Fluid replacement in sports

Position of the working group sports nutrition of the German Nutrition Society (DGE)

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Abstract

Recommendations for drinking quantities during all kinds of exercise provide some guidance for athletes on how to avoid health problems and performance impairment. Sporting activities should always be commenced with a balanced fluid level (apparent by urine colour, which is light yellow in the case of balanced fluid level). The weighing method to determine individual fluid loss offers guidance as to optimal fluid intake during exercise. In principle however, athletes should trust their own feeling of thirst. Generally in the case of activities lasting less than 30–40 minutes, fluid intake is not necessary, minor fluid deficits during exercise are tolerable. In the case of longer-lasting activity (> 1.5 hours) it is advisable to take in beverages rich in carbohydrates and sodium. After sport, fluids and electrolytes must be replaced.

Keywords: sports nutrition, fluid intake, fluid and electrolyte balance

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Introduction

Adequate hydration is an important precondition for the health and performance of athletes. The quantity and type of fluid intake before, during, and after exercise affect an athlete's performance. Both inadequate and excessive fluid intake has a negative effect or represents a health risk. In the past athletes have frequently been guided by the principle "drink before the thirst hits". However, this can increase the risk of hyponatremia ("water intoxication"), which in extreme cases has already led to deaths of recreational athletes (triathletes and marathon runners) [1–3]. This highlights the particular importance of fluid intake in sports.

Since water and electrolyte levels are closely connected, the composition of drinks also plays a role in water absorption. In the following article the importance of balanced fluid and electrolyte levels for sporting performance as well as the benefits and risks of fluid intake in sports are presented. From statements by international specialist associations, recommendations are derived for fluid intake for all kinds of sporting activity.

Fluid loss during sport

In the case of intense physical activity there is a greater need for water due to increased sweat production. Sweat production is necessary to protect the body from overheating because around 75% of the energy obtained from nutrients during sports is released in the form of heat (thermal efficiency). This has to be released into the atmosphere by the body so that the body's core temperature doesn't get too high, otherwise performance and health are impaired or endangered [4]. Sweat production depends on the type of sports, the duration and intensity of the physical activity, climatic conditions, gender (men sweat more than women), body weight, clothing, and level of training. Trained athletes generally sweat more and faster than untrained ones: In the case of endurance athletes and games athletes it has been proven that as the athletes' maximum oxygen intake (VO_{2max}) increases, their sweat glands react faster and start to sweat [5, 6]. In addition a higher VO_{2max} is accompanied by higher sweat production per gland and higher gland density. This enables trained athletes to release more heat to keep their body temperature under the critical level at which performance is impaired [6]. Furthermore, the sweat rate is higher in faster, heavier athletes and at warmer temperatures. In the case of vigorous exercise at high temperatures 4–10 l of water and 3.5–7 g of sodium can be lost per day [7, 8]. But high humidity levels also increase sweat production since less sweat evaporates or more runs off, so thermoregulation is less effective.

Moreover, fluid needs are greater at higher altitudes, since here due to the low oxygen partial pressure of the air, breathing rate is increased, meaning that more water is expelled through the lungs [4]. In addition a change in renal blood flow, hypocapnea[1], hyperventilation, and hormonal effects (reduced aldosterone effect) cause an increase in the level of urine output in the form of diuresis[2] [9] resulting in haemoconcentration. At low temperatures too there can be increased diuresis which is induced by a drop in the release of antidiuretic hormone (ADH).

Effects of dehydration

Insufficient fluid intake can have severe effects on the organism. Water deficiency causes a reduction in the overall volume of blood plasma, leading in turn to poorer flow properties of the blood. Central blood volume and cardiac stroke volume are reduced. The heart rate increases while skin circulation and sweat production decrease. As a result core body temperature rises. Sure signs of water deficiency are dark urine, because urine production decreases, and dryness of the mouth due to reduced saliva production [7]. Overall, dehydration has a negative effect on both physical and mental performance. In the case of fluid loss of more than 2–4% of body weight impairments to strength and endurance are to be expected [7, 10, 11]. The lack of blood circulation in the brain in the case of yet more intense dehydration can lead to symptoms such as tiredness, headaches, difficulties in concentrating and longer reaction times, and ultimately increase the risk of heat illnesses such as heat cramps, heat exhaustion, heat collapse, and heatstroke [12].

