



Effectiveness of Programmed and Non-Programmed Rehydration Protocols on Athletes: A Systematic Review

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ABSTRACT

Optimizing an athlete performance requires an effective hydration management to maintain the fluid-electrolyte balance. This systematic review analysed the comparative effectiveness of programmed (based on individual physiology) and non-programmed (relying on thirst and subjective cues) rehydration protocols on athletic performance, physiological responses, and safety. A systematic literature search using the PICOS framework was conducted through Scopus, PubMed, and Web of Science databases within the last decade. Selection criteria included RCTs design with English full-text availability following PRISMA guidelines. Systematic deduplication yielded 364 articles for title and abstract screening. The review encompassed 86 trained athletes aged 20-30 years. Programmed rehydration showed a consistent superiority in maintaining fluid-electrolyte homeostasis. PVO protocol limited body fluid loss to 1%-1.3% compared to ad libitum approaches reaching 2.9% loss. The PHP method enhanced power output (+2.13 inches jump performance) and superior neurocognitive function compared to the normal hydration. The PFI strategy yielded a superior power output (278±41W) and fatigue prevention. Optimal strategy selections depend on the competition level, environmental conditions, exercise durations, and resource availability. While programmed approaches benefit elite athletes in high-risk scenarios, non-programmed strategies remain practical for recreational athletes or a routine training with adequate fluid access. Individualized hydration management is essential as there is no universal solution to optimize performance across all contexts and individuals.

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INTRODUCTION

Proper hydration management is an essential component in optimizing athletic performance, particularly under environmental stress. Physical exercise causes rapid increases in the core temperature (Fernández et al., 2022) and fluid and electrolyte loss through sweating (Amstrong, 2021). Environmental variables and exercise intensities contribute significantly to sweat rates (Barnes et al., 2019; Périard et al., 2021) that they potentially increase fluid and electrolyte depletions (Smith et al., 2021).

Body mass reduction $\geq 2\%$ negatively impacts the muscle strength, including decreased muscle strength up to 2%, reduced muscle power output up to 3%, and impaired high-intensity endurance performance up to 10% (Armstrong et al., 2025; Collins et al., 2021). Furthermore, a mild dehydration has adverse consequences on neurocognitive functions, metabolic processes, and homeostatic stability (Amstrong, 2021; Dube et al., 2022). Conversely, overhydration can cause hyponatremia and gastrointestinal disturbances (Jardine et al., 2023).

This phenomenon underscores the importance of implementing appropriate rehydration during training and competition periods. Several sport organizations, including the American College of Sports Medicine (ACSM), International Olympic Committee (IOC), and Sports Dietitians Australia, have consistent statements regarding inter-individual variability in fluid requirements, sweat rates, and electrolyte losses among athletes (McCubbin et al., 2020; Racinais et al., 2022; Sawka et al., 2007). Implementations of effective hydration protocols must be able to compensate for fluid and sodium losses in athletes.

Fluid consumption practices have become a focus of contemporary discussion in the scientific literature (Amstrong, 2021; Kenefick, 2018; Rowlands et al., 2022). Several studies have evaluated rehydration strategies based on physiological principles aimed at maintaining body fluid homeostasis through structured and predictable methodologies, including Drinking to Weight Loss (DWL), Individualized Fluid Plan (IFP), Pre-exercise Fluid Intake (PFI), and Planned Hydration Protocol (PHP) (Amstrong, 2021; Emerson et al., 2017; Jeker et al., 2022; Kenefick, 2018; Li et al., 2024). Several other studies have also evaluated rehydration strategies based on regulatory mechanisms that control thirst sensation and individual athlete preferences, including Drinking Ad Libitum (DAL) and Thirst-Driven Fluid Intake (TDFI) (Amstrong, 2021; Armstrong et al., 2020; Funnell et al., 2023; Goulet et al., 2023).

