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<https://ejournal.upi.edu/index.php/penjas/article/view/66552>DOI: <https://doi.org/10.17509/jpjo.v9i1.66552>**Roles of Carbohydrate-Electrolyte Solutions in Athlete Hydration Status and Performance: A Narrative Review**Ervira Wahyuni^{1*}, Diana Sunardi¹, Bernie Endyarni Medise²¹Department of Nutrition, Faculty of Medicine, Universitas Indonesia, Indonesia²Department of Child Health, Faculty of Medicine, Universitas Indonesia, Indonesia**Article Info***Article History :**Received January 2024**Revised February 2024**Accepted March 2024**Available online April 2024**Keywords :**carbohydrate, dehydration, electrolyte, performance***Abstract**

Dehydration is prevalent among athletes. Dehydration may cause fluid and electrolyte imbalance and impairment of an athlete physical and cognitive performance. Carbohydrate electrolyte solutions (CES) are often used by athletes as a rehydration fluid because it is claimed to have numerous beneficial effects on hydration status and performance. Studies on the use of carbohydrate-electrolyte solutions showed mixed results. Some studies also highlighted the side effects of carbohydrate-electrolyte solutions on gastrointestinal system. This review aimed to summarize the roles of carbohydrate-electrolyte solutions on hydration status and performance of athletes. The literature review was conducted in the narrative type. Database search was conducted using Pubmed Central search engine. The search terms used were "carbohydrate", "electrolyte", "athlete", "hydration", and "performance". The results show that carbohydrate-electrolyte solutions may prevent dehydration and electrolyte disturbance by increasing water absorptions and retentions. The maintenance of hydration status and the ergogenic effect exerted by carbohydrate can also prevent performance deteriorations. The formulation and administration of carbohydrate-electrolyte solutions must be done with caution and be given at the right timing to reduce side effects, primarily the gastrointestinal discomfort.

INTRODUCTION

Dehydration is a process of water loss in the body that can cause hypohydration, a state of lack of body fluid. Dehydration among athletes is prevalent, both in elite and non-elite athletes, young and adult athletes. More than fifty percent of athletes start training hypohydrated and remain in the same state or getting worse after the training (Arnaoutis et al., 2015; Klimesova et al., 2022; Magee et al., 2017). Hypohydration, usually defined as >2% body mass loss, can cause a reduction in the central and peripheral blood flows, thus altering metabolism in the cerebral and musculoskeletal tissues respectively, inducing early fatigue and impacting the athlete physical and cognitive performance (Nuccio et al., 2017; Trangmar et al., 2015; Trangmar & González-Alonso, 2017). Hypohydration, especially in a warm-hot environment, impairs a submaximal aerobic exercise by an additional 1% for every 1°C skin temperature elevation (Sawka et al., 2015). Moreover, hypohydration also causes a decrease in sport-specific skills, such as field goal accuracy (Carvalho et al., 2011) and the total number of shots (Baker, Dougherty, et al., 2007) in team sports. In terms of its effect on cognitive performance, studies reported that hypohydration >2% of body mass loss could impair working memory reaction time (Bandelow et al., 2010), vigilance (Baker, Conroy, et al., 2007), and decision-making time (MacLeod & Sunderland, 2012) of team sport athletes.

Intense and prolonged exercises cause the core body temperature to rise, stimulating the central thermoregulation system in the hypothalamus to increase the sweat production, leading to the loss of body fluid and electrolytes (Trangmar & González-Alonso, 2017). Many forms of carbohydrate-electrolyte solutions sold commercially with highly varied carbohydrate levels are often used by athletes and non-athletes to replace the fluid and electrolyte loss, provide energy, reduce fatigue, and improve performance (Khan et al., 2022). Studies regarding its use among elite athletes showed that 66,7% athletes consumed carbohydrate-electrolyte solutions at least 1-2 times a week (Khan et al., 2022). The same trend is also found in adolescent athletes and non-athlete population (White, 2019). The addition of carbohydrate and electrolyte to water can increase water absorptions and retentions and enhance the solution palatability to increase the voluntary fluid intake, thereby preventing a performance decline due to dehydra-

tion. The carbohydrate formulation may also have an ergogenic effect by restoring the muscle glycogen store (Khan et al., 2022). However, a high carbohydrate concentration in many commercially sold carbohydrate-electrolyte solutions can cause gastrointestinal discomforts (de Oliveira & Burini, 2014), obesity (Muñoz-Urtubia et al., 2023), and other general health effects (Khan et al., 2022) when consumed excessively and at inappropriate times, such as in non-strenuous physical activities, often by recreational athletes or moderate exercisers.