It is undisputed that larger fluid losses (over 2–4% of body weight) and the associated symptoms, such as muscle cramps, faintness, disturbed brain function (concentration and coordination problems, headaches, dizziness) have a negative effect on performance. For these reasons too it is recommended that, in the case of exercise lasting longer than one hour, drinks are taken already during the activity.

Intentional dehydration in weight class sports

In sports with weight classes, so mainly in the case of combat sports (e.g. judo, wrestling, karate, or taekwondo) and bodybuilding, many athletes hope to gain an advantage by managing to get into the next lower weight class, and they practice "making weight", i.e. rapid weight reduction before competitions. In studies on wrestlers [13, 14] and bodybuilders [15] it has been shown that more than half of the athletes use unsuitable methods for weight loss before competitions, such as "cutting weight" and radically reducing energy intake shortly before the competition. In the case of "cutting weight" on the day before the weigh date and on the day itself the athletes restrict not only energy intake, but also water and table salt intake and at the same time increase fluid output (training with heat accumulation through thermal clothing, saunas and laxatives). In this context the use of diuretics which are on the doping list should also be viewed critically. The resulting dehydration with increased excretion of minerals, particularly potassium, magnesium, and sodium, can cause thickening of the blood, a drop in blood pressure, reduced blood flow to muscles, reduced renal blood flow, renal dysfunction, and cardiac arrhythmias. Rapid "weight making" also has a negative effect on energy reserves, fluid and electrolyte balances, and performance [16, 17] and has also already led to deaths from heatstroke in high-performance sport [18].

Hyponatremia in sports

An excessive intake of drinks low in minerals, such as tap water or low-sodium

[1] Hypocapnea is to be understood as reduced carbon dioxide partial pressure (pCO_2) in the arterial blood ($paCO_2$ less than 32–35 mm Hg). Hypocapnea can occur for instance in the case of too rapid and/or deep breathing (hyperventilation) or also in the case of respiratory compensation of metabolic acidosis (exhalation of acid valences).

[2] Diuresis: increased urine output via the kidneys; sodium causes the storage of water in the body and can counteract increased urine production.

Body weight (kg)	Climate	8.5 km/h	10 km/h	12.5 km/h	15 km/h
50	cool	0.43	0.53	0.69	0.86
	warm	0.52	0.62	0.79	0.96
70	cool	0.65	0.79	1.02	1.25
	warm	0.75	0.89	1.12	1.36
90	cool	0.86	1.04	1.34	1.64
	warm	0.97	1.15	1.46	1.76

Tab. 1: **Calculated sweat rate (l/h) when running (8.5–15 km/h) at cooler temperatures (15 °C) and at warmer temperatures (28 °C)** [7]

mineral water, coupled with simultaneous high levels of sweat loss, e.g. in the case of long endurance exercise, can lead to hyponatremia (sodium level in the plasma < 135 mmol/l) [1]. This can occur when athletes take in more fluids during exercise than they are losing via sweat and urine. This hyperhydration goes hand in hand with hyponatremia which can be associated with nausea, vomiting, headaches, disturbed consciousness, muscle cramps, and even respiratory arrest, pulmonary and cerebral oedema and coma [1, 10]. Cerebral oedema occurs because the lack of sodium reduces the osmotic pressure in the blood. The fluid is therefore absorbed by the cells, which however cannot expand their volume in the skull, leading to increased cerebral pressure. In the worst case scenario exercise-associated hyponatremia (EAH) can lead to death. It is mostly recreational athletes unaware of the risks of excess fluid intake that are affected by hyperhydration or water intoxication. In general their exercise intensity and sweat rate is lower compared to high-level athletes. On the other hand recreational athletes usually have more opportunity to drink and sometimes overdo in compliance with recommendations to drink on a regular basis. A study of the Boston Marathon by Almond et al. [3] has shown that 13% of the runners studied displayed hyponatremia (sodium concentration < 135 mmol/l). Three participants even had critical hyponatremia of less than 120 mmol/l. Here the hyponatremia affected mainly recreational runners who needed a lot of time to complete the course (> 4 hours) and took drinks at every drinking point or every mile. Some of the participants drank more than 3 l during the race and had a higher body weight after the race than before. To avoid EAH it is recommended not to drink more than your thirst dictates. Because athletes who were guided by their thirst were able to avoid both EAH and performance impairments due to dehydration [1, 19]. According to Goulet [20] thirst is caused by changes in plasma osmolality and can be used as a good indicator of the need for fluid intake.