The literature shows diverse results, where some studies support the superiority of strategies with structured and predictable methodologies (Ayotte & Corcoran, 2018; de Melo-Marins et al., 2018; Jeker et al., 2022; Li et al., 2024), while others highlight the effectiveness of spontaneous approaches under certain conditions (Funnell et al., 2023; Goulet et al., 2023; Perreault-Briere et al., 2019). Inter-individual variability, training conditions, and methodological differences are major factors contributing to different findings. Scientific evidence on optimal hydration strategies remains inconclusive due to conflicting findings between structured physiological protocols and self-regulation approaches.

The lack of a systematic synthesis comparing these two fundamental approaches hinders evidence-based decision-making. Therefore, this systematic review aims to systematically analyze the comparative effectiveness of programmed versus non-programmed hydration strategies on athletic performance, physiological responses, and safety profiles, thereby providing evidence-based guidance for optimal hydration managements in athletes.

METHODS**Database Search Strategy**

This systematic review follows the PRISMA (Preferred Reporting Items for Systematic Reviews and Meta-analyses) guidelines. It conducts a structured literature search in Scopus, PubMed, and Web of Science within the last 10 years. The search methodology employs the PICOS (Population, Intervention, Comparator, Outcomes, and Study design) framework (Table 1), utilizing MeSH keywords such as individual fluid plan, rehydration plan, drink ad libitum, normal hydration plan, athletic performance, hydration status, cognitive function, and gastrointestinal manifestations. The database search strategy using MeSH keywords is displayed in Table 2.

Table 1. The PICOS Framework

The PICOS Components	Explanation
Population	Trained athletes
Intervention	Programmed rehydration, including programmed fluid intakes, individual fluid plans, and rehydration plans
Comparator	Non-programmed rehydration, including drink ad libitum and a normal hydration plan
Outcomes	Effectiveness of rehydration applications on hydration status, athletic performance, neurocognitive functions, gastrointestinal manifestations, and body fluid homeostasis
Study Design	Randomized Controlled Trial design

Table 2. The Database Search Strategy Using MeSH Keywords

MeSH Keywords in Database	Identified Studies	Studies After Deduplication
Scopus Athletes AND (“Individual Fluid Plan” OR “Rehydration Plan”) AND (“drink ad libitum” OR “normal hydration Plan”) AND (“Athletic Performance” OR “Hydration Status” OR “Cognitive Function” OR “Gastrointestinal Manifestations”)	282	213
PubMed Athletes AND (“Individual Fluid Plan” OR “Rehydration Plan”) AND (“drink ad libitum” OR “normal hydration Plan”) AND (“Athletic Performance” OR “Hydration Status” OR “Cognitive Function” OR “Gastrointestinal Manifestations”)	169	112
Web of Science Athletes AND (“Individual Fluid Plan” OR “Rehydration Plan”) AND (“drink ad libitum” OR “normal hydration Plan”) AND (“Athletic Performance” OR “Hydration Status” OR “Cognitive Function” OR “Gastrointestinal Manifestations”)	51	39

Article Selection Process

Predetermined inclusion criteria encompassed: limited to studies with Randomized Controlled Trial design that are accessible as full-text in English, trained athlete populations, oral fluid replacement interventions, exercise protocols lasting a minimum of 30 minutes, exercise-induced dehydration protocols, and quantitative assessment of intervention effects on hydration status, athletic performance, neurocognitive functions, gastrointestinal manifestations, and body fluid homeostasis. Studies were excluded if they had uncontrolled environmental conditions, used diuretics for dehydration inductions, or assessed hydration status with urine colour scales.

The systematic search conducted following PRISMA guidelines is illustrated in Figure 1. Initial database deduplication procedures were applied before the systematic title and abstract screening stage. Articles presenting narrative reviews, using non-experimental designs, or investigating non-athlete populations were eliminated during the abstract screening stage. Study eligibility was confirmed through a comprehensive, full-text, and methodological assessment. After applying strict eligibility requirements, seven articles were selected for the final qualitative synthesis and analysis.

