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EVALUATING THE IMPACT OF INNOVATIVE HYDRATION TECHNOLOGIES ON ATHLETE PERFORMANCE: A SYSTEMATIC REVIEW OF ALKALINE WATER EFFICACY

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ABSTRACT

Background. Alkaline water often above pH 7 with a defined mineral profile is introduced to athletes as a means of hydration and recovery. The claims include increases in acid–base balance, the markers of hydration and performance. However, empirical evidence is mixed.
Aim. To integrate the human evidence around the effects of alkaline water intake on hydration status, acid–base balance and athletic performance, and to contextualize the claims against sports nutrition protocols.
Material and methods. A review of the literature was conducted to search for studies related to impacts of alkaline water on hydration, acid–base balance, and exercise performance. The search of the databases PubMed, Scopus, and Google Scholar was conducted for papers published between 2010 and 2025 with the following words: "alkaline water", "electrolyzed water", "hydration", "acid–base balance", "exercise", "athletes", and "performance". Only human interventional or controlled studies were included.
Results. Consistently, alkaline water elevated urine pH and reduced urine specific gravity, sometimes decreasing blood viscosity upon rehydration [1]. However, results for systemic hydration markers (e.g., plasma osmolality, body mass restoration) were varied [1–4,7,8,10]. Only minor, inconsistent improvements were noted in acid–base markers (e.g., bicarbonate) and certain anaerobic performance metrics; these gains were limited to small, short-term trials [1,2,7]. Many studies found no performance advantage over neutral water or standard sports drinks [4,8,10].
Conclusions. Alkaline water is safe and consistently induces urinary alkalinization and modulates acid–base markers. However, its superiority over traditional hydration practices remains unproven. Future research requires well-powered, blinded RCTs with standardized water composition and athletic outcomes. Practical guidance should view alkaline water as an optional preference, not a replacement, for established hydration protocols [6].

KEYWORDS

Alkaline Water, Hydration, Acid–Base Balance, Athletes, Performance, Recovery

CITATION

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1. Introduction

Hydration and acid–base homeostasis: fundamental determinants of exercise capacity, thermoregulation and recovery. Mild dehydration (~1–2% body mass loss) or dehydration will impair cardiovascular efficiency and the ability to reason, just as intensity will increase hydrogen-ion accumulation and stress the body's buffers. Such constraints spur the pursuit of nutritional strategies for sustaining performance under high physiological load. Alkaline water—pH > 7 derived from mineral enrichment or electrolysis—has been promoted as an ergogenic assist. Suggested benefits are enhanced rehydration, lessening of exercise-induced acidosis, and less oxidative stress. Yet the empirical basis for this is mixed; in controlled trials in athletes and active adults favorable changes in urinary markers have been found, and in some cases blood rheology or anaerobic parameters may be assessed as well. In other cases there are no material differences to show over neutral water or standard sports drinks [1–4,7,8,10]. Given the popularity of alkaline water amongst athletes and practitioners, synthesis is warranted: there is much need for an evidence-based, critically done survey. This review evaluates relevant human investigations of alkaline water, hydration status, acid–base balance and performance/recovery and provides a comparison of findings against consensus recommendations in sports nutrition [6]. Recent reviews also emphasise the critical role of hydration and nutrition in injury prevention and recovery in athletic populations [31] and point to electrolyte imbalances as a key factor in athlete health and performance [32]. Similar perspectives are discussed in the broader context of sports education and performance optimization [33,34].

2. Physiological Background

Hydration and acid–base balance are closely related and interrelated systems involved in cardiovascular, thermoregulatory, and musculo-performance and muscular training processes during exercise. In general, even mild dehydration (1–2% body mass loss) causes a decrease in plasma volume, cardiac output and blood circulation to the skin, limiting heat and oxygen transfer [14, 16, 30]. Hydrogen ions will collect in exercising muscles and lower intracellular and blood pH. Bicarbonate–carbonic acid system, to some degree phosphate and protein buffers buffer these changes [17, 18]. Alkaline water has bicarbonate, magnesium, calcium and other cations which could affect the systemic buffering and renal acid excretion [1,2,5]. A mineral composition rich in bicarbonate (≥ 300 mg/L) may inhibit/mitigate metabolic acids, thereby prolonging recovery from exercise (high-intensity). At least on a smaller scale, this mechanism mimics the ergogenic effect of sodium bicarbonate supplementation, which delays fatigue and increases tolerance to metabolic acidosis in anaerobic efforts [17, 18]. Hydration status impacts oxidative stress and inflammation as well. Hypohydration increases production of reactive oxygen species (ROS), decreases the bioavailability of nitric oxide and increases proinflammatory cytokines [25]. Preliminary analyses show that the stress responses of the water with an alkaline-reduced or electrolyzed water can be reduced by the inclusion of hydrogen-rich products or enhanced acid-base buffering [7, 8, 10]. The physiological potential of water as a buffer for alkaline fluids may result from all three activities: effect upon fluid balance, redox homeostasis and buffering capacity.