Previous studies have shown that carbohydrate-electrolyte solutions can maintain the fluid balance and improve an athlete performance better than plain water by promoting the net water influx across intestine via sodium-glucose cotransporters and increased osmolality, delaying fatigue by preserving endogenous CHO oxidation and stimulating glycogen resynthesis, especially in prolonged exercises (Fan et al., 2020; Harris et al., 2019; Phillips et al., 2010; Rowlands et al., 2022). Meanwhile, other studies showed opposing results and suggested that the magnitude of its effect on hydration status and performance is influenced by many factors, such as age, gastric emptying rate, and intestinal absorption which are affected by fluid characteristics, fluid administration manners, and physiological changes during the exercise (Schleh & Dumke, 2018). Therefore, to achieve its most beneficial effect on hydration status while minimizing the side effects and maintaining a long term health, several factors need to be considered to ensure the proper use of carbohydrate electrolyte solutions. For this reason, this review aimed to provide a summary of the roles of carbohydrate-electrolyte solutions on an athlete hydration status and performance and the factors affecting the effects.

METHODS

The design used in this study was the literature review using the narrative type. The study began with the formulation of the research question through the author panel meeting. The agreed primary research question was “when is the golden period for the administration of carbohydrate-electrolyte solutions to athletes and how to make its use effective?”. The primary research question was followed by several ancillary questions, including “what is the current prevalence of dehydration among athletes and what are the conse-

quences of the current dehydration prevalence for the athlete performance and general health?”, “what is the current prevalence of carbohydrate-electrolyte solution use among athletes?”, “what is the effect of carbohydrate-electrolyte solutions on the athlete hydration status, performance, and general health?”, “what are the factors influencing the magnitude of the effect of carbohydrate-electrolyte solutions on the athlete hydration status and performance?”, “what is the current best practice of carbohydrate-electrolyte solution administration for athletes?”.

Literatures from peer-reviewed articles, book chapters, reports, and “grey-literature” stored in the database search were included in the study. We excluded literatures related to energy drinks and sports drinks with added ergogenic substances, such as caffeine, lipids, protein, and amino acids, as we focused on the role of carbohydrate and electrolytes. All sports and athlete age categories were considered relevant for this study. Literatures published after 2000 and in English language were included in the study. The literature search was conducted using the Pubmed Central search engine, the most extensive database of biomedical literature. Using the Boolean function, the search terms used were (carb* OR glucose) AND (electrolyte*) AND (sport*) AND (drink* OR beverage* OR solution* OR fluid*) AND (athlete*) AND (dehydration OR hypohydration OR hydration) AND (performance). The initial search using the Boolean function resulted in 51 articles. From the 51 articles, 5 articles did not meet the inclusion and exclusion criteria. Therefore, the final 46 articles were included in the study. The final stage of the review process included further discussion and critical appraisal of the literatures with all authors. The discussion focused on the suitability of theories and methods used in the study, physiological factors which might confound study outcomes, a resonance with personal or group experiences, gaps, and shortfalls within the data in relation to the author knowledge and experiences.

RESULT AND DISCUSSION

Dehydration and Electrolyte Disturbances in Athletes

Dehydration is a process of body water loss due to the imbalance of water intake and loss. It can occur

from a state of hyperhydration to euhydration or from a state of euhydration to hypohydration. Dehydration among athletes is mainly caused by the increased sweat production, decreased voluntary fluid intake, and insufficient fluid availability. Exercise affects thermoregulation and cardiovascular and metabolic systems due to the increased muscle contraction. The body metabolic rate increases to meet more energy needs for the continuity of muscle contractions. This leads to heat production and an increase in the core body temperature. To maintain a normal core temperature, the hypothalamus will stimulate heat dissipation through evaporation by increasing blood flows to the skin and sweat secretions. Sweat is relatively hypotonic to body fluids. Increased sweat secretions can increase the extracellular tonicity and cause the fluid transfer from intracellular to extracellular. Exercise duration and intensity are directly related to the sweat production rate (Jeukendrup & Gleeson, 2019).