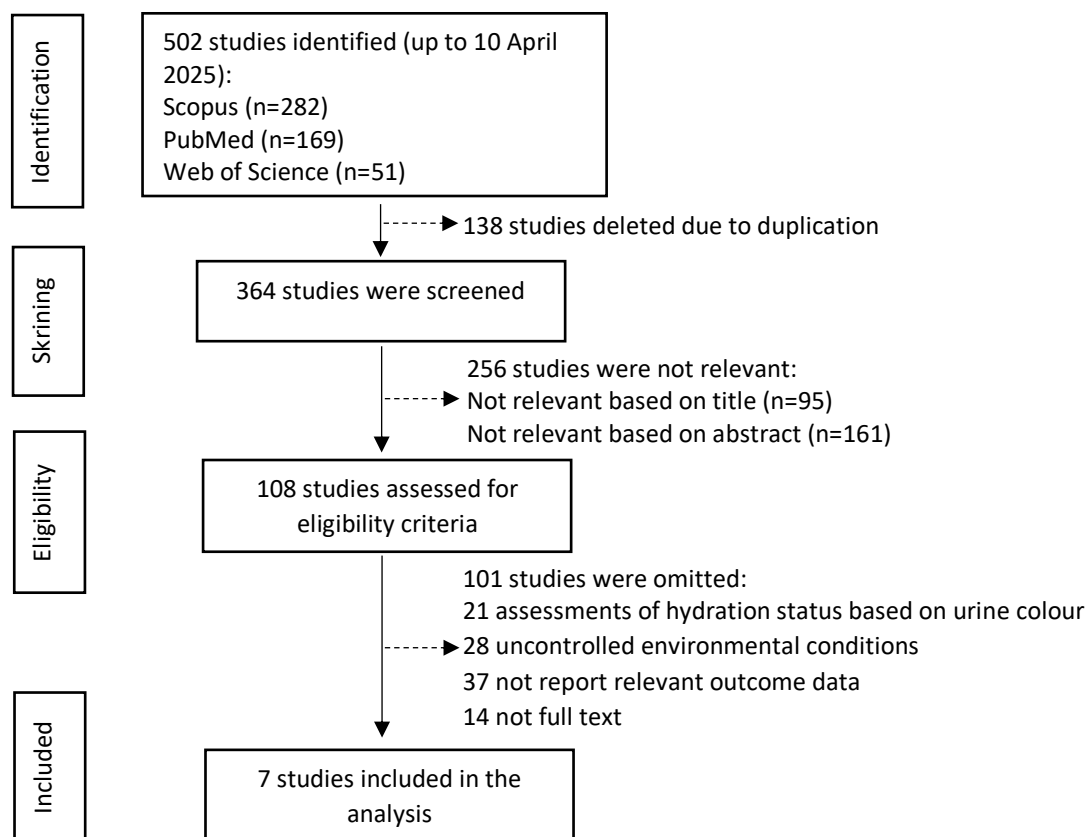


Figure 1. Study Selection Flowchart

RESULTS

Study Characteristics

The systematic deduplication process resulted in 364 studies to be screened based on the title and abstract (Figure 1). Based on the eligibility assessment of 108 publications, seven studies were found to meet the inclusion criteria for analysis. These studies examined hydration strategies in trained athletes published between 2017-2023 (see Table 3). All

studies used a *randomized, crossover, and counterbalanced* design. Geographically, three studies originated from the United States, two from Brazil, and two from Canada.

Research Sample Characteristics

Analysis of seven studies involved a total of 86 trained athletes (80.2% male; 19.8% female) aged 20-30 years. The research population included various sports disciplines, namely ice hockey players, cross-country runners, endurance athletes, collegiate athletes, and recreational cyclists. Exercise protocols included sport-specific activities, cycling, and running, with the moderate to high intensity lasting for 45 minutes to 5 hours. Environmental conditions showed ambient temperature variations of 8-34°C and relative humidity of 35-72.5%.