3. Mechanistic Considerations: Metabolic and Cellular Pathways

When the muscles respond vigorously, glycolysis in the anaerobic mode enhances the production of lactate and H^+. The depressed intracellular pH blocks critical glycolytic enzymes (phosphofructokinase and lactate dehydrogenase), decreases the calcium sensitivity of contractile proteins and impacts muscle excitability through altered Na^+/K^+-ATPase activities. Increased systemic bicarbonate and base in the form of alkaline mineral supply can have beneficial effects on the extracellular buffering and preserve the transmembrane gradients that are highly conserved for action potential propagation [1, 2, 5]. Some high-hydrogen and magnesium containing alkaline waters also have antioxidant properties and may influence oxidative stress markers such as malondialdehyde (MDA) and superoxide dismutase (SOD) [7, 8]. Alkaline water with high amounts of hydrogen may also down-regulate NF-κB and Nrf2 pathways to decrease inflammatory signaling, all the while mitochondrial function and ATP can be preserved [7, 8, 10, 25]. In regards with dehydration, improvements in blood viscosity observed by Weidman et al. [3] propose increased erythrocyte deformability and microvascular perfusion, which indirectly aid in recovery. These small effects explain the marginal performance gains seen in a few small RCTs; and they give a reasonable biological rationale for these marginal improvements.

4.Oxidative Stress, Inflammation, and Fatigue Responses

New insights indicate that alkaline-reduced or electrolyzed waters impact redox homeostasis and perceived fatigue during or post-exercise. In healthy young adults, a short-term intake lowered the biomarkers of oxidative stress (e.g., malondialdehyde) and enhanced the antioxidant enzyme activity (e.g., superoxide dismutase), and in turn a concurrent reduction in fatigue ratings [5]. For sustained heat endurance exercise, electrolyzed hydrogen/alkaline water has also been associated with decreased oxidation in exercise [7]. In other samples, combined lifestyle interventions (alkaline electrolyzed water) may decrease systemic inflammation and oxidative stress in physically active individuals with metabolic disease while clinical reports provide mechanistic support for the possibility of this effect through dissolved hydrogen and mineral-mediated redox effects [9]. From a mechanistic perspective, molecular dissolved hydrogen can serve as an antioxidant and signaling modulator, magnesium and other cation components can affect endothelial function and enzymatic antioxidative defenses [5,9]. However, the duration of interventions is usually a short period of time, its sample sizes small and its water type inhomogeneous, thus, uncertainty regarding the cause and effect mechanisms and the dose-response relationships is limited [5,7–10]. Significantly, declines in oxidative stress do generally not correlate with measurable performance benefits—this finding is consistent with mixed ergogenic findings that have occurred across studies. From a translational point of view, redox and inflammatory markers (e.g., MDA, F2-isoprostanes, SOD, glutathione, CRP) should also be used, in combination with standardized hydration, acid-base, microcirculatory, cognitive, and performance measures, to ascertain whether biochemical modifications provide a functional benefit [5–8,25]. As chronic low water consumption, oxidative stress, and change in immune response are associated [25], future studies might also evaluate baseline hydration practices and dietary acid consumption as potential covariates.