Dehydration can occur in both extracellular and cellular compartments. Extracellular dehydration will decrease the blood volume and central venous pressure. Baroreceptors detect and transmit the signal to the vagus nerves which will activate the renin-angiotensin system and cause the release of antidiuretic hormone (ADH) and aldosterone from the kidneys. Antidiuretic hormone and aldosterone will increase sodium and water absorptions in the kidneys and stimulate thirst. In cellular dehydration, osmoreceptors will detect an increase in the cellular osmolarity which will also contribute to the activation of the renin-angiotensin system, sending signals to the thirst center in hypothalamus to increase fluid intake (Baker & Jeukendrup, 2014).

Dehydration can cause electrolyte disturbances. The most common electrolyte disturbance among athletes is hypernatremia. Hypernatremia among athletes is largely caused by under-replaced hypotonic sweat losses and can be asymptomatic, symptomatic, or fatal. Short duration, high intensity exercise may cause transient asymptomatic hypernatremia due to the plasma volume contraction and return after the cessation of the exercise. Symptomatic hypernatremia is more common in endurance athletes due to the prolonged duration of exercise which may cause gastrointestinal symptoms, such as vomiting and lower tolerance to oral fluid (Hew-Butler et al., 2019). Exercise may also induce hyponatremia due to overdrinking and fluid retentions

caused by the production of antidiuretic hormone during exercise. Likewise, hyponatremia can be asymptomatic, symptomatic, and fatal. Hyponatremic encephalopathy or Varon-Ayus syndrome is well documented among ultra-endurance athletes as a fatal consequence of exercise-induced hyponatremia. A pronounced hyponatremia (<120 mmol/L) may cause cerebral edema, respiratory failure, and death. Imbalances of potassium, the body main intracellular cation, can also be induced by exercise (Acosta & Varon, 2005; Knechtle et al., 2019).

Table 1. The prevalence of exercise-associated hyponatremia (EAH) in marathon races

Race	Prevalence of EAH
Houston Marathon 2000	<1%
Zurich Marathon	3% (five of 167 subjects)
Boston Marathon 2001-2008	4.8% (in 1319 collapsed runners)
Marathon	5.6%
Boston Marathon	13%
Houston Marathon 2000-2004	22 % (21 of 96 subjects)

(Knechtle et al., 2019)

Hypokalemia among athletes is mainly caused by under-replaced sweat K⁺ losses from endurance exercises and upregulation of Na⁺/K⁺ ATPase activity within skeletal muscles. Transient K⁺ efflux from contracting musculature during exercise causes hyperkalemia. Both hypokalemia and hyperkalemia may cause muscular weakness, arrhythmia, nausea, vomiting, and paresthesia which may compromise the athlete performance (Hew-Butler et al., 2019).

Effects of Dehydration on Athlete Performance

It is well known that dehydration can cause a decrease in an athlete performance. Its effects on athlete performance are affected by several factors, such as exercise characteristics, the environment temperature, and the level of body mass loss (Nuccio et al., 2017). The moderate-high intensity and prolonged exercise, duration >60 minutes, may increase the sweat rate production and dehydration risks. Moreover, when conducted in a warm-hot environment, the exercise may cause higher levels of body mass loss. A study reported that performing exercise in the heat caused cognition, skill, sprinting, lateral movement, power, and intermittent running capacity impairments (Baker, Conroy, et

al., 2007; Baker, Dougherty, et al., 2007; Bandelow et al., 2010; Dougherty et al., 2006). Meanwhile, when performed in a temperate condition, the dehydration induced by exercise alone may not impair lateral movements, jumping, and sprint performance (Ali et al., 2011; Carvalho et al., 2011). Studies found 1-2% body mass loss difference between the control trials and hypohydration trials showing mixed results in how hypohydration impacted performance, but studies involved a 3-4% body mass loss, mainly due to performing exercise in the heat, showed performance impairments consistently (Nuccio et al., 2017). Further body mass loss, > 4%, has been associated with heat illness, heat exhaustion, heat stroke, and possibly death (Jeukendrup & Gleeson, 2019; Maughan & Shirreffs, 2010).