Effectiveness of The Programmed Rehydration

The programmed rehydration protocol integrates individual characteristics into personalized rehydration protocols. The rehydration implementation is adapted to physiological characteristics, health status, type of activity, and environmental conditions (Rollo *et al.*, 2021; Suarez-Ortegón *et al.*, 2024). This review identified five programmed rehydration protocols, including Individual Fluid Plan (IFP), Prescribed Hydration Plan (PHP), Programmed Fluid Intake (PFI), Personalized Volume (PVO), and Drink to Replace Weight Loss (DWL).

Evaluation of the IFP protocol in professional ice hockey athletes yielded contradictory results, where significant increases in fluid and sodium intake failed to produce statistically meaningful improvements in hydration status (Emerson *et al.*, 2017). Conversely, the PVO protocol proved effective in preventing dehydration through a sweat rate-based regimen (3.5 ml/kg every 10 minutes for 30 minutes), minimizing body fluid loss (~1%-1.3%), although its impact on performance capacity was limited (de Melo-Marins *et al.*, 2018).

The PFI approach yielded heterogeneous but predominantly positive results in two different studies. Perreault-Briere *et al.* (2019) applied a sweat rate-based PFI strategy to limit body mass loss to ~0.5%. This strategy proved capable of maintaining performance equivalent to control conditions, although some participants reported mild gastric discomfort (Perreault-Briere *et al.*, 2019). Implementation of PFI by Jeker *et al.* targeting ~1% body weight reduction showed superior endurance training results with significantly higher power output (278±41W) (Jeker *et al.*, 2022). These results indicate PFI effectiveness in preventing fatigue and maintaining exercise intensity.

Similar to the PFI approach, the DWL hydration protocol is also based on the participant body weight reduction. The evaluation of this strategy proved capable of maintaining significantly lower body mass loss ($p < 0.01$), although 30-km cycling time trial completion times remained comparable ($p = 0.13$) (Ferreira *et al.*, 2018). Meanwhile, the PHP strategy showed promising functional performance results through individual protocols based on sweat rate (L/hour) and sodium concentration (mmol/L) (Ayotte and Corcoran, 2018). The study results demonstrated significant improvements in power enhancement (+2.13 inches) and neurocognitive function compared to normal hydration patterns.

Table 3. Study Characteristics

Country, Years	Study Design	Population	Age (Me±SD Years)	Type of Intervention	Protocol of Drink	Exercise Modalities	Environmental Conditions	Outcomes
United States (Emerson et al., 2017)	Randomized Controlled Trial	Professional ice hockey players (21 male athletes)	I: 23,3±2,2 C: 25.5±2.6	I: IFP C: ad libitum	I: Water and E-CEB C: Drink water or Powerade	High-intensity on-ice training sessions in the morning lasting 50-78 minutes	Training was conducted in a cool climate (12.6°C) and covered	IFP group had higher fluid and Na intake, yet hydration status did not significantly improve.
Brazil (Ferreira et al., 2018)	Randomized, Crossover, Controlled Trial	Trained recreational cyclists (11 males)	30.4±6.2	CMR: Carbohydrate mouth rinse, then spit out DWL: Fluid replacement based on familiarization weight loss. DAL: Ad libitum fluid intake	CMR: 25 ml (6.4% maltodextrin) every 10s DWL: Water and electrolyte capsule if loss >2% of body weight DAL: Water (not measured)	30-km stationary cycling time trial (±81–82% HRmax, 54 minutes)	Air-conditioned room with an average temperature of 22.1°C and humidity of 72.5%	All strategies induced mild dehydration. DWL showed greater weight loss than CMR and DAL (p<0.01). Completion times were similar across strategies (p=0.13).
Brazil (de Melo-Marins et al., 2018)	Randomized crossover design	Recreational cyclists (11 males)	30±7	PVO: Drink according to 80% of the individual sweat rate DAL: Ad libitum Control: NFI	Interventions use plain water. PVO: 3.5ml/kg every 10 minutes DAL: Drink from an 800ml bottle as desired NFI: No drinking at all	High-intensity cycling (~85% HR max) for 45 minutes	Room temperature is 34°C with a relative humidity of 40%	PVO prevented dehydration better than DAL/NFI (~1%–1.3% loss), but cycling capacity remained unchanged (±37–38 min; p = 0.801).

