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Hydration Management in Sports

Füssigkeitsmanagement im Sport

CLINICAL REVIEW

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Summary

- **Hydration management** is challenging, but adequate hydration is of importance for health and performance in elite and recreational athletes. This brief, scoping review summarizes important aspects of hydration management in sports and offers practical guidance.
- **We focus on the health risks** of hypo- and hyperhydration and highlight preventive and therapeutic strategies. References may guide the interested reader towards more extensive literature on further aspects related to hydration and nutrient management during competition, training, and recovery.
- **The physiological loss of fluid** during prolonged exercise (i.e. marathon running, repeated training sessions within a day, multi-match sports event) occurs mainly through sweat, metabolic water and respiration. Substantial hypohydration (i.e., >2-4% of body mass) is likely to decrease performance and should be avoided. If athletes seek to prevent hypohydration by overdrinking, this can impose exercise associated hyponatremia and life-threatening cerebral edema. Overdrinking can generally be avoided by drinking to thirst, but individual rehydration strategies for training and competition may be advisable when barriers such as competition stress or poor availability are present. A variety of methods exists to assess hydration status in laboratory settings or in the field. Urine and blood markers combined with body mass changes currently offer the optimum of feasibility and validity.

KEY WORDS:
Dehydration, Hypohydration, Rehydration, Hyperhydration, Plasma Osmolality, Urine Specific Gravity, Sweat, Sodium, Hydration Assessment, Exercise

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Introduction

Total body water makes up about 66% of the human body mass. It is distributed as intracellular volume with approximately 37% of the body mass and as extracellular volume with approximately 29%. Extracellular volume includes all water outside the cells, including interstitial (about 24%) and plasma volume (about 5%). There is a continuous exchange between these compartments. Due to stress, sweating or heat, the total volume and distribution change very dynamically. The hydration status is therefore not static, but fluctuates around the continuously changing mean value of the total body water (16).

Exercise without fluid uptake leads to a loss of body fluid, although sweat loss is partly and transiently counterbalanced by metabolically produced water. The magnitude of fluid loss mainly depends on exercise duration, intensity, ambient conditions like temperature, humidity and radiation, and on individual sweat rate (see below). If hypohydration is profound, it may trigger relevant health problems, particularly heat illness, and may also decrease physical performance while increasing physical strain. Therefore, adequate hydration is crucial for health and performance in elite and recreational athletes.

This brief scoping review summarizes important aspects of hydration management in sports (Table 1), particularly for endurance (0.5-5.0 h duration) and ultra-endurance exercise (>5.0 h duration), and offers practical guidance. It focuses on the health risks associated with hypo- and hyperhydration (i.e. the situation of a relative lack or excess of fluid) and on preventive and therapeutic strategies. Importantly, this work does not comprehensively analyze and discuss all aspects related to hydration and nutrient management during competition, training, or recovery in athletes. The references may guide the interested reader towards more extensive literature.

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Table 1
Definitions of terms describing hydration status and management.

ABBREVIATION	TERM
Hypohydration	Negative hydration balance (i.e. body water deficit)
Euhydration	Neutral hydration balance
Hyperhydration	Positive hydration balance (i.e. body water overload)
Dehydration	Process of losing body water
Rehydration	Process of replenishing body water

Hypohydration

Endurance exercise leads to a loss of body fluid, mainly through sweating. The magnitude of fluid loss mainly depends on exercise duration and intensity, ambient conditions (e.g., temperature, humidity, wind, radiation, and also altitude, which can also aggravate the need of rehydration due to fluid shifts resulting in reduced plasma volume (18)), heat acclimatization status and individual sweat rate. Sweat rate is highly variable within athletes and between athletes, conditions, and pacing. In running, sweat rates range between approximately < 0.5 L/h in smaller athletes at low pace and 1.8 L/h in taller athletes at high pace (17). Hence, strategies to avoid severe hypohydration must be adopted to the individual and to the situation. Clothing and sports equipment can hinder evaporative cooling through sweating (e.g. modern pentathlon, dressage, fencing, winter sports) and such barriers may impair thermoregulation and in turn cause more intense sweating. During repeated bouts of exercise and especially when two or more training sessions are performed on a day, a considerable loss of fluid can accumulate. In these situations, a loss of 7-10 L/day is possible, especially if the ambient temperatures are high (19). If the fluid loss of a training session is not replenished, the subsequent session will start in a hypohydrated state.

