

Review

Different Waters for Different Performances: Can We Imagine Sport-Related Natural Mineral Spring Waters?

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Abstract: Preserving the hydration status means to balance daily fluids and salt losses with gains, where the losses depend on several physiological and environmental factors. Especially for athletes, these losses could be relevant and negatively influence the performance: therefore, their hydro-saline status must be preserved with personalized pre- and rehydration plans all along the performance period. Scientific literature in this field is mainly dedicated to artificial sport drinks. Different territories in most world areas are rich in drinking natural mineral spring waters with saline compositions that reflect their geological origin and that are used for human health (often under medical prescription). However, scarce scientific attention has been dedicated to the use of these waters for athletes. We therefore reviewed the existing literature from the innovative viewpoint of matching spring water mineral compositions with different athletic performances and their hydro-saline requirements.

Keywords: hydration status; natural mineral waters; spring waters; performance



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1. Introduction

Water makes up 50–70% of body mass and is distributed in the intracellular (65%) and extracellular (35%) spaces [1]. Physiologically, our body requires a minimum of 4 to 6 glasses of water daily, also gained by solid food. Over the years, international institutions such as the European Food Safety Authority (EFSA) or the National Research Council have issued guidelines on daily water intake: 2.0–2.4 L/day are recommended for males and 1.6–2.0 L/day for females [2]. These values must be adjusted depending on climate and level of physical activity. Exercising leads to water and electrolytes loss that must be replenished, and when a subject is dehydrated plasma volume decreases. Tight regulation of blood volume is related to multiple organ systems and is closely associated with electrolytes content and hydration status. Since it is necessary for the constant perfusion of body tissues, the maintenance of plasma volume is crucial to normal multiorgan function. Hence, changes in blood volume can result in different clinical situations such as edema or hypovolemic shock. Several aspects of the hematologic system itself can also be influenced by physical activity [3], for instance, besides the well-known effects on red blood cells, dehydration, hypovolemia, and physical exercise per se generate a catecholamine response that in turn induces thrombocytosis and affects hemostatic function [4]. On the other hand, inherited abnormalities of the blood, including platelet disorders [5] can manifest in athletes under stress [6] conditions.

Traditionally, coaches tell athletes that thirst is not a good indicator of hydration status, because “once you’re thirsty, you’re already dehydrated”. The American College of Sport Medicine (ACSM), in their fluid replacement position stand, highlighted that

“perception of thirst [...] cannot be used to provide complete restoration of water by sweating” and that “athletes should start drinking early and at regular intervals [...] or consume the maximal amount that can be tolerated” [7]. ACSM suggested for athletes a water intake plan of about 500 mL of fluids 2 h before exercise, followed by an interval hydration during exercise every 15–20 min, especially in ultra-endurance sports at high humidity and temperature. Indeed, a condition of water deficit negatively impacts sport performances. Therefore, customizing a drinking plan for athletes means preventing dehydration during physical activity and restoring the initial hydration status in the post-exercise recovery [8–10]. Environmental conditions influence exercise capacity and athlete performance. When preparing a competition, athletes and their technical staff must consider meteorological factors as temperature and humidity, indoor or outdoor field.

To face fluid imbalance during sport performance, studies on the so-called “sports drinks” developed. Sports drinks were created to provide quick replacement of fluids, electrolytes, and carbohydrates during physical activities [11]. Generally, with these beverages at low carbohydrate concentration (<10%), athletes can replace sweat losses, restore the hydration status, and supply a little source of carbohydrates before and during exercise [12]. As expected, however, the “perfect mix” has never been found, not to say of other frequent accompanying side problems such as palatability or gastrointestinal discomfort.

Different territories in most world areas are rich in drinking Natural Mineral Spring Waters (NMSWs) with saline compositions that reflect their geological origin and that are used for human health (often under medical prescription). While most scientific literature is focused on carbohydrate/electrolyte composition of artificial sport beverages [13–15], scarce scientific attention has been dedicated to the mineral composition(s) of natural spring waters as related to the average hydro-saline requirements of the different athletic performances. Indeed, after the European directive 2009/54/EC of the European Parliament and of the Council of 18 June 2009 on the Exploitation and Marketing of natural mineral waters [16], then adopted by European Member States, it is possible to take advantage of a natural mineral waters classification—from low to high mineral content with different dissolved salts—and a specific nomenclature based on the prevailing minerals (e.g., bicarbonate water, if the content of bicarbonate is more than 600 mg/L or magnesium water, if the magnesium content is greater than 50 mg/L, etc.) NMSWs—differently from tap water—ultimately contain a specific mix of natural elements, with associated beneficial effects often generically reported on the bottle’s tag as water properties (“suitable for a low-sodium diet”, “may be laxative”, “may be diuretic”, “promote digestion”, etc.)

Given this background, we asked if there was sufficient scientific data to predict that the biological properties of specific NMSWs could optimally respond to the physiological needs of athletes in relation to their specific sport activity and performance. For example, it was shown that after a prolonged aerobic exercise, the rehydration of athletes with a natural and moderately mineralized water was more effective in inducing recovery and leg power compared to plain water [17]. As shown by Chycki et al. (2018) [18], a mineral alkaline water enhances the hydration status of combat sport athletes compared to commercial table water. The same authors [19] also proved that alkaline, low mineralized waters had a positive impact on hydration status in response to high-intensity interval exercise. A rationale then exists for the idea of a hydration/rehydration plan with specific NMSW, to give the optimal hydration status before the competition and to restore fluid balance during and at the end of it.