Dehydration combined with hyperthermia and a strenuous exercise could reduce blood flows to the brain, limb, and whole body. Study by Trangmar et al. reported that, at an incremental strenuous exercise, dehydration caused a decline in the internal carotid artery flow, while cerebral metabolism remained stable due to the enhanced O₂ and glucose extractions (Trangmar et al., 2015). Reductions in skin blood flows exert physiological strains by increasing the heat storage in the body. Reductions in the systemic blood flow followed by reduced cardiac stroke volume and cardiac output are associated with heart rate elevations toward maximum heart rate (HR_{max}). The loss of body fluid during exercises could also reduce the peripheral blood flow and tissue oxygen supply to active muscles and suppress its aerobic metabolism. The reduction of aerobic metabolism in the active limb and systemic blood flow are likely to contribute as the mechanism for dehydration-induced early fatigue (Trangmar & González-Alonso, 2017). Dehydration can also affect an athlete perception of fatigue, as shown in a study conducted by Cesanelli et al., that the greater the fluid loss the greater the rating of perceived exertion (RPE) (Cesanelli et al., 2021).

Roles of Carbohydrate-Electrolyte Solutions to Maintain Hydration Status and Prevent Deteriorations of Athlete Performance

The diverse and complex effect of exercise-induced dehydration on performance creates an opportunity window for proper administration of carbohydrate-electrolyte solutions to maintain the athlete hydra-

tion status and to prevent the deterioration of their performance. In regards to physical activity, an appropriate time to use CES is mainly during a prolonged strenuous exercise in a warm-hot environment, where 3-4% BML occur or at a condition where the athlete is chronically dehydrated for restoring the euhydrated state purpose. To ensure its administration achieve maximal effects, factors impacting the magnitude of the effect need to be considered. Physiologically, the rehydration ability of carbohydrate-electrolyte solution depends on the rate of gastric emptying and the absorption in the gastrointestinal tract. Fluid generally empties from an empty stomach in 5-30 minutes. This gives fluids an advantage as carriers of other fuel nutrients that the athletes need, particularly the carbohydrates and electrolytes, compared to solid foods. Factors affecting the gastric emptying rate of fluid are fluid volume, energy density, osmolarity, dehydration, type of exercise, exercise intensity, gender, and psychological factors such as stress or anxiety (Jeukendrup & Gleeson, 2019).

The current recommendation suggests athletes to rehydrate 150% of the total fluid loss through sweat in a periodic manner by consuming smaller volumes, approximately 200 milliliters, of fluid every 15-20 minutes (Rodriguez et al., 2009). The administration of a greater volume of rehydration fluid than fluid loss through sweat results in a more complete rehydration effect (Baker & Jeukendrup, 2014; Fan et al., 2020; Schleh & Dumke, 2018). However, it is important to consider that the sweat production rate can be very high, reaching 2-3 liters per hour, where the ingestion of fluid more than 1 liter per hour can cause a gastrointestinal discomfort. Recent study conducted by Jeukendrup shows that gastrointestinal system is highly adaptable. Gastric emptying, stomach comforts, and intestine absorptions can be trained. By this knowledge, the administration of rehydration fluid in a periodic manner is preferred over a single bolus (Jeukendrup, 2017).

The addition of carbohydrate can increase the energy density of the solution which can affect the gastric emptying rate. Carbohydrate-electrolyte solutions, with 2% of carbohydrate, show a tendency to empty at a similar rate or even faster compared to water, but the solution of 8% or more significantly inhibits gastric emptying, causing gastrointestinal discomforts on athlete (Pfeiffer et al., 2009; Pfeiffer et al., 2012). Howev-