In addition to the loss of fluid, sweating leads to a higher excretion of electrolytes. A loss of sodium of approximately 900 mg/L with a range of 175-1512 mg/L of sweat has been reported (14). Thus, sodium excretion via sweat glands is subject to large individual variations ("salty" and "non-salty" sweaters), and also highly dependent on environmental influences and on the degree of heat acclimatization.

Aside from fluid losses due to sweating and respiration, athletes might intentionally restrict fluid intake before and during competition. This is a frequent behavior in body mass limited sports (e.g. "making weight" in wrestling, boxing, light weight rowing). Also in other sports disciplines, athletes may assume performance benefits, may fear exercise associated stress incontinence and gastrointestinal discomfort or compete within a schedule/environment that limits opportunities to drink and/or to void the bladder.

Consequences of Hypohydration

Profound hypohydration may trigger relevant health problems, particularly heat illnesses such as heat cramps, heat exhaustion, heat collapse, and heatstroke (6, 15). It may decrease performance while increasing physical strain, because it reduces the circulating blood volume. As a consequence, cardiac preload and stroke volume decrease and heart rate is higher for a given cardiac output. Hypohydration is also associated with reduced saliva, tiredness, headaches, concentration deficits or delayed reactions (12).

A generally accepted level of hypohydration to compromise endurance exercise performance is a reduction of more than 2-4% of body mass (7). However, there is an individual variability, at which extend of water loss a decline of exercise performance occur (1). Hence, each hydration strategy is an individual strategy.

Avoiding Excessive Hypohydration

The process of dehydration can be modulated by drinking. Thus, adequate voluntary drinking should be subject of educating athletes and staff (2). "Drinking to thirst" is generally a recommendable rule for many athletes and conditions. It is sufficient, especially if (palatable) fluids are accessible and feasibility of drinking while competing is high (1, 8). Otherwise, use of special equipment (e.g. drinking bladders) may facilitate such strategies when drinking from a bottle would substantially interfere with athletic locomotion (e.g., in ski-mountaineering). However, there are multiple influences on thirst and drinking behavior during endurance exercise with high inter-individual variability (1).

Thus, individualized hydration strategies integrating sweat rate assessments may be warranted (3, 15) especially as these have been associated with performance benefits (2). The sweat rate is the volume of sweat produced per hour. It depends on modifiable (e.g., intensity, clothing, or acclimatization) and fixed factors (e.g., ambient conditions). Knowledge of the sweat rate at given conditions is of utmost importance for an individualized hydration strategy. A convenient way for its determination is:

Eq. 1

Simplified fluid balance (mL) = dietary fluid intake (mL)
– [sweat volume (mL) + urine volume (mL)]

It is worth mentioning that the within- and between-subject variability of hygro- or gravimetric measurements is quite high (5-17%) for body sweat rate and extreme (up to 360%) for local sweat rate and sodium concentration in sweat.

Post-exercise consumption of solid food containing sodium promotes rehydration (12). Thus, meals and snacks should not be skipped in athletic settings like e.g. training camps. Cooled (<10° C) or iced drinks may contribute performance benefits in hot environments (12). However, very cold drinks or ice slushies may indeed reduce whole body sweat losses (and thus decrease risk of hypohydration), but possibly at the cost of lower net heat loss and larger heat storage increasing the risk of heat exhaustion.