Thus, we will first summarize the physiological relevance of hydration status of athletes in pre-, during and post-competition, and then explore the existing categories of NMSWs, trying to assign to each at least a theoretical sport-specificity.

2. Materials and Methods

This review was conducted following the PRISMA-ScR (PRISMA extension for Scoping Reviews) Checklist and Explanation [20]. We searched PubMed, Google Scholar and ResearchGate for publications in English in the last two decades (2000 to 2020) using the

terms “natural spring OR mineral water AND hydration OR rehydration AND exercise performance NOT fluid therapy NOT review”. We took into consideration all the relevant studies including at least athletes, spring waters and sports performance, describing the hydration and/or rehydration methods with spring waters or the effect of these waters on the sport performance (endurance and/or resistance).

3. Hydration Status and Sport Performance

Water requirement for adults typically ranges from 2 to 4 L/day [21]. Water minerals are of course essential to the hydro-electrolytic balance. Therefore, also beverages different from water (like tea, infusions, fruit juice or milk) can restore hydration [22–25]. However, these usually contain added or natural sweeteners that increase the daily calorie intake [26] or can generate unwanted effects during sport performances (like gastrointestinal discomfort, etc.) Therefore, water, with its specific mineral content, should be considered as the main hydration source for the daily fluid balance.

A well-fed adult engaged in a moderate physical activity at 20 °C loses 2200–2300 mL of water daily, of which 800–1250 mL by sweat and respiration, 100–150 mL by faeces, and 800–1500 mL by urine. The ACSM fluid replacement guidelines show that the total fluid intake must be proportional to individual sweating rate, exercise duration and drinking [27]. Sport performance is deeply influenced by the hydration status of athletes, and therefore, a personalized hydration plan is strongly sought [28]. In general, water supply should be taken at small rates before and during performance, with intervals of 15–20 min, depending on environmental conditions and type of physical activity.

In a recent review, Nuccio et al. (2017) [29] showed that sport-related dehydration risk (body mass loss > 2%) can be predicted starting from three parameters: exercise intensity, environmental temperature, and fluid availability. When the intensity and temperature are high and there is a limited fluid availability, the dehydration risk is—of course—high; whereas it is lower if any of the three mentioned parameters is favourable. In parallel, other authors classified sports as at low, moderate, or high dehydration risk. For example, track and field events like jumping, throwing, and sprints are classified as at low-dehydration risk, due to their short duration (up to 30 min) and limited sweating [21,30]. However, even in this case, if sufficient hydration is not guaranteed before competition, performance will be negatively affected: track and field sprinting performance is impaired by a reduction of body mass (dehydration) of 2–3% 2 h before performance. Prolonged exercises like middle (800 m to 3 km) and long-distance running (5–10 km) are associated with a moderate dehydration risk, whereas long-distance walking, running or ironman between 20 and 50 km are at high-dehydration risk [21].

Exercising in a warm environment (temperature > 30 °C) leads to a dehydration ranging 2–7% of body mass, impairing endurance performance [29,31–33]. Heat dissipation by sweating is affected by temperature, humidity, air flow, sun radiation and clothing. An average sweat rate ranges between 0.5 and 2 L/h, with a maximum rate of 3 L/h, but in long-distance events (e.g., the 50-km walk or run) sweat losses are significantly higher, up to 3.5 L/h for elite athletes [27,30]. When performing in cooler environments, sweat loss—although smaller—must however be prevented and replenished [34]. Consequently, Garth and colleagues (2013) [35] classified sports (outdoor, indoor, or open water) according to the sweat loss. Outdoor and/or field-based sports like soccer, rugby, field hockey, lacrosse, cricket, baseball, softball, etc. are characterized by intermittent high-intensity efforts and players show different rates of sweat volumes due to game demands, clothing, playing times and total match duration. Indoor sports (e.g., basketball, volleyball, netball, and futsal) are similar to the outdoor sports in terms of intensity, game and breaks, but the court is generally smaller, with increased accelerations, decelerations, and changes of direction, that all together lead to an increase in the energy cost and sweat volume. However, air conditioning in the arena controls the temperature, eliminating seasonal differences. Racket sports like tennis have specific Heat Policies, namely, in extreme heat conditions, the rules allow to add more breaks during the match in which athletes can drink. Open water

swimming, synchronized swimming, and water polo are sports characterized by increased sweat loss due to warm water, high-intensity, and humid external environment (or hot weather for outside pools) [35].

Hydration levels act on different determinants of performance. Evidence on team sports show that the hypohydration affects sport-specific skills. For example, 2–4% hypohydration impairs shooting precision in basketball and throwing in cricket. By contrast, the same rate of hypohydration minimally impacts soccer, field hockey, and tennis skills [29]. Muscular strength and power are negatively affected by a reduction of approximately 2% and 3% of body mass. Moreover, dehydration exacerbates the onset of fatigue and muscle soreness during exercise [36].