United States (Ayotte & Corcoran, 2018)	Randomized cross-over design	Merrimack Collegiate athletes (6 male and 9 female athletes)	20±0.85	PHP: Based on sweat rate (L/h) & sweat [Na ⁺] (mmol/L) NHP: hydration according to individual habits	PHP: Consume water/sports drinks with NaCl every 15 min during exercise NHP: Majority consuming water	Two sessions of Sport-specific training: 45–120 min at ≥75% HRmax	Ambient temperature ±8°C with relative humidity ±37%	PHP increased jump power (+2.13 inches) and enhanced neurocognitive function (focus, spatial awareness, 3D tracking) NHP decreased it (-2.42 inches) and showed no improvement.
Canada (Perreault-Briere et al., 2019)	Randomized, crossover, and counterbalanced	Trained endurance athletes (7 males, 2 females)	30±9	PFI: Programmed drinking to maintain weight loss at around 0.5% TDFI: Drink cold water based on thirst NFI: Without drinking at all	All liquids are cold water (4°C) served in tightly closed bicycle bottles.	An hour of high-intensity cycling time-trial	Room temperature 30°C with humidity 50%	Performance remained similar across all conditions despite varying dehydration levels (NFI 2.9%, TDFI 2.2%, PFI 0.6%). Performance unaffected despite >2% losses in NFI/TDFI. PFI caused minor abdominal discomfort.
Canada (Jeker et al., 2022)	Randomized crossover trial	Well-trained endurance	26±6	PFI: Estimation of fluid requirements	All liquids are cold water (4°C).	5 hours of cycling at moderate	The test environment is	PFI power output is superior to TDFI (278±41W vs.

			athletes, (8 males)		based on body mass loss according to thirst	PFI: Drink every 15 minutes, to limit body mass loss to ≤1%. TDFI: Drink water without a specific body mass target.	intensity (±61% VO ₂ peak), followed by a 20 km time-trial	30°C and 35% humidity.	263±39W), same completion duration (p=0,48). PFI vs. PFI has superior intake, with more optimal fluid balance (1.5±1.0% vs. 2.5±0.9%), although not significant (p=0.10).
United States (Benjamin et al., 2023)	Randomized controlled crossover trial,	NCAA Division I cross country athletes (5 males and 6 females)	20±1	PER: Hydration posts (3.2km intervals), 200m drinking zones. DAL: Personal bottles allowed; course bottles available.	All interventions use plain water. PER: Water is only available at designated posts. DAL: Additional bottles are available along the route if the initial bottle runs out.	10-km runs at moderate intensity in two conditions, separated by ≥1 week.	Average environmental temperature 25.2±1.9°C with relative humidity 42.2±7.7%,	DAL vs. PER consume more fluids (242,7 vs. 111,4 mL), but does not improve GI symptoms. Both maintain optimal hydration.	

DAL: Drink ad libitum; DWL: Drink to replace all weight loss; Elektrolit-enhanced Carbohydrate Electrolyte Beverage (E-CEB); IFP: Individual Fluid Plan; NFI: No Fluid Intake; NHP: Normal Hydration Plan; PFI: Programmed Fluid Intake; PHP: Prescribed Hydration Plan; PVO: Personalized Volume; TDFI: Thirst-Driven Fluid Intake

Similar to the PFI approach, the DWL hydration protocol is also based on the participant body weight reduction. The evaluation of this strategy proved capable of maintaining significantly lower body mass loss ($p < 0.01$), although 30-km cycling *time trial* completion times remained comparable ($p = 0.13$) (Ferreira *et al.*, 2018). Meanwhile, the PHP strategy showed promising functional performance results through individual protocols based on sweat rate (L/hour) and sodium concentration (mmol/L) (Ayotte and Corcoran, 2018). The study results demonstrated significant improvements in *power enhancement* (+2.13 inches) and neurocognitive function compared to normal hydration patterns.