Hyperhydration

Definition of Hyperhydration

Hyperhydration has been defined as „[…] the state of excessive total body water content with expanded intracellular and extracellular fluid volumes." (13). However, it is crucial to understand that hyperhydration is relative to the euhydrated status estimated for any given time point of exercise and not to pre-exercise conditions. That is because the net mass change due to glycogen oxidation during prolonged exercise amounts to approximately 0.4 g per 1 g of glycogen. Consequently, a mass decrease of 3% in an ultramarathon runner can be considered as a balanced hydration status, while a 0% change would clearly point to a relative excess (10). Excessive total body water during prolonged exercise in healthy humans is generally the result of excessive fluid intake (i.e., overdrinking) and may be exaggerated by insufficient renal

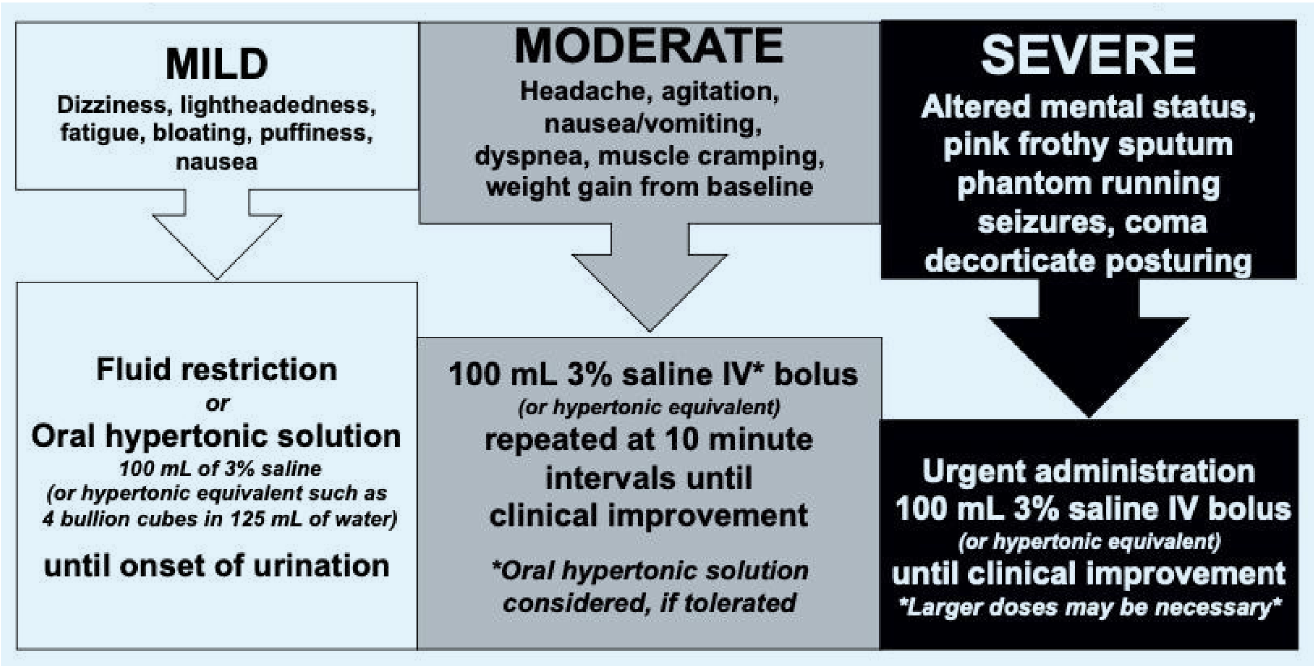

Figure 1

Clinical signs and symptoms of mild, moderate, and severe exercise associated hyponatremia (EAH) are categorized and coupled with the most appropriate treatment strategy. Figure adapted from Hew-Butler 2019 (8).

excretion due to an inadequate endocrine response especially of the antidiuretic hormone vasopressin. This combination can result in a body mass gain of more than 10% (7.8 kg) in 12.7 h while competing in an ultra-endurance triathlon (9). Acute renal failure is also a possible but very rare mechanism.