Surprisingly however, competition efficacy can sometimes improve under (controlled) hypohydration because of lower body mass, like in vertical jumping [29,31,32]. A reduction of body mass allows competing in a lower weight category in combat sports such as kickboxing, mixed martial arts (MMA), judo, wrestling, taekwondo, etc. [37–39]. Athletes participating in weight category competitions can seek losing up to 4–5% of body mass shortly before the competition [32], rapidly rehydrating after performance. Such water restriction can impair the neuromuscular performance of athletes, but Tan et al. (2019) [40] showed that even if brain structures are affected by dehydration, associated motor functions are preserved. Obviously, most authors suggest the development of policies on weight cutting in these sports, considering the wide diffusion of such potentially harmful practices [37–39]. Finally, also postural control is affected by dehydration. Gauchard et al. (2002) [41] compared the postural control of athletes before and after aerobic tests (at cycloergometer) in hydrated and dehydrated conditions, showing an altered balance control in dehydrated subjects [41].

Studies on sport performance showed that an optimal hydration status is necessary at the beginning of exercise (prehydration) to prevent body weight loss >2% and excessive modifications of electrolyte balance during performance. A prehydration program should start several hours before the event: fluid intake should be between 5 and 7 mL/kg at least 4 h before performance while, according to urine volumes, additional 3–5 mL/kg might be indicated. However, since during exercise renal blood flow and filtration decrease, attention should be paid to pre-exercise hyperhydration because: (i) it increases the risk of hyponatremia [27]; (ii) it increases the need of voiding during competition. As recently reported by Vitale et al. (2019) [7] and Armstrong et al. (2017) [8], sport-related hyponatremia is the result of overhydration and net water retention. Mild hyponatremia occurs at plasma $[\text{Na}^+]$ of 130–135 mmol/L, whereas $[\text{Na}^+] < 125$ mmol/L is symptomatic and incompatible with physical exercise. On the other hand, also a pre-exercise hypohydration reduces sport performance: A hypohydration above 3% of body mass negatively affects short-duration (5–30 min), high-intensity exercise, while maximal oxygen consumption decreases by 2.4–2.9% for each percent unit of body weight loss [42,43].

Due to the multifactorial nature of exercising (metabolic requirements, exercise intensity and duration, clothing, equipment, weather conditions, etc.), it is difficult to recommend a specific fluid and electrolyte intake prior to exercise. However, existing literature agrees on the need of a customized hydration program based on individual parameters (sweat rate or, in general, daily fluid intake and losses) of athletes [8,9,29].

4. Rehydration and Athlete's Health

As for prehydration, also optimal rehydration during/after exercise must be obviously based on the type of activity and availability of water during performance. Of course, it becomes critical with middle- and long-distance sport events, due to higher intensity and higher sweating [1,44]. By contrast, short duration events can be faced by a well-planned water intake pre- and post-exercise [1]. Sanchez-González et al. (2005) [45] showed that female athletes dehydrate more than males, because of their quicker fluid turnover, however with no significant impact on performance [27]. Interestingly, individuals with

a better aerobic capacity tend to lose less liquids due to the broken-in mechanisms of fluids reabsorption.

Rehydration during/after exercise also needs to be modulated. Holland and co. (2017) [46] matched different hydration protocols to road cycling performances of different duration. Performances shorter than 1 h required relatively low water assumption (between 0.15 and 0.34 mL/kg body mass/min); larger fluid assumption compromised the gastric emptying leading to abdominal bloating, gastrointestinal discomfort, and a worse performance. Conversely, 1–2 h cycling performances improved if the rate of fluid intake was around 0.15–0.20 mL/kg body mass/min while performances longer than 2 h were optimized by ad libitum drinking. It should however be considered that a dehydration around 2.4% of body mass has a higher impact in terms of performance on acclimated than on non-acclimated athletes (cyclists) [47]. Acclimation before short-duration efforts was recently studied by Barley et al. (2019) [48]. The authors evaluated a passive acclimation protocol (exposure to the heat) before a maximal sled-push exercise, reporting an improvement in performance not related to the hydration level of athletes.

The post-exercise recovery period has been widely studied, because in this period it is possible to replenish in excess the energy expenditure. Taking advantage of this so called “window of opportunity” by a well-planned recovery amplifies physical efficiency in the subsequent training session or sport performance [49]. The ACSM Position Stand suggests 1.5 L/kg per body weight loss to reach a fast and complete recovery; however, a personalized rehydration plan is needed depending on individual sweat rate, exercise duration, and water availability [27].

Hydration protocols during and after exercise rarely provide for water or different types of water. Rather, they generally consider artificial sport drinks, essentially carbohydrate–electrolytes enriched drinks, for a quick fluid rebalance and a little surplus of energy during exercise. In most studies, water is rather a placebo or not considered at all.

Morris et al. (2003) [50] compared a carbohydrate-electrolyte solution (6.5 g carbohydrate, Na⁺ 21 mmol/L) with a taste placebo (Na⁺ 2 mmol/L) or flavoured water (0.1 g carbohydrate, Na⁺ 6 mmol/L) during high-intensity running in a hot environment. Interestingly, they found no differences between test groups in sprint performance and covered distance; however, body temperature was higher in the carbohydrate-electrolyte group. Even the onset of fatigue and other parameters such as heart rate, blood pressure, and rate of perceived exertion were not different between groups.

Summarizing: (i) the progressive dehydration induced by exercise negatively impacts sport performance, in particular in long-distance events; therefore, (ii) a customized prehydration plan is strongly recommended, and (iii) rehydration during and after performance must be planned as well, since the ad libitum drinking does not optimize the hydration status [46,48]; (iv) an acclimation protocol [47,48] together with an aerobically fit background [45,47,51,52] help optimizing fluid balance; (v) despite some advantages (elevated amount of carbohydrates, glycogen synthesis, etc.) of a supplementation with carbohydrate-electrolytes solutions, these often carry associated unwanted “side effects”.