er, the solution containing 2-6% carbohydrate content can increase the gastric emptying rate and intestinal water absorption through the glucose and sodium transport mechanism (Jeukendrup et al., 2009). The absorption of carbohydrates in the form of monosaccharides occurs through a carrier-mediated process. Sodium-dependent glucose transporter-1 (SGLT-1) mediates glucose and galactose uptakes through the apical membrane of intestine epithelial cells. For each glucose molecule, two sodium molecules and water are transported to epithelial cells. Sodium will be pumped back into the intestinal lumen via the Na⁺/K⁺ ATPase pump. The transfer of sodium, in and out of the cells, also creates a favorable osmotic gradient for water absorptions. Fructose is carried into intestinal epithelial cells by sodium-independent facilitated-diffusion transporter GLUT-5. The transporter on the contra luminal side of intestinal epithelial cells, GLUT-2, receives all three monosaccharides and transports them to the circulation (Baker & Jeukendrup, 2014). Differences in monosaccharide transporters provide an opportunity for the use of multiple transportable carbohydrate in the solution to deliver high amount of carbohydrates, which will be explained further (Jeukendrup & Moseley, 2010).

Other roles of carbohydrate in the solution are to prevent fatigue and to enhance performance. The mechanism of fatigue is multi-factorial and varies across different exercise durations and intensities. Furthermore, the impact of carbohydrate on performance also depends on exercise intensity, duration, carbohydrate intake rate, and carbohydrate type. A systematic review by Stellingwerff et al. showed a different mechanisms of performance enhancement by carbohydrate supplementations. In a less than 60-minute exercise, where the potential for glycogen-limiting condition is low, carbohydrate supplementations can improve performance by a mental or cognitive stimulation of central nervous system through oral exposures (Stellingwerff & Cox, 2014). In line with this study, a functional magnetic resonance brain imaging study conducted by Chambers et al. showed that carbohydrate mouth-washing could stimulate brain centers responsible for reward and motor controls (Chambers et al., 2009). Study administered by Sinclair et al., related to a dose-response relationship among oral caloric sweet receptor activations, brain centers, and performance, showed that a 10 second mouthwash resulted in a superior 30-minute cycling performance compare to the 5 second mouthwash

(Sinclair et al., 2014). In line with this study, Carter & Jeukendrup showed that, in a short duration exercise (<1 hour) type, the amount and carbohydrate oxidation were relatively irrelevant to enhance performance (Carter et al., 2004).

Table 2. Effects of carbohydrate mouthwash only during exercise lasting less than 1-h on exercise performance or capacity

Study	n	Subject type	Exercise and performance description/duration	CHO type: study-dependent variable	Performance effect vs P
Carter et al. (2004)	9	Male (7) and female (2) endurance cyclists	Simulated time trials to complete a set amount of work (914±40kJ) in the shortest time possible	6.4% maltodextrin solution (CHO) vs water (PLA) mouth rinse	Performance time: 59.57±1.50 min (CHO) vs 61.37±1.56 (PLA) Power output: 259±16W (CHO) vs 252±16 W (PLA)
Chambers et al.	8	Endurance-trained male cyclists	The total cycling work for 1-h	25 ml of 6.4% glucose solution (GLU) or non-caloric (PLA) mouth rinse for 5s every 12.5% of the TT	60.4 min (GLU) vs 61.6 min (PLA)
Sinclair et al. (2014)	11	Healthy active male recreational cyclists	Maximum distance of cycling for 30-minute time trials	25 ml of tasteless 6.4% maltodextrin (CHO) vs water (PLA) 5s or 10s mouth rinse every 6 minutes of the total protocol	Cadence (RPM): 87.39±10.07(PLA) vs 91.18±9.76 (5-s CHO) vs 92.95±9.69 (10-s CHO) Speed (km.h ⁻¹)

Table 3. Effects of carbohydrate mouthwash only during exercise lasting less than 1-h on exercise performance or capacity