Health Risks of Hyperhydration

Hyperhydration per se is not dangerous. However, overdrinking during exercise may lead to exercise associated hyponatremia (EAH), which is a potentially lethal condition. EAH is a biochemical diagnosis, confirmed when serum sodium is below the normal reference value of generally 140 mmol/L for the lab or the instrument performing the blood test within several hours post-race (9). EAH is typically due to excessive dilution of the available sodium and not due to an absolute deficiency. EAH is often asymptomatic. If symptomatic, bloating, vomiting, headache, and altered mental status are frequently reported. EAH can also lead to cerebral encephalopathy with or without non-cardiogenic pulmonary edema. Severe EAH is a life-threatening emergency that must be treated appropriately (see. Figure 1 for more details on symptoms and treatment). Noteworthy, also repeated overdrinking may induce exercise associated hyponatremia e.g., in training camp situations (11).

Prevention of Hyperhydration

No sports drink can safely prevent EAH if consumed in excess (21). Hence, prevention of EAH and water intoxication can only consist in the avoidance of overdrinking. From an athlete's perspective, the easiest way to do this is to drink to thirst (8) and to stay within the limits of individual sweat rate and in any case below ~ 700 mL/h (1). The drawback of such strategy is that thirst sensation within and between athletes is highly variable and could be masked by additional factors like race associated stress that can also negatively impact fluid intake (1). Organizers of endurance events can contribute by avoiding an unreasonably high number of rehydration points (e.g., no more than every 5 km during running) (5, 8).

Current literature predominantly advises against sodium supplementation to prevent EAH, as it has either little or no effect on increasing sodium concentration in blood (1). However, there is no strong argument against replacing sweat losses with adequate amounts of sodium enriched fluids (21). For exercise in hot environments, appropriate acclimatization is warranted to allow for prolonged sweating and reduced loss of sodium via the sweat.

Methods to Assess Hydration Status

The choice of the appropriate method for the individual athlete should consider the environment of testing (i.e., laboratory versus field), the intention of the measurement (e.g., hydration status versus course of change in hydration status) and the time domain (acute versus chronic changes). Furthermore, the assessment of at least two compartments (i.e., blood, urine or sweat) or of one compartment plus changes in total body mass facilitate the interpretation of measurements (Table 2, see supplemental material online).

Blood Variables

Blood variables are an estimate of the change of plasma volume during exercise. Changes of the interstitial vs. intracellular fluid are not considered and fluid shifts between the intra- and extracellular space might skew the results.

A measurement of plasma osmolality (Posm) allows to determine the hydration status with only a single measurement at best. Yet, sensitivity of this method is questioned, as half of plasma volume lost during exercise is compensated within 60 min by fluid shifts from the interstitial space. Therefore, actual hydration deficit might be underestimated. The ingestion of especially carbohydrates may alter Posm due to osmotic shifts of fluid into the guts. Furthermore, Posm has a high inter-individual variability. Hence, individual baseline needs to be considered (4).

Hematocrit (Hct) is less expensive and more feasible in the field, especially when capillary samples are obtained. Hct is useful to discriminate iso- vs. hypotonic hypohydration. Hct requires a high level of standardization (e.g., 15-min rest before blood sampling).

Serum sodium is closely linked to Posm, thus sharing the same strengths and limitations. However, it is less responsive to fluid shifts due to the sodium lost in sweat and endogenous availability of sodium from skin and bones and therefore less accurate.

Urine Variables

Urine variables depend on renal fluid re-uptake in response to fluid loss. The more concentrated the urine is, the higher its osmolality, specific gravity, and more intense its color, while frequency of bladder void and urine volume decrease.

Urine osmolality (Uosm) is the most accurate urine variable to assess hydration status. However, large ethnic differences and dietary variations need to be considered. An osmometer is expensive and requires trained personnel.