5. The Goals of Hydration and Rehydration in Athletes

Athlete performance is multifactorial. Several intrinsic and extrinsic parameters of sport performance impact on the hydration status of the athlete and vice versa: sweating rate; type of exercise; environment (climate, humidity, and wind); duration and intensity; drinking availability. Taken together, these parameters are the basis of the preliminary assessment necessary to plan the optimal hydration and rehydration programs, customized to each athlete (Figure 1).

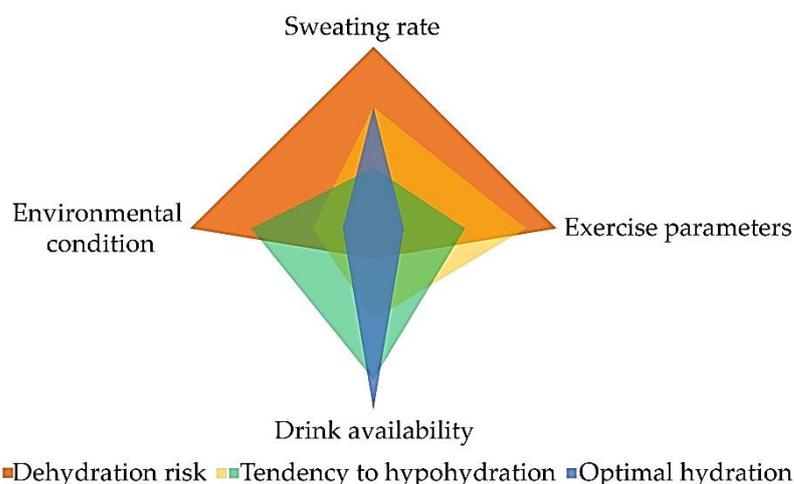


Figure 1. Multifactorial parameters of exercise and their effect on hydration.

The diamond colours are representative of the hydration status (blue diamond = optimal hydration; green and yellow = tendency to hypohydration, unfavourable conditions; dark orange = dehydration risk), and they are matched with the diamond extremities, according to the nature of exercise. For example, the optimal hydration is gained when the sport performed allows athletes to drink, the environmental conditions are favourable to the sweating rate that is preserved, and the exercise duration and/or intensity are short and/or low (short-repeated effort, tennis, table tennis, diving, weightlifting, etc.) On the contrary, the dehydration risk is shown by dark orange diamond, when there is no drink availability during a high-intensity, long-duration performance, where the environment mostly influences the individual sweating rate (long-distance running or cycling events, iron man, etc.) There are also sports (team sports, with intermittent efforts on middle-distance) characterized by transient fluctuations of fluid balance and tendency to hypohydration at certain moments during performance (green and yellow diamonds) [27].

Thus, (a) if the sweating rate is preserved and the environmental conditions are comfortable, with an existing although limited drinking availability, the exercise duration or intensity is well managed (yellow diamond); (b) during a match that lasts beyond 30 min but less than 1 h (e.g., first half of a soccer match) the sweating rate and the environmental condition (outdoor, hot weather) can be compensated by the drinking availability (green diamond).

This preliminary assessment is followed by the prehydration plan, that essentially consists in the water intake the day of performance, starting from some hours before. As said, the aim of prehydration is to start performance without excess or lack of water and electrolytes, in view of the upcoming physical effort. Adjusting the water intake according to urine volume is sufficient for short-duration events, but not for the long-duration performances, for which evidences suggest the addition of an acclimation protocol [47,48]. According to the guidelines [27], the fluid balance can be preserved during performance with an interval hydration (every 15–20 min). Therefore, short-duration events (up to 30 min) are hypothetically characterized by only one “drink availability check” or time out. It is more likely that short-duration events do not include drinking breaks or time outs, whereas long-duration performances likely do. However, as also reported by Holland et al. (2017) [46], for performances lasting less than 1-h, small rates of water intake assessed according to the individual rate of gastrointestinal absorption are suggested. In any case and especially for team sports and competition with breaks as per regulation (middle-distance events, long-duration events with time out), the “drink availability check” should be always estimated before performance to implement both prehydration and rehydration plans.

6. Natural Mineral Spring Waters (NMSWs) and Athletic Performance

According to the European directive 2009/54/EC [16] the natural mineral waters are primarily defined as “microbiologically wholesome water [. . .] originating in an underground water deposit and emerging from a spring tapped at one or more natural or bore exits”. The original nature (mineral content) and purity at source must be preserved and unaltered after bottling. To define water as “natural mineral”, there are some requirements and criteria: a geological report of the catchment site, its altitude, origin, and nature of the terrain; physical and chemical characteristics (water temperature at source, ambient temperature, dry residues at 180° and 260°, type of minerals, etc.) are also required, as long as microbiological analyses to test the absence of parasites or pathogenic micro-organisms. If biological properties of NMSWs on different organ systems are established (e.g., urinary [53], digestive [54], respiratory [55], and gastrointestinal [56] tracts; bone [57]; and skin [58,59]), these must be confirmed by clinical and pharmacological analyses that state them as specific characteristics of each particular NMSW. Several of these parameters contribute to the classification of natural mineral waters: the 180 °C fixed residue, for example, defines the water mineral content (very low: <50 mg/L), low (<500 mg/L), medium (from 500 mg/L to 1500 mg/L) and high (>1500 mg/L). However, since the biological effects of NMSWs are mainly related to their mineral content, their most common classification is based on the mineral element(s) present in higher proportions, as detailed in Table 1.