Study	n	Subject type	Exercise and performance description/duration	CHO type: study-dependent variable	Substrate oxidation effect vs P
Jeukendrup & Moseley (2010)	8	Males	2-h cycling at 50% maximal work rate (Wmax)	86 g/L glucose only beverage (GLU), 86 g/L combined glucose+fructose beverage (GLU+FRU) 2:1 ratio, water (P)	CHO Oxidation: 2.3g/min (GLU and GLU +FRU), 1.4±0.2 g/min (P) Fat Oxidation: 0.5 g/min (GLU and GLU+FRU), 0.9±0.1 g/min (P)
O'Brien & Rowlands (2011)	10	Trained male cyclists and triathletes	150 min cycling at 50% Wmax followed by an incremental test to exhaustion	Fructose and maltodextrin solution 4.5 and 9% (0.5 Ratio), 6 and 7.5% (0.8-Ratio), 7.5 and 6% (1.25-Ratio), artificially sweetened water (P)	Total CHO Oxidation: 2.04 g/min (0.5 Ratio), 2.07 g/min (0.8 Ratio), 1.91 g/min (1.25 Ratio) 0.86 g/m (water) Exogenous CHO Oxidation: 1.04 g/min (0.5 Ratio), 1.14 g/min (0.8 Ratio), 1.05 g/min (1.25 Ratio) Endogenous Fat Oxidation: 0.59 g/min (0.5 Ratio), 0.61 g/min (0.8 Ratio), 0.62 g/min (1.25 Ratio) 0.98 g/m (water)
Schleh et al. (2010)	10	Aerobically fit adult males	1.5 h treadmill at 50% VO2max followed by an incremental test	SDS (355 mOsm.L-1, 59g/L CHO) vs ORS (235 mOsm.L-1, 33 g/L)	CHO Oxidation 90 min after fluid ingestion: ~1.9g/min (SDS) vs ~1.6 g/min (ORS) Fat Oxidation: ~0.35 g/min (SDS) vs ~0.45 g/min (ORS)

When the exercise duration is longer than 60 minutes, there is a potentially glycogen limiting condition. The primary mechanism to improve performance is by maintaining the plasma glucose and carbohydrate oxidation augmentation by the muscles. The rate limiting step to exogenous carbohydrate oxidation is the intestinal carbohydrate transport mechanism (Stellingwerff & Cox, 2014). Multiple transportable carbohydrates, such as glucose-fructose blends or maltodextrin, utilize both SGLT-1 and GLUT-5 transporters to increase carbohydrate absorptions and oxidations when the intake rates are greater than 60-70 g/hour. Meta analysis administered by Shi et al., regarding the carbohydrate-electrolyte solution absorption based in triple-lumen-perfusion studies, showed a significantly greater water absorption for multiple types of carbohydrates in duodenum and jejunum compared to a single carbohydrate (Shi & Passe, 2010). A study conducted by Jeukendrup, during a prolonged exercise (>2 hours) with carbohydrate ingestion rate of more than 60-70 g/hour of glucose-fructose or maltodextrin-fructose blends, showed 20-50% higher carbohydrate oxidation compared to the individual glucose or maltodextrin (Jeukendrup & Moseley, 2010). In line with the study, O'Brien & Rowlands also showed that the ingestion of higher ratio (0.8 to 1.25) of fructose-maltodextrin solutions at a high carbohydrate-ingestion rate provides greater benefits to endurance performance (O'Brien & Rowlands, 2011). Study of Schleh et al. also showed linear results that a higher carbohydrate drink content increased carbohydrate oxidation and decreased fat oxidation (Schleh & Dumke, 2018).

The main purpose of electrolyte addition is to replace the electrolyte loss through sweat and to increase fluid absorptions in the intestine to maintain hydration. Inter-individual sweat sodium concentration varies widely (20-100 mmol/L) (Baker, 2017). The average sweat production rate of athletes is 1.5-2 liters per hour which can cause a sodium deficit of 75 mmol/hour. In a prolonged exercise, the demand to replace fluid and electrolyte loss through sweat will be higher. Therefore, drinking water only for rehydration, especially during a prolonged exercise, increases the exercise-induced hyponatremia risk and hinders a complete restoration of extracellular fluid, including plasma volume, which can only be sustained with the replacement of lost sodium. A well-formulated carbohydrate-electrolyte solution that can replace fluid and electrolyte loss is needed in

this condition.