Recommendations for fluid intake in sports

The American College of Sports Medicine (ACSM) has listed the results of numerous studies on fluid requirements in sports by level of evidence and the resultant up-to-date recommendations for fluid replacement in sports were published in its position papers [7, 10]. Furthermore, athletes can take the paper by Hew-Butler et al. [1] from the "International Exercise-Associated Hyponatremia Consensus Development Conference" as a guide. Contrary to earlier recommendations, such as "drink before the thirst hits", researchers emphasize that athletes should trust their own feeling of thirst since drinking as required can both minimize the risk of hyponatremia and prevent extreme dehydration.
Fluid requirements in sports are based upon individual sweat rates which can vary considerably both between and within individuals. How much fluid is lost during exercise and how the mineral content of the sweat is made up depends on many factors (Section "Fluid loss during sport") [7, 21]. The mineral content of the sweat also differs significantly between and within individuals. Of primary significance is the sodium content of the sweat. On average this is around 900 mg/l. However, the individual sodium level in the sweat varies considerably and is given in the literature as 175–1,512 mg/l [22]. What are known as "salty sweaters" lose more salt through their sweat; evident by the salt residues on clothing and skin.
♦ Table 1 gives an example of the different sweat rates during running depending on speed, body weight, and ambient temperature [according to 7].

It is advisable to establish individual sweat levels by way of weight controls and not to stick rigidly to fixed recommendations. The easiest way to establish fluid loss is by absolute weight checks before and after sport [7]. The difference in body weight is approxi-

	Carbohy-drates (g/l)	Sodium (mg/l)	Chloride (mg/l)	Potassium (mg/l)	Calcium (mg/l)	Magnesium (mg/l)	Osmolality (mmol/kg)
Recommen-dation	60–80	400–1,100	400–1,500	120–225	45–225	10–100	< 300

Tab. 2: **Recommendations for nutrient content in an isotonic rehydration drink**

mately equivalent to the amount of water lost through sweating. If during physical activity fluid is taken in, this fluid quantity must be deducted from the "weight after sports".

Suitable drinks

The optimal sports drink should provide athletes with water and in the case of longer-lasting exercise (> 60 min) also with carbohydrates (CHO) as quickly as possible to ward off fatigue. In order to replace the sodium lost through sweating the drink should also contain sodium. The best water absorption is achieved with slightly hypotonic or isotonic drinks with a CHO concentration of 4–8% and 400–1,100 mg/l of sodium [8, 23, 24] (♦ Table 2). This drink composition enables rapid passage through the stomach as well as rapid fluid absorption in the intestines. The addition of further minerals is not necessary during exercise. But if additional electrolytes are added to the drink then concentrations should not exceed maximum levels of approx. 200–250 mg/l (potassium and calcium) or 75–125 mg/l (magnesium) [25, 26]. It is important not only during exercise but also in the recovery phase that in the first instance the above-mentioned amount of sodium is provided by the drink to prevent diuresis [10]. Suitable sources are e.g. bouillon, sodium-rich sports drinks, or soups [24]. Diluted fruit juices mixed from one part fruit juice and two parts sodium-rich, non-carbonated mineral water make good rehydration drinks.