Table 1. Nomenclature of natural mineral waters classified according to their prevailing mineral content.

Nomenclature	Criteria
Bicarbonate	Bicarbonate content greater than 600 mg/L
Sulphate	Sulphate content greater than 200 mg/L
Chloride	Chloride content greater than 200 mg/L
Calcium	Calcium content greater than 150 mg/L
Magnesium	Magnesium content greater than 50 mg/L
Fluoride	Fluoride content greater than 1 mg/L
Iron	Bivalent iron content greater than 1 mg/L
Acidic	Free carbon dioxide content greater than 250 mg/L
Sodium	Sodium content greater than 200 mg/L
Suitable for a low-sodium diet	Sodium content less than 20 mg/L

Modified from Directive 2009/54/EC of the European Parliament and of the Council of 18 June 2009 on the exploitation and marketing of natural mineral waters, Official Journal of the European Union, 26 June 2009 [16].

Authors [60–63] reviewed the existing literature of drinkable NMSWs and their biological properties. Given the mineral content of a specific water and the pre- and rehydration needs related to a specific sport performance, it appears conceivable to match different types of mineral waters to sport activities and physiological needs of athletes.

7. Optimal NMSWs to Hydrate and/or Rehydrate: Water Salts/Volumes and Sport Performance (Explosive/Endurance)

The minerals from drinkable NMSWs are highly bioavailable and drinkable NMSWs mineral content contributes to mineral daily requirements [64–69]. Although drinkable NMSWs have a geological origin [70] that confers a rich and differentiated mineral content, completely different from average tap waters, in the best of our knowledge, scientific literature never directly focused on best natural mineral water composition to preserve the hydration status of athletes and possibly improve their performance. However, our knowledge of the physiology of fluid balance in sport activities on one side and of NMSW chemistry on the other, today allows to hypothesize such a correlation. Some preliminary information on the drinking behaviours and voluntary intake of water are available. Hoseinlou et al. (2013) [71] assessed the voluntary intake of water at different temperatures (from cold to warm) in subjects cycling in a hot environment at moderate intensity. The

higher intake was reported for water at 16 °C (like the cool tap water). This temperature preserved the hydration status better than the others (5°, 26°, and 58 °C), due to lower sweating. Drinking behaviours had also been previously studied by Cuddy et al. (2008) [72] in firefighters (a hard job that usually takes place in hot environments and that—from the standpoint of fluid balance—might be comparable to ultra-endurance sport activities), comparing the assumption of water versus water and electrolytes (45 mg magnesium, 125 mg sodium, 390 mg chloride, 130 mg potassium, and 20 mg sulphate/L). The water volume assumed was higher in the case of plain water, whereas ingestion of water + electrolytes allowed a better control of thirst sensation. Consequently, workers could spend more time at work maintaining a good hydration status for longer and reducing the amount of liquids transported. Sodium-rich mineral waters were suggested for rehydration after physical activity [73], but volumes and concentration of Na⁺ must be balanced to avoid unpalatable mix. Studying the fluid balancing during two subsequent cycling performances, Merson et al. (2008) [73] administered four water solutions differing only for sodium chloride content (1, 30, 40, and 50 mmol/L) reporting that rehydration with 40 or 50 mmol/L NaCl was most efficient to keep fluid balance, with an acceptable palatability. However, they observed no difference in the physical performance with any of the drinks tested. Evidence on muscle fatigue and damage were reported by two studies on deep mineral waters. Hou et al. (2013) [74] studied the effects of a deep ocean mineral water (taken from the Pacific Ocean at 662 m below sea-level) drinking after a prolonged bout of dehydrating exercise. This water was rich in boron, magnesium, lithium, and rubidium. Similarly, Stasiule et al. (2014) [17] tested deep mineral water taken at 689 m from a geological sandstone, dolomite, and gypsum layers, with moderate mineralization. This was a calcium–magnesium–sulphate water with other trace elements (boron, phosphorus, chromium, manganese, iron, and copper). The results from these studies were consistent since the recovery from dehydrating exercise (physical fatigue and leg muscle power) was more efficient and accelerated with both waters. Magnesium and boron favoured exercise performance, as magnesium levels correlate with muscle strength while boron counteracts both the magnesium loss and lactate elevation induced by exercise [75]. Oxidative damage [76] was reduced, with lower levels of circulating creatine kinase and myoglobin (indicators of exercise-induced muscle damage). Moreover, VO₂max was significantly higher after a 4-h recovery period when rehydrating with deep mineral water compared to tap water. Similar results were reported recently by Harris et al. (2019) [75] when comparing deep ocean mineral water with mountain spring water and a sport beverage after a dehydrating exercise.