5. Cognitive and Psychomotor Aspects of Hydration

More than performance, fluid balance can affect cognition and psychomotor performance. Indeed, a 1–2% loss of body water can adversely affect one's ability to focus attention, make decisions, and process information – attributes fundamental to complex sports [14, 16]. Steffl et al. [8] showed that three days of high-mineral alkaline water did provide an improvement in post-exercise reaction time over placebo and can perhaps be attributed to better rehydration or less central fatigue. In contrast, Dobashi et al. [4] reported no significant advantage of alkaline carbohydrate-electrolyte water for repeated sprints during heat stress, and thus it is likely that any of the cognitive or neuromotor benefits of the water was context-specific. The increase in cerebral perfusion (and consequent decrease in blood viscosity) is potentially mediated by hydration as Weidman et al have indicated [3]. Acid–base balance regulation could also favor neurotransmitter metabolism, especially glutamate–GABA balance, though this phenomenon is speculative. Current evidence, though limited, strongly suggests that optimal hydration irrespective of fluid pH affects psychomotor performance in participants, alkaline water can make only a minor contribution under heat or fatigue stress.

6. Composition and Standardization of Alkaline Waters

Even though the suggestion that alkaline water increases urinary pH is often documented, its interpretation of these biochemical effects into performance improvement presumably relies on water properties and standardization. Interventions differ (pH ≈ 8.0–10.5), amount of bicarbonate, proportion of total mineralization, and product mineral or electrolyzed/hydrogen-rich, which may complicate comparisons and explain diverse effects on systemic hydration, acid-base indices, and exercise performance. Physiologically, bicarbonate and sodium have the most influence on buffering ability and fluid retention and magnesium and calcium on neuromuscular function and vascular tone. Sports nutrition position statements highlight that the timing, volume and electrolyte profile of fluids, are key factors in determining hydration efficacy [14,16,23,29]. Ultimately the point from a practical perspective is to evaluate alkaline water via its mineral profile in relation to sweat sodium losses and its dietary acid load with respect to fluid retention. Water higher in bicarbonate can provide a little extra extracellular buffering during high-intensity work, but the evidence suggests that it is a small effect in respect of standardized sodium bicarbonate supplementation protocols [17,28,18,19]. On the other hand in case of low sodium, the low salt alkaline properties alone may not compensate for electrolyte loss during long, hot period exercise. From educational and clinical viewpoints, findings emphasize electrolyte balance and athlete behaviours as being the main sources of influence: a sustained sodium or magnesium imbalance might compromise readiness and recovery [32], hydration knowledge, preferences, and palatability influence voluntary drinking and real life outcomes [33,34]. In doing so, alkaline water also can be framed as a second line of treatment, available to athletes for taste and stomach tolerance (especially for athletes that cannot tolerate sodium bicarbonate), by acknowledging that pH or redox characteristics will not replace evidence-based hydration regimes. It is necessary to propose minimum reporting standards for future trials to include, pH (method), bicarbonate (mg/L), $Na^+/K^+/Mg^{2+}/Ca^{2+}$ (mg/L), total dissolved solids, redox potential (for electrolyzed products), and dose ($Lday^{-1}$) and duration of intervention. Blinding, habitual dietary acid load, and sex-specific analyses ought to be uniformly logged. Standardisation of this data would establish whether specific composition thresholds correlate to reproducible differences in acid–base regulation, microcirculatory indices, cognition, or performance.

7. Gastrointestinal Tolerance and Compliance Considerations

Sodium bicarbonate supplementation is a powerful extracellular buffer but can be constrained by gastrointestinal intolerance [17–19]. Alkaline mineral waters provide mild alkalinizing effects and are generally well tolerated; prolonged consumption has been associated with improved gastrointestinal symptoms in non-athletic cohorts [10]. For athletes who may not tolerate bicarbonate but want some buffering support at high-intensity exercise, alkaline water can be used as a pragmatic, low-risk adjunct, acknowledging that its effects are weaker and should not replace evidence-based electrolyte strategies [17–19].

8. Oral Health and Beverage Choice in Athletes

Acidic sports and energy drinks contribute to dental erosion, a practical concern in athletes who sip frequently during training [20–22]. Alkaline waters have not been tested directly for dental outcomes, but replacing an erosive beverage during a training session with a neutral or mildly alkaline water can minimize acid exposure to the dental tissues. Oral health should therefore be considered when developing an overall hydration program in concert with performance and recovery goals [20–22].

