull, pressure builds up inside the skull and can reduce the flow of blood to the brain. On very rare occasions brain damage and death ensue.

Exercise Depletes Carbohydrate

- Exercise results in loss of carbohydrate stored as glycogen in muscles and liver. After an hour of hard exercise, the loss contributes to the feeling of fatigue, either because the brain is affected by a fall in blood glucose concentration (via inability of the liver to maintain the concentration in the face of demand for glucose by muscle) or because the depletion of glycogen stored in muscle reduces the ability of muscle to do work. Performance therefore declines.

Drinks Can Offset These Depletions

- Drinks containing appropriate concentration of salt and appropriate types and concentrations of carbohydrate consumed at an appropriate rate can offset the losses when consumed before and during exercise and can therefore enhance performance.
- Research on what is appropriate is based on measurement of several variables: rate of emptying of the stomach, rate of uptake across the small intestine, rate of oxidation of ingested carbohydrate, and endurance performance.
- Salt and carbohydrate in a sports drink act synergistically to stimulate the uptake of water. That is, the uptake of water is more rapid than occurs with pure water, with water plus salt, or with water plus carbohydrate, even though the concentration gradient for absorption of water in the small intestine is reduced by adding salt and carbohydrate to the drink. The mechanism of the synergistic

effect presumably involves opening of water channels in the wall of the small intestine.

- A sports drink can obviously speed full recovery of the losses post exercise. Fast recovery is an issue for athletes training hard every day, especially if they train twice a day.
- Nevertheless, it may be beneficial to perform some training sessions in a somewhat dehydrated state and/or to delay restoration of fluid after training. The body may then supercompensate by increasing blood volume above normal, which would benefit endurance performance. It may also be beneficial for longer endurance and ultraendurance athletes to perform some training sessions in a state of depleted carbohydrate stores, to produce supercompensation of those stores and/or to switch the body to greater use of fat rather than carbohydrate in such events. Research on this question is in progress in several laboratories.

With these issues in mind, we made the following recommendations for the optimum composition of a sport drink for use by endurance athletes in competitions lasting several hours.

- The concentration of salt is determined partly by the need to meet at least partly the expected rate of loss of salt in sweat.
- The concentration of carbohydrate is determined partly by the maximum rate of absorption from the gut. (The maximum rate that carbohydrate can be used to fuel exercise by aerobic and anaerobic processes is greater than the rate it can be absorbed.)
- The combined concentration of salt and carbohydrate is determined by the rate at which water needs to be consumed to replace losses, and the need to limit the inhibiting effect of high solute concentrations both on emptying of the stomach and on transport of water across the wall of the small intestine.
- All of the above are determined partly by the duration and intensity of the exercise and by the environmental conditions in which it is performed.
- A diagram summarizing the recent state of the art for exercise of durations up to 24 hours can be found in Rehrer (2001). She opted for 20 mM (1.2 g/L or 0.12% w/v) NaCl and 60 g/L (6% w/v) carbohydrate at

least partly in the form of glucose polymers for an expected consumption rate of 1.5 L/h in exercise lasting 2 hours, through to twice as much NaCl and half as much carbohydrate for half the expected rate of fluid intake in exercise lasting 24 hours.

- Recent research by Jeukendrup and colleagues indicates that the rate of absorption and oxidation of carbohydrate can be increased by using several kinds of carbohydrate, apparently because the rate of absorption of each kind of carbohydrate is limited by specific carriers in the wall of the small intestine.
 - With glucose or glucose polymers alone, the maximum rate is ~1.0 g/min, but Jentjens et al. (2004) achieved a rate of 1.7 g/min when their subjects ingested a mixture of glucose+fructose+sucrose at the rate of 1.2+0.6+0.6 g/min, in a drink containing 20 mM NaCl. After an initial bolus of 600 ml, the drink was consumed at a rate of 600 ml/h. We have calculated that the drink was therefore 12% glucose, 6% fructose, and 6% sucrose, which is 4× the usual recommended total concentration of carbohydrate. We have also calculated that the osmolarity of the drink was 1215 mOsm, which is more than 4× the concentration of body fluids. There was no indication of the effects of this drink on water absorption, but presumably it was strongly impaired.
 - In a more recent study, Wallis et al. (2005) achieved a rate of absorption/oxidation of carbohydrate of 1.5 g/min with a more realistic drink consisting of 7.5% maltodextrins and 3.75% fructose (total carbohydrate 11.25%). After an initial bolus of 600 ml, the drink was consumed at 800 ml/h. There was no NaCl in this drink, and the osmolarity was 260 mOsm. Rate of water absorption was not reported. Addition of 20 mM NaCl to this drink would presumably increase the rate of water absorption and probably also the rate of carbohydrate absorption. A reduction in the carbohydrate content would probably accelerate water uptake at the expense of reducing carbohydrate uptake slightly.
- Use of a highly branched glucose polymer with a high molecular weight can reduce the

solute concentration and accelerate emptying of the stomach. A drink containing 10% of this polymer had a total solute concentration of 150 mOsm and emptied from the stomach more rapidly than a drink containing 10% of the usual maltodextrins with a concentration of 270 mOsm (Takii et al., 2005). Effects on absorption/oxidation of carbohydrate were not reported.

- Research on the composition of sports drinks will presumably continue for several years yet. In the meantime we would opt for a drink containing ~20 mM NaCl and ~10% carbohydrate in the form of the usual maltodextrins (6.5%) and fructose (3.5%). It would also be worth trialing a drink containing 11% of the glucose polymer of Takii et al. (2005) along with 4% fructose and 20 mM NaCl.

In conclusion, we emphasize that our recommendations apply to use of a drink in endurance competitions, not in training for such competitions. The optimal composition of a drink for training will depend on various factors, including whether it is consumed before, during or after training, what kind of training session is undertaken, and in what training phase the session occurs. On occasions the best drink may contain protein, amino acids, carbohydrate, or only water. Sometimes no drink might be the best strategy.

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