Recent evidence also focused on bicarbonate/calcic or, more generally, alkaline waters showing—as expected—a better acid-base balance control, efficiently counteracting exercise-related acidosis [18,19]. Brancaccio et al. (2012) [77] correlated the hydration status to the urine specific gravity. This was taken as a descriptive parameter of density and particle concentration in urines. Normally it ranges from 1.010 to 1.020, whereas certain conditions (e.g., diabetes or renal dysfunction) increase or decrease this value [78]. Fluid balance impacts the urine specific gravity as an excessive fluid intake decreases it, and vice versa [78,79]. The athletes in the Brancaccio's study underwent a modified repeated Wingate test (the first test was submaximal, the second one until exhaustion) during which they were rehydrated with (i) low-mineralized water or (ii) a bicarbonate-calcic mineral water (pH 6.14 ± 0.11, fixed residue mg/L 878.41 ± 25.21, CO₂ mg/L 1890.12 ± 72.51, HCO₃[−] mg/L 981.11 ± 33.82; Ca²⁺ mg/L 313.70 ± 9.81) or (iii) not rehydrated. According to the authors, the rehydration with mineral water lowered the urine specific gravity, namely, the athletes had a better capacity to retain water, with a positive effect on urine pH. The same effects of alkaline waters were found also by Chycki et al. (2018 and 2017) [18,19] who also reported a more efficient lactate utilization after anaerobic performance. In Chycki et al. (2017) [19], the aim of the study was to compare the effects of drinking different types of water (high-, low-mineralized waters, and table water) in soccer players. The high-mineralized water composition was HCO₃[−] mg/L 1326 ± 11.3; Cl[−] mg/L 8.4 ± 0.3; SO₄^{2−} mg/L 28.7 ± 2.0; Na⁺ mg/L 82.7 ± 6.2; K⁺ mg/L 7.41 ±

0.05; Ca^{2+} mg/L 177 ± 5.2 ; Mg^{2+} mg/L 151 ± 4.1 ; the low-mineralized water composition was HCO_3^- mg/L 260 ± 6.14 ; Cl^- mg/L 7.9 ± 1.3 ; SO_4^{2-} mg/L 68.0 ± 3.6 ; Na^+ mg/L 8.24 ± 1.1 ; K^+ mg/L 1.83 ± 0.5 ; Ca^{2+} mg/L 89.6 ± 4.6 ; Mg^{2+} mg/L 11.4 ± 2.7 ; the table water composition was HCO_3^- mg/L 3.62 ± 0.12 ; Cl^- mg/L 0.41 ± 0.03 ; SO_4^{2-} mg/L 1.60 ± 0.09 ; Na^+ mg/L 1.21 ± 0.05 ; K^+ mg/L 0.30 ± 0.03 ; Ca^{2+} mg/L 1.21 ± 0.05 ; Mg^{2+} mg/L 0.40 ± 0.04 . The specific urine gravity decreased with both high- and low-mineralized alkaline waters, but a significant increase of urine pH and improved lactate utilization were found with low-mineralized water. This would suggest that a hydration protocol with alkaline waters might favour anaerobic high-intensity performances. The same authors also investigated alkaline waters in combat sports athletes as an effective alternative to sodium bicarbonate water, to preserve the acid–base equilibrium and improve plasma buffering capacity. Results showed no difference in performance. Athletes using sodium bicarbonate waters showed a better cotransport of hydrogen and lactate (H^+/La^-) ions, due to the buffering properties of NaHCO_3 . However, sodium amount had to be finely controlled because an overload could easily cause gastrointestinal distress (metabolic alkalosis) [18]. Alkaline mineral waters might therefore be a valid alternative to sodium bicarbonate because they have no side effects.

The prehydration or hydration protocol with hydrogen-rich water has recently emerged as a new research area. As for the deep ocean water [17,74], hydrogen-rich waters are not NMSWs, but these studies could potentially give a useful contribution to the general understanding of the topic. Molecular hydrogen (H_2) has anti-inflammatory and anti-oxidative properties, especially against ROS and reactive nitrogen species (RNS). Botek et al. (2019) [80] evaluated hydrogen-rich water versus placebo in twelve healthy students showing a reduction in blood lactate and in exercise-induced perception of effort, and a better ventilatory efficiency. It should also be noted that the well-known protective effects of Protein Kinase C ϵ (PKC ϵ) against oxidative stress [81] also prevent joint cartilage chondrocytes from differentiation into an osteoarthritic phenotype [82]. Thus, these findings could be the basis for an innovative hydration strategy in endurance sports, where it is important to reduce the strain perception. Taken together, data can be summarized as follows: (1) Medium- or high-mineralized water (according to the foreseen sweating) are in general indicated for rehydration. In hot environments, water temperature of 16 °C improves the hydration status of athletes and increases their voluntary water intake. Evidence for athletic performances in cold environments is scanty, likely because sweat loss is not critical [83]; (2) deep-ocean or deep-mineral waters have positive effects on fatigue and oxidative damage during and after performance, improving muscle strength and power; (3) evidence on alkaline and bicarbonate-calcic waters shows their positive effects on the acid-base balance and urine pH. From these evidences and the timeline shown in Figure 2, short-duration sport events should focus on prehydration and post-exercise rehydration (Figure 3, Short-PRE/RE). If athletes can drink during the performance, the better mineral composition of water is the same as prehydration, namely, high magnesium/adequate calcium content. On the contrary, bicarbonates in this phase are not relevant. In the recovery time of short-duration events, like in the prehydration phase of long-duration events, magnesium and calcium water content are equally relevant. Carbonated waters become relevant at the end of performance, because the buffering properties of HCO_3^- are desirable for working muscles and a better management of metabolic end-products. Magnesium and calcium intakes should be however adequate also in long-duration events, trying to keep their levels stable during and after performance because of their role in muscle contraction.