9. Evidence Quality

The evidence is limited overall by methodological limits that weaken confidence in any ergogenic claims. The majority of trials included small samples and short interventions which add to the imprecision and restrict the scope for small effects [3,2,7,6]. The randomization and allocation concealment were rarely described in detail. Blinding was often hindered by recognisable taste or labeling of products, posing performance and detection bias risks [3,6]. Cross-over designs were highly efficient, but some studies found inadequate washout or did not verify return to baseline acid–base state before the next interval [5,4]. Indirectness is substantial. Alkaline water is not a homogeneous exposure with diverse compositions of products in pH, buffer, minerals content (e.g. bicarbonate, sodium, calcium, magnesium), total dissolved solids, and sometimes dissolved hydrogen [3,7,5]. From acute pre-exercise doses to low daily volumes in chronic doses, the timing in relation to training was often erratic. Participant demographics were also different (training- versus recreational-based, mixed sports, variable-heat stress) and so were performance testing (time-to-exhaustion, time-trials, sprint testing) and hydration endpoints (urine pH/specific gravity vs blood acid-base panels) [2,30]. This heterogeneity decreases comparability and is an important cause of mixed results. There is inconsistency, across results. Urinary alkalinization is a strong, repeatable effect, and its implementation into systemic acid–base gradients during or after exercise is imprecise and often slight [6,5]. Performance findings demonstrate mixed outcomes with wide confidence intervals; at best, the beneficial effects were small and not replicated across different protocols [4,5]. Both perceptual recovery and GI tolerance were at times greater for alkaline or mineral waters, although the extent was limited and subject also to expectation effects in inadequately blinded settings [3,6]. Imprecision is certainly the main drawback. Most studies were powered for biochemical surrogates, not performance, hence wide intervals for the functional endpoints. Few trials reported a priori sample-size calculations and attrition – frequently related to GI complaints or scheduling – increased the uncertainty [3,6]. Dose-response evidence is limited, there are no consistent gradients that relate the degree of water pH or bicarbonates to either physiological or performance effects within the study time-to-response range [7,5]. There could be no exclusion from the selection effect of reporting, and publication bias. Pre-registration and trial protocol availability was infrequent, and negative or null findings may be downplayed. Some products, or associations with a brand or industry, were considered, but the materials were not presented in detail (e.g., specific buffering capacity, strong-ion difference). With hydrogen-based alkaline water, possible antioxidant effects blur the conclusion of alkalinity in itself [7,5]. In combination through a GRADE-like lens, it is moderate for urinary pH change [3,2], low for blood acid–base modulation [6,5], and low to very low for performance effects [4,5], as well as perceptual recovery. Safety signs are usually encouraging for short-term use; GI tolerance depends on patient/formulation [3]. Larger, preregistered, well-blinded trials measuring standardized exposures with appropriate outcomes are needed to modify estimates and allow for meta-analysis; in a contextual comparator, high-dose sodium bicarbonate exerts clearer albeit tolerance-limited effects [17,28].

10. Discussion

Major results for each of the trials that were synthesized, alkaline or mineralized water consistently enhances urinary pH; but its effect on systemic acid–base balance is intermittent and generally minor during or immediately following exercise. Over heterogeneous protocols no stable ergogenic effect can be observed in endurance or high-intensity performance. Advantages on subjective self-assessment or GI comfort are sometimes observed, but they are limited and product-based with associated blinding [4,5]. Mechanistic context. Classical ergogenic benefits of sodium bicarbonate depend on providing a sufficiently high extracellular buffer to increase H^+ efflux during severe attempts [17,28]. In contrast, the majority of "alkaline waters" are relatively "low-buffering," and noted urinary alkalinization is more indicative of renal handling than of a durable extracellular reserve that can alter intramuscular pH following exercise [3,2]. Differences in mineral composition (bicarbonate, sodium, calcium/magnesium) can affect strong-ion difference, gastric emptying, and palatability but such effect sizes are small and readily counterbalanced by differences in training status, environmental heat and availability of carbohydrates. How results vary between studies. Much of the inconsistency is the result from exposure heterogeneity (pH, buffering capacity, total dissolved solids), timing and dose (acute pre-exercise bolus vs chronic daily intake), and from which tests to use (surrogates versus sport-specific performance) [7,5]. Small participants increase random error and the suboptimal blinding promotes expectancy effects [3,6], which tend to become very real—especially for perceptual measurements [3,6]. Underlying the effect on acid–base responses in addition there is also a possible background diet (bicarbonate salts, fruit/vegetable consumption or salt in diet and sodium balance, which also modulates acid–base responses while also masking the water effects [30]. Relationship to broader literature. The trend accords with general hydration and ergogenic guidance: (i) fluid volume and sodium are major factors in plasma-volume retention and heat performance [14,16]; (ii) high-dose sodium bicarbonate is useful in certain high-intensity tasks where it is tolerated [17,28]; (iii) low-dose alkalinity in most of the bottled water products rarely exceeds physiologically significant systemic limits [3,2]. Modern scientific consensus work on supplements also suggests that claims should be made cautiously, including not overstating the claims, in the absence of high certainty evidence [15]. Practical interpretation. Alkaline or mineralized water in an athletic setting can be a low-calorie, relatively low-risk, option in supporting overall fluid adherence and may be ideal for persons who dislike acid sports drinks or are intolerant of oral bicarbonate preparations. However, it must not be marketed as a standalone ergogenic benefit. Total fluid availability, appropriate sodium and carbohydrate strategies, and individualized GI tolerance should be the focus of programming. The sports-nutrition frameworks are still the ground on which practice is grounded [29,23,14,16]. Generalizability: Most participants in the included studies were healthy adults with various training backgrounds. Few studies studied elite competition demands or long mesocycles. Extension to prolonged stage races, to different tournament platforms and to female-specific considerations is tentative. The control of environmental stressors (heat, altitude) was not consistent, and the relationship among alkalinity and subsequent heat adaptability was poorly studied [6,5].