Current recommendations suggest athlete to drink a solution containing carbohydrate (20-50 g/L) and sodium (20-60 mmol/L) and should not exceed 290 mOsm/L (Rodriguez et al., 2009). Study by Fan et al., comparing oral rehydration solutions having a high electrolyte concentration (DD, carbohydrate: 33 g/L, sodium: 60 ± 3 mmol/L, 382 ± 31 mOsmol.kg⁻¹), sports drink (SD, carbohydrate: 62 g/L, sodium: 31 ± 3 mmol/L, 216 ± 4 mOsmol.kg⁻¹), and water (WA), showed a greater fall in the serum sodium concentration in WA group than in the DD and SD groups at 3h of recovery. The study also showed a higher fluid retention in DD than in WA and SD which can be caused by the increase of serum sodium concentration and osmolarity, thus stimulating the renal water absorption (Fan et al., 2020). In contrast, study carried out by Schleh et al. showed a greater fluid retention in sports drinks with higher carbohydrate and lower electrolyte content (355 mOsm.L⁻¹, 59g/L CHO, 458 mg/L sodium) than in the oral rehydration solution (235 mOsm.L⁻¹, 33 g/L CHO, 1330 mg/L sodium) (Schleh & Dumke, 2018). Taken together, it shows that solution osmolarity, determined by its carbohydrate and electrolyte composition, can also affect the magnitude of fluid retention. More than 330 mOsm/L of high osmolarity, or often called hypertonic solutions, also results in net efflux of water from the body into the intestinal lumen, causing a net negative effect on the water absorption and plasma volume. Moreover, hypertonic solutions can slow gastric emptying. Hypotonic (<270 mOsm/L) or isotonic (270-330 mOsm/L) may be more beneficial to aid water absorptions as a result of a favorable osmotic gradient which promotes more water movements from the proximal small intestines across the mucosa (Rowlands et al., 2022).

Electrolytes, specifically sodium, also play a role to stimulate thirst to increase the voluntary fluid intake. The consumption of plain water decreases the plasma osmolarity and sodium concentration, reducing the drive to drink, oftentimes, before the body water volume has fully restored. The presence of sodium maintains a slight increase of plasma osmolarity that will act as a signal sensed by the osmoreceptors to stimulate physiological thirst in higher brain regions. The voluntary fluid intake is also influenced by the solution palatability (Armstrong, 2021). Sodium and specific carbo-

hydrate types added to the solution can enhance its palatability. The presence of 20-30 mmol/L sodium in a replacement beverage has been shown to stimulate physiological thirst and to improve beverage palatability and fluid intake volume. However, solutions with too high electrolyte contents (>75 mmol/L) often have a less favorable taste/palatability compared to higher carbohydrate sports drinks, which could hinder the voluntary fluid intake. Substituting sodium chloride, the typical sodium in carbohydrate-electrolyte solutions, with

sodium citrate decreased the unpalatable salty taste from the high concentration of sodium chloride (Sawka et al., 2007).

Recommendations of Carbohydrate-Electrolyte Solution Administrations for Athletes

The use of carbohydrate-electrolyte solutions in sports needs to be done properly to obtain a maximum hydration effect and performance improvement with minimal side effects. The purpose of carbohydrate-

Table 3. Effects of carbohydrate mouthwash only during exercise lasting less than 1-h on exercise performance or capacity