Fluid intake before exercise

Athletes should always start well hydrated with normal plasma electrolyte concentrations. For this sufficient quantities of fluid should be supplied over the day and no meals missed, since the consumption of meals and snacks supports hydration through the water content and osmotic components, such as sodium [7]. If sufficient drinks and fluids in food were consumed prior to exercise and there was a relatively long recovery period (8–12 h) after the last training session then there is a high likelihood that the athlete is sufficiently hydrated. But in fact many athletes are not sufficiently hydrated before exercise. This is the case if, for instance, they complete several training sessions in a day or have already undergone longer exercise sessions at higher temperatures in advance, so that there was not enough time to replace the fluids and electrolytes lost. A good fluid balance before exercise is generally achieved if athletes take in fluid quantities of 5–10 ml/kg body weight in the last 2–4 h before exercise so that the colour of the urine is light yellow [7, 10]. This is equivalent to a fluid quantity of approx. 350–700 ml in the case of a person with a weight of 70 kg in the final hours before exercise. On the other hand excess water intake before physical activity should be avoided since this leads to an increased need to pass urine and is disadvantageous with regard to a good water balance. Excessive fluid intake can also reduce the sodium concentration in the plasma and reduce the sodium content so far before exercise that there is a risk of hyponatremia [27].

Fluid intake during exercise

The idea of fluid intake during exercise is to avoid excessive dehydration and major electrolyte fluctuations and overheating in order to ultimately maintain performance.

When and what to drink?

When sporting activities are commenced with sufficient hydration, endurance sports of up to 60 min can be done without fluid intake during the exercise. Here losses through sweating and energy consumption are relatively low and it is sufficient if fluid is supplied after the activity. In the case of physical exercise lasting longer than 60 min drinking during the activity is advisable. In the case of endurance sports this affects e.g. running, cycling, long-distance swimming, cross-country skiing, etc. In the case of longer endurance periods of over 90 min and in the case of game sports (e.g. football, handball, tennis, etc.) athletes' drinks should contain not only water but also carbohydrates (30–60 g/h or 60–80 g/l). In addition, sodium should be supplied during exercise if the sweat rate is very high (sweat rate > 1.2 l/h) and the activity lasts more than 2 h [8, 10, 28]. The absorption of water in the intestines is supported by sodium content in the drink of 500–700 mg/l [10]. These details also correspond to the Health Claims use conditions of the European Food Safety Authority (EFSA) for carbohydrate-electrolyte drinks (460–1,150 mg sodium/l and 80–350 kcal/l from carbohydrates) [29, 30].

How much to drink?

In the case of rehydration the ACSM considers a fluid intake of 0.4–0.8 l/h during intense endurance activities to be optimal [7], although higher drinking quantities apply for faster, heavier athletes at warm temperatures and lower recommendations for slower, lighter

Overview 1: Procedure and example for calculation of sweat rate in training

1st step: record body weight before training (unclothed, after emptying bladder) → **49.5 kg**
2nd step: training (note duration of activity) → **105 min**
3rd step: record body weight after training → **47.9 kg**
4th step: difference in body weight in kg = sweat loss in l → **49.5 kg – 47.9 kg = 1.6 kg (approx. 1.6 l)**
5th step: sweat loss in l/duration of exertion in h = sweat rate in l/h → **1.6 l/1.75 h = 0.91 l/h**

Overview 2: Sample calculation on drinking behaviour during the marathon based on individual sweat rate

marathon time: 2:32:45 (outdoor temperature: approx. 15 °C)
calculated **fluid loss** during exercise: 0.91 l/h x 2.5 h = **2.3 l** (→ 4.65% of body weight)
drinking recommendation: max. 80% of fluid loss
→ 0.8 x 2.3 l = 1.84 l during the marathon (maximum) → approx. 0.7 l/h
→ 2–3% dehydration tolerable (approx. 1.3 kg)
→ **recommended fluid intake** during the marathon:
→ 2.3 kg – 1.3 kg = 1 kg → 1 l fluid during the marathon (1 l/2.5 h = **approx. 0.4 l/h**)

athletes at cooler temperatures. The optimal drinking quantity is based upon the sweat rate, which can be between 0.3 and 2.5 l/h (sample sweat rates ♦ Table 1).
As described above the ideal drinking quantity for competitions is calculated individually (weighing method). Complete rehydration during exercise is not necessary since fluid losses of 2–4% of body weight can be tolerated and increased fluid intake during physical activity can cause gastrointestinal problems and increases the risk of hyponatremia. Ideally athletes should drink a maximum of 80% of the determined sweat loss during a longer period of exercise. ♦ Overviews 1 and 2 explain this drinking strategy using the example of a marathon runner (high-performance athlete).