Effectiveness of The Non-Programmed Rehydration

Non-programmed hydration strategies use flexible and intuitive approaches. This systematic review analyzed *Normal Hydration Plan* (NHP), *Drink Ad Libitum* (DAL), and *Thirst-Driven Fluid Intake* (TDFI). NHP represents baseline hydration patterns without specific intervention, which consistently showed inferior results compared to evidence-based strategies, including decreased *jump power* with limited neurocognitive benefits (Ayotte and Corcoran, 2018).

DAL becomes less effective under heat stress to the extent that it can cause significant dehydration and thermoregulatory disturbances (de Melo-Marins *et al.*, 2018; Périard, Eijsvogels, and Daanen, 2021). However, DAL shows efficacy in competitive settings when logistical barriers are removed and athletes have full autonomy (Benjamin *et al.*, 2023; Goulet *et al.*, 2023). Meanwhile, TDFI can be tolerated during the moderate-duration exercise, it often results in suboptimal intake and significant dehydration (Perreault-Briere *et al.*, 2019; Goulet *et al.*, 2023).

DISCUSSION

Among the five programmed rehydration protocols examined, PHP uniquely incorporates a comprehensive analysis of both sweat rate kinetics and sweat sodium concentrations as fundamental parameters for the intervention design. Contemporary hydration assessment methodologies require the systematic integration of plasma osmolality and volume parameters alongside traditional body weight measurements to ensure physiological accuracy (Baker *et al.*, 2022). Unregulated fluid consumption in the absence of electrolyte considerations during extended exercise bouts exceeding four hours may precipitate hyponatremia (Armstrong, 2021), particularly given the pronounced inter-individual heterogeneity observed in sweat sodium concentrations across athletic populations (Baker *et al.*, 2022).

Conversely, non-programmed rehydration approaches, exemplified by ad libitum drinking protocols, facilitate unrestricted fluid consumption patterns governed by individual behavioral preferences and physiological perceptions (Funnell *et al.*, 2023; Goulet *et al.*, 2023). Divergent from TDFI protocols, where consumption patterns are predominantly thirst-mediated, these approaches function through the reliance upon intrinsic osmoregulatory mechanisms as the primary homeostatic control system (Armstrong *et al.*, 2020; Kenefick, 2018). While these approaches demonstrate a contextual adaptability under specific environmental and exercise conditions, their efficacy becomes compromised in physiologically demanding scenarios (Jeker *et al.*, 2022). The variability effectiveness of non-programmed rehydration is related to individual differences in thirst sensitivity, exercise experience, and hydration awareness (Armstrong *et al.*, 2020).

Direct Comparison: Programmed vs Non-Programmed Rehydration

Programmed strategies demonstrate consistent superiority in maintaining fluid-electrolyte homeostasis compared to non-programmed approaches. Interventions such as PVO (de Melo-Marins et al., 2018) and PFI (Jeker et al., 2022) successfully limited body fluid loss between 1%–1.5%, while thirst-driven rehydration, including DAL and TDFI, showed losses up to 2.9%. Although some differences were not statistically significant ($p=0.10$) (Jeker et al., 2022). The main advantage of the programmed hydration lies in its proactive approach to anticipating hypohydration. Conversely, non-programmed strategies rely on thirst mechanisms or individual preferences, which often result in fluid deficits that risk hemoconcentration, dehydration, and physiological stress during exercises (Pařka et al., 2023). These mechanisms are often inadequate for the complete post-exercise rehydration, as fluid consumption tends to stop when thirst subsides, rather than when fluid balance is truly restored (Capitán-Jiménez & Aragón-Vargas, 2022).