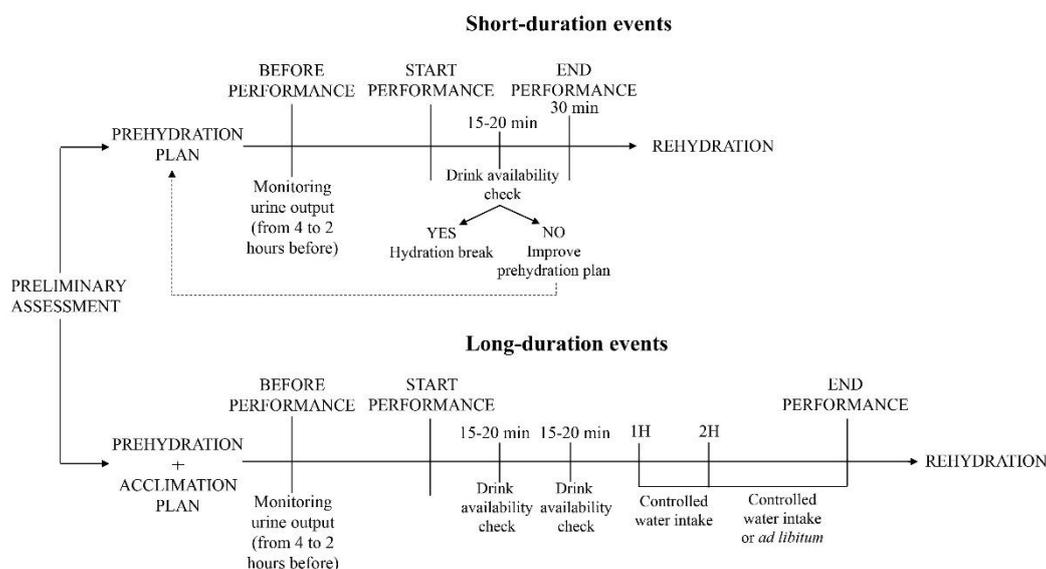


Figure 2. Timelines of hydration status in short- and long-duration events.

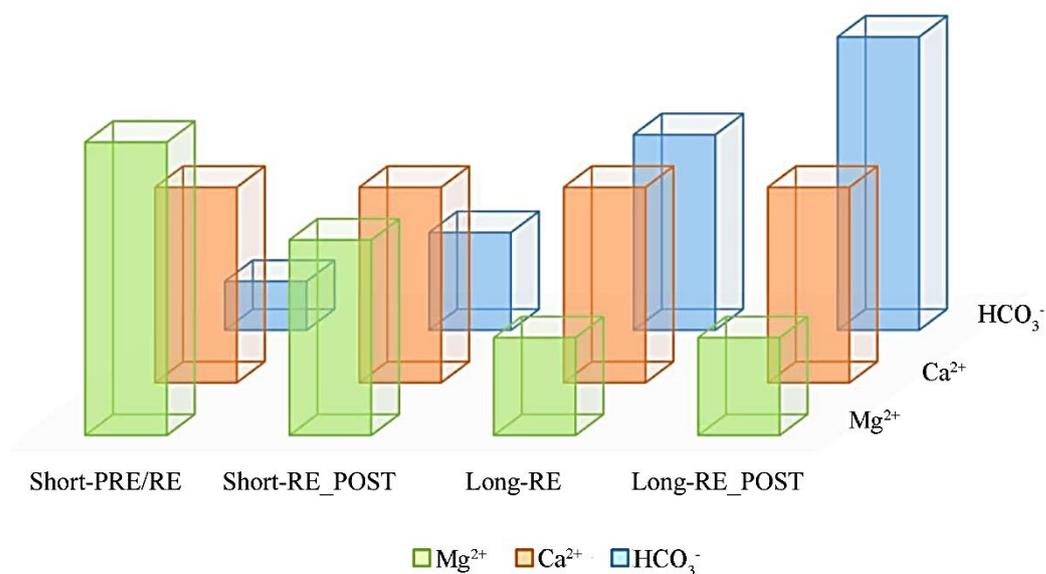


Figure 3. Natural Mineral Spring Waters composition before, during and after short- and long-duration sport events. The relative distribution of magnesium, calcium, and bicarbonate is reported for a qualitative evaluation of the best composition of the waters. Short-PRE/RE = prehydration/rehydration before/during short-duration events; Short-RE_POST = rehydration post-exercise (recovery time) in short-duration events; Long-RE = rehydration during long-duration events; Long-RE_POST = rehydration post-exercise (recovery time) in long-duration events; Mg²⁺ = magnesium; Ca²⁺ = calcium; HCO₃⁻ = bicarbonate.

Spring waters in Italy are classified starting from an historical but currently adopted classification of Marotta and Sica (1933) [84]. Accordingly, spring waters have been classified by (i) temperature at source (cold, up to 20 °C; thermal, higher than 20 °C and, specifically, tepid waters from 20 to 30 °C, warm waters, up to 40 °C; and hot waters, higher than 40 °C); (ii) dry residue at 180 °C (mirroring that of the European Directive [16]); (iii) prevailing anion/s (sodium chloride or saltwater, sulphate, salty-sulphate waters, bicarbonate, bicarbonate-sulphate waters, sulfuric waters, salt-bromine-iodine waters, etc.) [60,61]. As stated above, some of these drinking NMSWs are used under medical prescription for human health. Therefore, assuming that athletes need medium/high-