Athletes should find their own ideal drinking quantities and develop their own drinking plan, possibly with the help of a qualified specialist. Contrary to the long-held belief, drinking beyond your thirst has no advantages [23]. Although most athletes do tend to dehydrate during endurance exercise, the risk of hyperhydration [1] should not be ignored. The International Olympic Committee (IOC) therefore points out that drinking quantities should on no account be so high that weight increases during the exercise [31]. According to Noakes [32], athletes guided by their own thirst ingest around 300–600 ml fluid/h in a competition lasting 3–6 h [4].

Conclusion: The weighing method to determine individual fluid loss provides guidance for ideal drinking quantity during physical exercise. If athletes are guided by their own thirst they generally supply sufficient fluid and do not risk hyponatremia.

Fluid intake after exercise

After sports fluid and electrolyte levels must be rebalanced. How quickly this should happen depends on the level of dehydration and the need for rapid rehydration. If body weight is reduced by less than 5% and there is no other physical activity within 24 h, athletes can replace fluids and electrolytes as they please. The consumption of normal meals and snacks combined with adequate amounts of water is sufficient to replenish fluid and electrolyte levels [7]. In the case of more severe dehydration and a short recovery period of < 12 h a stricter rehydration plan should be implemented. For rapid and complete rehydration approx. 1.5 l of fluid per kg of weight loss is recommended [7, 33]. In order to avoid diuresis water should be consumed in smaller sips over a longer period and ingested together with the necessary electrolytes, e.g. in combination with a meal to enable optimal rehydration [34, 35]. After sports glycogen stores must also be replenished. For this it is necessary to supply sufficient potassium (e.g. in fruit juices and dried fruit), because potassium is needed to store carbohydrates in the body. Every gram of glycogen requires 19 mg of potassium and around 3 g of water [36]. So after exercise a salty drink containing potassium and carbohydrates is most suitable. For the replacement of fluid and electrolytes isotonic diluted fruit juices (e.g. diluted apple juice) are therefore appropriate and e.g. pretzels. In addition there are many promising studies on the use of low-fat milk and mixed milk products [37] such as cocoa which should be ideal drinks due to their favourable carbohydrate/protein ratio [38].

Conclusion

Adequate hydration is necessary for the health and performance of athletes. Fluid deficits of 2–4% of body weight are associated with deterioration of endurance, strength, and cognitive performance. Athletes should therefore always start training with balanced fluid levels. Guiding factors here are the colour of the urine, which is light yellow in the case of balanced fluid level. How much fluid is lost during exercise depends on many factors, such as level of fitness, the intensity and duration of training, the type of activity, and environmental factors. Since the fluid losses vary considerably both between and within individuals, fixed recommendations for drinking quantities during sports make little sense. In principle athletes should be guided by their own thirst to avoid both dehydration and the risk of hyponatremia due to excess fluid intake during exercise. The weighing method to establish individual fluid loss serves as a guide for optimal drinking volume during exercise. In general in the case of exercise lasting less than 30–40 min no fluid intake is necessary, small fluid deficits are tolerable during sports. In the case of longer activity (> 1.5 h) the intake of carbohydrates and sodium is recommended. A sports drink should therefore contain not only carbohydrates (4–8%) but also 400–1,100 mg/l of sodium. After sports fluid and electrolyte balances must be re-established. If during the next 24 h no other physical activity is planned and if body weight is reduced by less than 5%, then consumption of normal meals and snacks in combination with adequate water intake is sufficient to replenish fluid and electrolyte levels. For rapid and complete rehydration an intake of around 1.5 l of fluid per kg weight loss is recommended.

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