Our synthesis is limited by the evidence base at-large: small, brief and fragmentary trials with infrequent preregistration and insufficient materials reporting. We also did not conduct a quantitative meta-analysis, due to heterogeneity of exposures and outcomes so effects are qualitative and conservative. Several studies may be missing from the literature or may be excluded from the database and analysis if language or data was incomplete; moreover, we also did not get hold of authors if evidence was missing (which could cause biased opinion to prevail). Advancement could be driven by preregistered, properly powered RCTs that (i) standardize the exposure (report pH, bicarbonate concentration, strong-ion difference, buffering capacity), (ii) target individual use cases (e.g. repeated sprint ability vs sustained endurance in heat), (iii) predefine clinical outcomes (sport performance with blinded perceptual scales), and (iv) longer interventions that might demonstrate behavior benefits (adherence, GI comfort) that are beyond the reach of acid–base physiology [17,28]; alignment with athlete-health recommendations is also advocated [24]. Summary. At present, there is evidence to support urinary alkalinization but no consistent effect on performance. Potential benefits are probably indirect—through palatability, adherence or GI comfort—and role of formulation and circumstance [3,5].

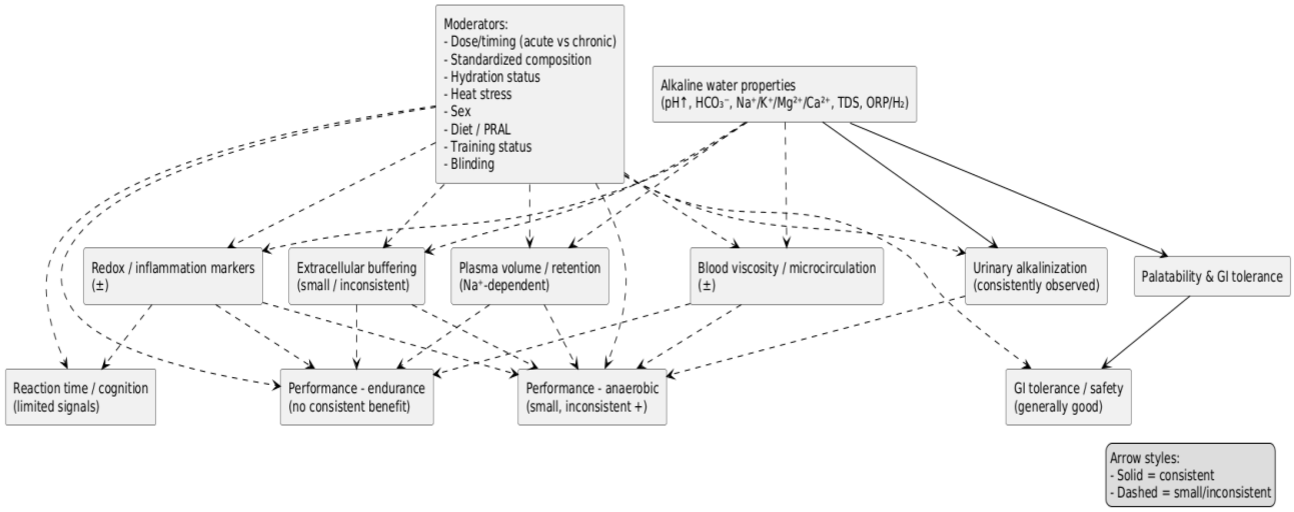

Fig. 1. *Conceptual logic model linking alkaline water properties to physiological mediators and exercise outcomes. Solid arrows denote consistent findings, dashed arrows denote small or inconsistent effects. Moderators include dose/timing, standardized composition, hydration status, heat stress, sex, diet/PRAL, training status, and blinding.*

11. Practical Applications

From the perspective of sports nutrition that is applied practice, athletes may find alkaline water to be a neutral or very beneficial water option for a liquid drink with moderate energy content and minor alkali effects. It can be safely used as a tool for daily hydration, even when in recovery or when exposed to heat, but certainly should not be used as an alternative choice to the evidence-based electrolyte compounds in long endurance events. It may have the following most useful tasks:

- Assisting acid–base restoration between fast bouts (combat match, sprints etc.).
- Improving the perception of subjective recovery by taste and buffering.
- Offering a low-risk substitute for athletes with gastric intolerance of bicarbonate supplementation.

However, there has not been yet any significant evidence of superiority versus standard mineral or isotonic waters. Coaches and practitioners should critically apply market-driven marketing claims and make sure to interpret marketing messages and hydration recommendations that are consistent with ACSM and IOC recommendations for hydration advice on the basis of appropriate guidelines [6, 15, 24].