Urine specific gravity (Usg) can be easily assessed with a refractometer delivering instant results also in the field. Results can be interpreted applying well-established normal values. Usg is closely correlated to Uosm, sharing similar strengths and limitations. Usg measurement is also possible with urine sticks, but it is less accurate and more expensive over the long term.

Urine colour (Ucol) assessed with an 8-point Likert scale is a very simple, inexpensive and easily administered tool to detect hypo- and hyperhydration.

A urine diary documents the frequency and volume (or duration) of bladder voiding, Ucol and fluid intake will help to identify inadequate fluid management during training, recovery, competitions and various climatic conditions. However, reliability of these data is low due to their subjective nature and an accurate monitoring of acute hypo- or hyperhydration is hardly possible.

Urine variables are feasible and of acceptable quality for monitoring an athlete's hydration status in the field. However, several limitations need to be considered: i) the timing of the last bladder void will influence the results, ii) ingestion of hypotonic fluids can falsely indicate euhydration, iii) the correlation of urine variables in the assessment of acute mild dehydration to more robust blood variables like Posm is low (20).

Sweat Variables

The non-invasive analysis of sweat shows great potential for guidance of hydration strategies but is not suitable for assessment of the hydration status. Environmental and technological limitations need to be considered, if guidance of a hydration strategy shall be based on sweat rate and sodium concentration (3).

Variables for Gross Assessment of Hydration Status (Total Body Mass, Total Body Water, Vital Signs, Thirst Sensation)

Several methods exist that allow for a gross estimation of changes in an athlete's hydration status. Due to their limited accuracy, they should only be used in combination with at least one other variable derived from urine, blood or sweat. Changes in body mass (body mass scale), ideally in combination with measures of body composition (e.g., bio-impedance analysis), thirst sensation and vital signs are easily applied in the field-setting and deliver prompt results that may allow instant guidance of rehydration (13). The most favored method by athletes is thirst sensation. However, the risk of delayed rehydration and subsequent loss of performance needs to be considered, if drinking by thirst is applied.

Further, less Practicable Methods for the Assessment of Hydration Status

Blood levels of hormones, salivary and tear fluid variables as well as radiological methods (e.g. dual-x-ray absorptiometry, neutron activation analysis and stable isotope dilution) are either too complex and time consuming or not yet sufficiently validated to be applicable in field settings (Table 2, see supplemental material online).

Conclusions / Recommendations

Hydration management in elite and recreational athletes is challenging but crucial for health and performance. The physiological loss of body mass during prolonged exercise (i.e. marathon running, repeated training sessions within a day, multi-match sports event) due to sweat, respiration, renal excretion and metabolism can be as high as 10%. Substantial dehydration (e.g. loss of >2-4% of body mass) is associated with higher risk for heat illness and decrease in performance. Overdrinking, on the other hand, leading to maintenance or even increase of body mass during a prolonged event can result in life-threatening conditions of exercise associated hyponatremia.

To avoid such situations, the following principles are recommended:

- Start exercise in a euhydrated state
- Avoid fluid losses exceeding 2-4% of body mass, but avoid overdrinking
- Drinking according to thirst is a good strategy
- However, such strategy has to be proven during training and competition by assessing pre- and post-hydration status and body mass
- If athletes struggle to meet the fluid uptake generally or in particular situations (e.g., exercise in the heat, competition stress, low availability, etc.), plan individual hydration strategies based on sweat rate assessments
- As a rule of the thumb, do not drink more than 700 mL/h in moderate conditions
- During and after exercise, drinks should contain 400-700 mg/L sodium. Of note, sodium consumption during exercise does not reduce the risk of exercise associate hyponatremia.

To assess hydration status during and after exercise in laboratory settings or in the field, several blood and urine markers are available, which allow a good indirect assessment of hydration status especially when combined with body mass changes on a regular basis. Finally, although not addressed in this review due to its focus on hydration management, rehydration should be combined with nutrient supply during prolonged exercise.

Conflict of Interest
The authors have no conflict of interest.

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