mineralized spring waters according to intensity, environmental conditions and sweat, it is conceivable to hypothesize that the hydro-chemical composition of NMSW may be the key to optimize the hydration status of the athletes and maximize their performance. In this perspective, some authors have recently investigated the sweat response (electrolyte loss) of team sports athletes [85–88] at different exercise intensities. These preliminary results can be matched with the specific mineral content of spring waters (Table 2) to compare the reported sweat losses in both low-intensity exercise (LIE) and moderate-intensity exercise (MIE). More specifically, chloride and sodium are often mixed in salt waters, and they are generally suggested for high-intensity exercises to counteract the sweating losses. For example, a commercially available water that springs in Tuscany (Italy) is a NMSW used in drinking or hydropinic therapy and its saline concentration (sodium content 114 mmol/L; chloride content 118 mmol/L; potassium content 2 mmol/L) potentially reflects the requested mineral composition to replace the sweat losses. Calcium, when present, can improve the biological properties of natural waters: bicarbonate-calcic water, for example, improves the acid-base balance during and after long-duration events, due to the alkalizing properties of both calcium and bicarbonate. Together with calcium, magnesiatic water can also have a potential role in the pre- and rehydration plan of short-duration events, favouring muscle contraction. There are NMSWs available that contain a mixture of bicarbonate, magnesium, and calcium that might provide for an optimal or duly diluted concentration of electrolytes according to the specific athletes' requirements. Finally, the combination of sulphate with other elements, such as sodium or magnesium, could maximize the effect of these waters [60].

Table 2. Comparisons between sweat electrolytes composition and losses during low- (LIE) and moderate-intensity (MIE) exercises and composition of medium- and high-mineralized natural mineral spring waters (NMSWs).

Sweat Composition			Sweat Losses		NMSWs Composition (mmol/L)
Mineral	Symbol	mmol/L	LIE (mmol/L)	MIE (mmol/L)	
Sodium	Na ⁺	10–90 ^a	32.6 ± 14.3 ^b	52.7 ± 14.6 ^b 31.1 ± 11.7 ^c	Salt waters (sodium content ≥ 8.70; chloride content ≥ 5.64) Sodium-sulphate waters (sodium content ≥ 8.70; sulphate content ≥ 2.08)
Chloride	Cl ⁻	10–90 ^a	29.8 ± 13.6 ^b	52.5 ± 15.6 ^b 31.1 ± 11.7 ^c	Salt waters (sodium content ≥ 8.70; chloride content ≥ 5.64)
Potassium	K ⁺	2–8 ^a	2.6 ± 1 ^b	5 ± 1.5 ^b 4 ± 1.4 ^c	Salt waters (potassium average content 2.60 ^d ; sodium content ≥ 8.70; chloride content ≥ 5.64)
Bicarbonate	HCO ₃ ⁻	0.5–5 ^a	nr	nr	Bicarbonate waters (bicarbonate content ≥ 9.83)
Magnesium	Mg ²⁺	0.02–0.40 ^a	nr	0.1 ± 0 ^c	Magnesiatic waters (magnesium content ≥ 2.06) Magnesium-sulphate waters (magnesium content ≥ 2.06; sulphate content ≥ 2.08)
Calcium	Ca ²⁺	0.2–2 ^a	nr	0.6 ± 0.2 ^c	Bicarbonate-calcic waters (bicarbonate content ≥ 9.83; calcium content ≥ 3.74)

^a Baker et al., 2020 [88]. Data are shown as a range of “minimum-maximum”; ^b Baker et al., 2019 [87]; ^c Kilding et al., 2009 [85]. ^{b,c} Data are shown as “mean ± standard deviation”; “nr” = not reported. “LIE” = low-intensity exercise, ^b 45% of VO₂max; “MIE” = moderate-intensity exercise; ^b 65% of VO₂max; ^c >70% HRmax, sodium lost was estimated as sodium chloride; ^d potassium average content according to the sweat losses; “NMSWs” = natural mineral spring waters, NMSWs composition according to the Directive 2009/54/EC [16] reported in mmol/L.

Further research is unquestionably needed to match fluid and electrolytes loss during exercise with NMSWs composition.

8. Conclusions

It has been established that it is necessary to start exercising optimally hydrated, thus with optimal plasma electrolytes levels, to prevent a body weight loss of 2% or more. However, athletes do not usually follow a prehydration customized plan and likely start performance under uncontrolled hydration conditions. An adequate rehydration plan during and after the performance, customized to the individual sweating rate, beverage availability, exercise duration and intensity, and environmental conditions is necessary as well, to preserve athlete's health and physical fitting. To this end, the presence of electrolytes into the water is essential to compensate fluid loss during exercise. Knowing that a matching of natural mineral water categories with athletes hydration needs had never been attempted, the aim of this review was to seek if existing scientific literature in these two fields could—at least in principle—allow this operation, thus opening, in our opinion, a new field of investigation.

NMSWs are a natural source of water-dissolved minerals that can optimize both pre- and rehydration needs of athletes. Although this topic deserves a higher scientific attention, available literature supports the idea that specifically chosen NMSWs can integrate athlete's diet replenishing sport-related fluid and electrolyte deficits. Magnesium waters optimize anaerobic performances, favouring muscle strength and power in response to load effort; bicarbonate and/or alkaline waters optimize endurance sports (running, cycling, long-distance and long-duration events, etc.), where the performance is strongly dependent on efficient control of pH levels and fatigue. The presence of calcium ions in both magnesium and bicarbonate waters favours muscle contraction, while sodium content should be accurately controlled, according to the individual needs.

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