Study	n	Subject type	Exercise and performance description/ duration	CHO type: study-dependent variable	Serum electrolyte level, plasma volume, drink palatability vs P
Maintenance of serum electrolyte levels					
Fan et al. (2020)	9	Physically active males	75 min cycling at 65% VO ₂ peak followed by 45 min cycling at 65% VO ₂ peak and 20 km time trial after 5h recovery period	Oral rehydration solution (DD, carbohydrate: 33 g/L, sodium: 60 ± 3 mmol/L, 382±31 mOsmol.kg ⁻¹), sports drink (SD, carbohydrate: 62 g/L, sodium: 31 ± 3 mmol/L, 216±4 mOsmol.kg ⁻¹), and water (P)	Serum sodium concentration at 3h recovery: ~139 mmol/L (DD, SD), ~135 mmol/L (WA)
Maintenance of plasma volume					
Fan et al. (2020)	9	Physically active males	75 min cycling at 65% VO ₂ peak followed by 45 min cycling at 65% VO ₂ peak and 20 km time trial after 5h recovery period	Oral rehydration solution (DD, carbohydrate: 33 g/L, sodium: 60 ± 3 mmol/L, 382±31 mOsmol.kg ⁻¹), sports drink (SD, carbohydrate: 62 g/L, sodium: 31 ± 3 mmol/L, 216±4 mOsmol.kg ⁻¹), and water (P)	% changes in plasma volume at 2h recovery: ~+15% (DD), ~+12%(SD), ~+9% (P)
Schleh et al.(2010)	10	Aerobically fit adult males	1.5 h treadmill at 50% VO ₂ max followed by an incremental test	SDS (355 mOsm.L-1, 59g/L CHO, 458 mg/L sodium) vs ORS (235 mOsm.L-1, 33 g/L CHO, 1330 mg/L sodium)	%changes in plasma volume post exercise: 2.2±6.3 (SDS), -2.4±6.5(ORS) %changes in plasma volume post exercise: -1.5±6.5 (SDS), -5.3±11.2 (ORS)
Increasing palatability					
Chambers et al.	8	Endurance-trained male cyclists	Total cycling work done for 1-h	25 ml of 6.4% glucose solution (GLU) or non-caloric sweetener (saccharin/PLA), 25 mmol KCl and 2.5mmol NaHCO ₃ tasteless solution (Control) mouth rinse for 5s every 12.5% of the TT	Sweetness: 55±21mm (GLU), 39±18mm (saccharin), 19±8mm (control)
Fan et al. (2020)	9	Physically active males	75 min cycling at 65% VO ₂ peak followed by 45 min cycling at 65% VO ₂ peak and 20 km time trial after 5h recovery period	Oral rehydration solution (DD, carbohydrate: 33 g/L, sodium: 60 ± 3 mmol/L, 382±31 mOsmol.kg ⁻¹), sports drink (SD, carbohydrate: 62 g/L, sodium: 31 ± 3 mmol/L, 216±4 mOsmol.kg ⁻¹), and water (P)	Mean ratings of palatability: 5.40±1.58(DD), 5.61±1.79 (SD), 4.25±2.60 (P)

electrolyte solution administration for athletes is to maintain the hydration status by increasing the gastric emptying and intestinal water absorption, water reten-

tion, and voluntary fluid intake by enhancing palatability and maintaining thirst sensation, blood glucose levels, and carbohydrate oxidations. All of which delay fatigue thus maintaining the athlete performance. The recommendation is administering carbohydrate-electrolyte solution containing 5-10% carbohydrates (glucose, fructose, or maltodextrin), sodium 20-30 mEq/L, and potassium 2-5 mEq/L, be given at the rate of 400-800 ml/hour in a periodic manner by consuming 150-200 ml of solution every 15-20 minutes during the exercise (Sawka et al., 2007). Carbohydrate-electrolyte solutions given during an exercise exert more contrast effects in a prolonged exercise, lasting more than 60 minutes, with moderate-to-high intensity compared to the less than 60-minute exercise.

It is also important for athletes to start exercise in a euhydrated state. If sufficient beverages with meals are consumed and a recovery period (8-12 h) has elapsed since the last exercise session, the person should already be close to being euhydration. However, if the athletes have suffered substantial fluid deficits and do not have an adequate time for fluid/electrolyte volumes to reestablish euhydration, a prehydration program may be merited. A prehydration process using carbohydrate-electrolyte solutions should be initiated at least several hours before the exercise task to enable fluid absorptions and allow urine outputs to return toward normal levels. The post-exercise rehydration goal is to fully replace fluid and electrolyte deficits. If time permits, this could be achieved by consuming normal meals with a sufficient volume of water and providing foods containing sufficient sodium to replace sweat losses. If the recovery period is short (<12 hours), carbohydrate-electrolyte solutions may be used to fully replace the fluid and electrolyte loss (Sawka et al., 2007). Factors to be considered to ensure the proper administration of carbohydrate-electrolyte solutions are solution properties (volume, energy density, osmolarity, carbohydrate type, fluid availability, diet), exercise (duration, intensity), and environment (temperature, humidity) (Leiper, 2015).

CONCLUSION

The study concludes that dehydration can cause many unwanted physiological effects on athletes and impair performance. The administration of carbohydrate-electrolyte solutions before, during, and after exercises may prevent dehydration and its negative effect especially on performance deteriorations. The formulation and administration of carbohydrate-electrolyte solutions must be done with caution and be given at the right timing to reduce side effects, primarily the gastrointestinal discomfort.

CONFLICT OF INTEREST

The authors declared no conflict of interest.

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