In the context of athletic performance, the rehydration implementation shows greater complexity than hydration parameters alone. Programmed strategies such as PHP successfully increased power output and neurocognitive functions significantly (Ayotte & Corcoran, 2018). However, not all hydration strategies show consistent performance advantages. The IFP protocol in professional ice hockey athletes failed to meaningfully improve hydration despite increased fluid and sodium intakes (Emerson et al., 2017). Conversely, non-programmed approaches such as DAL showed surprising adaptive flexibility in competitive contexts. In cross-country runners, DAL was able to maintain optimal hydration (<2% fluid loss) without compromising performance (Benjamin et al., 2023). The ad libitum strategy also proved capable of producing relatively stable fluid intakes, although there were inter-individual variations under uniform hot environmental conditions (Goulet et al., 2023).

Individual characteristics and environmental conditions contribute to the rehydration implementation effectiveness. Programmed strategies show superior consistency across various environmental conditions, as illustrated by PFI efficacy at 30°C with 50% relative humidity (Perreault-Briere et al., 2019) and at 35% humidity (Jeker et al., 2022). Conversely, the effectiveness of non-programmed approaches heavily depends on the individual accuracy in interpreting physiological signals under various environmental conditions. Thirst perception is influenced by non-osmotic factors, including oral and gastric sensations, not just physiological needs (Armstrong et al., 2020). In cold conditions and light activities, thirst does not always emerge despite mild dehydration (Périard et al., 2021), so physiological thirst mechanisms may not adequately compensate for fluid loss. Further analysis indicates programmed strategies tend to be more effective under extreme heat stress conditions, as demonstrated by PVO superiority over DAL at 34°C temperature and 40% humidity (de Melo-Marins et al., 2018).

From a practical implementation perspective, non-programmed strategies offer greater simplicity and accessibility. DAL and TDFI do not require complex physiological measurements, making them more accessible across various athletic levels. However, this simplicity is accompanied by several significant shortcomings, including a high hydration outcome variability and risks of dehydration or hyponatremia (Armstrong, 2021). Conversely, programmed strategies, particularly PHP, which integrates sweat rate analysis and sodium concentration, require laboratory infrastructure and specialized expertise (Ayotte & Corcoran, 2018). Although the implementation demands are substantial, this complexity provides superior precision and result consistency, making it the preferred choice for elite athletes and situations demanding optimal performance under high thermal stress.

In the context of side effects, programmed strategies such as PFI and PVO offer wider safety margins. Adjustments to individual physiology better enable reduced risks of hyponatremia and fluid overload (de Melo-Marins et al., 2018; Perreault-Briere et al., 2019). However, some participants in the PFI implementation study by Perreault-Briere et al. reported mild gastric discomfort, indicating the importance of individual adjustments in practical applications (Perreault-Briere et al., 2019). Conversely, non-programmed strategies are well-tolerated but with higher safety variability. Overly conservative TDFI potentially causes significant dehydration (>2% body mass loss) (Perreault-Briere et al., 2019), while overly liberal DAL risks triggering fluid overloads, particularly in prolonged activities.

CONCLUSION

Programmed hydration strategies consistently demonstrate superiority in terms of precision, predictability, and physiological optimization. However, the selection of the most appropriate approach depends on the context, such as competition levels, climate, exercise durations, and available resources. It is recommended that elite athletes participating in high-risk competitions or extreme environments implement programmed strategies, particularly PHP or PFI. Conversely, for recreational athletes or routine training conditions with adequate fluid access, non-programmed strategies such as DAL can provide practical and effective solutions. These findings emphasize the importance of individual approaches in sport nutrition, where universal solutions are rarely optimal for all situations and individuals.

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AUTHORS' NOTE

The authors declare that there is no conflict of interest regarding the publication of this article. The authors confirmed that the paper was free of plagiarism.

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