From an applied perspective, athletes and coaches ought to take a balanced approach. When it comes to timing, amount, and electrolyte composition of fluids remain important in performance hydration. One of those adjuncts could be alkaline water during high-intensity training blocks, heat exposure, or for athletes who experience gastrointestinal discomfort with traditional buffering agents like sodium bicarbonate. From a sports medicine standpoint, promoting regular fluid intake, regardless of its pH, remains the most evidence-based recommendation. Hydration strategies should be determined by preference, taste, and gastrointestinal tolerance. Adequate hydration in the rehabilitation and post-injury period not only contributes to metabolic recovery but also to tissue healing, as evidenced by recent studies showing that good fluid balance can be associated with collagen synthesis and inflammatory modulation. On the educational side, the trend of consuming alkaline water also demonstrates the importance of improved communication with athletes, nutritionists, and sports scientists. Realizing performance is less about the specific water type and more about consistency and overall hydration might deter misinformation and optimize training recovery practices.

12. Conclusions

Human studies on alkaline water demonstrate an overall elevation of urinary pH with minor increases in systemic bicarbonate concentration, but the biochemical effects are small and vary across studies. Though the alkalinizing effect is well established, the physiological importance of these effects for improving performance are unclear. In terms of exercise outcome measures, short-term anaerobic or repeated-sprint activities show evidence of improvement, with no major effect on endurance performance, maximal oxygen uptake, or time to exhaustion. Such benefit, as suggested by the data, is context-specific, and likely affected by hydration status, mineral composition, and individual variability in acid–base regulation. From a hydration and recovery aspect, alkaline water has similar action and properties as standard mineral or isotonic fluids. Some studies suggest potential microcirculatory benefits, including lower blood viscosity and higher erythrocyte deformability, but the findings need to be confirmed in larger randomized trials. Similarly, preliminary evidence about cognitive and psychomotor recovery, particularly of reaction time changes following fatigue remains lacking to say whether they're causal. In the literature, we consistently find alkaline water to be safe and well tolerated with no adverse effects recorded. Taking this profile into account, it appears to be a safe complementary hydration option for athletes with mild buffering effects in response to supplementation with sodium bicarbonate. However, its superiority to traditional sports drinks, or neutral mineral water, has not been verified. Alkaline water should be regarded as an option, not as a substitute for hydration protocols established by the American College of Sports Medicine (ACSM) and the International Olympic Committee (IOC), which are evidence-based. Future research should use well-powered, blinded randomized controlled trials using standardized water composition, including both male and female participants, and measure real-world athletic and cognitive outcomes.

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