Effects of dehydration and the optimal beverage for healthy children and adolescents while being physically active

Efectos de la deshidratación y bebida óptima para niños y adolescentes sanos físicamente activos.

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Abstract

Current public health guidelines aim at getting children and adolescents to be more physically active and to practice at least one hour per day of exercise or sport-related activity. The practise of physical exercise implies increased water requirement since sweat loss for thermoregulation is increased, especially in warm weather conditions. Sweating also leads to loss of electrolytes, mainly sodium, but also potassium. Involuntary dehydration is quite frequent among young people and there is a consensus in the literature that dehydration status can lead to a significant reduction in exercise performance and may adversely affect cognitive performance and health. Recent findings establish that there is no thermoregulatory difference between children and adults when practicing sports as was presumed some years ago, although research analysing all these aspects in children and adolescents is scarce. After reviewing the literature, adequate fluid intake and to instruct children, teachers, trainers and parents about hydration strategies seem desirable. Until more specific recommendations are available, current fluid replacement guidelines for adults with the specifications mentioned in this review could be taken into account by children and adolescents while being physically active and practising sports.

Key words: Health, sports, hydration, children, adolescents, fluid replacement

Running title: Optimal hydration in physically active children and adolescents

Resumen

Las directrices actuales de salud pública pretenden conseguir que los niños y adolescentes sean más activos físicamente practicando al menos una hora diaria de ejercicio o actividad relacionada con el deporte. La práctica de ejercicio físico implica una mayor necesidad de agua debido a la pérdida de líquido a través del sudor, como consecuencia del proceso de termorregulación, cuya necesidad se ve incrementada especialmente en condiciones de clima cálido. La sudoración también conduce a la pérdida de electrolitos, principalmente sodio, aunque también potasio. Entre los jóvenes es bastante frecuente la deshidratación involuntaria, existiendo consenso en la literatura al afirmar que el estado de deshidratación puede conducir a una reducción significativa en el rendimiento físico, afectando negativamente en el rendimiento cognitivo y en la salud. Recientes hallazgos establecen no haber diferencias en el sistema de termorregulación entre niños y adultos mientras practican deporte, como se presumía hace unos años, aunque las investigaciones analizando todos estos aspectos en niños y adolescentes son escasas. Tras el análisis de la literatura, parece adecuado instruir, a niños, maestros, instructores y padres acerca de la adecuada ingesta de líquidos así como de las estrategias de hidratación necesarias. Hasta que estén disponibles recomendaciones más específicas, las actuales directrices de reposición de líquidos en adultos, junto con las especificaciones mencionadas en esta revisión, podrían ser tenidas en cuenta por los niños y adolescentes mientras practican actividad físico-deportiva.

Palabras clave: Salud, deporte, hidratación, niños, adolescentes, bebida de reposición

Título abreviado: Hidratación optima en niños y adolescentes físicamente activos.

Introduction

Most of the studies published in the literature agree upon the importance of drinking sufficient amounts of fluids, that is water or other beverages, while doing exercise at any age, especially in hot climates, due to the fact that the human body needs to replace water lost in sweat, urine and through the respiratory tract (1-3).

Water is quantitatively, the most important component of the body. In children and adolescents, as a function of age and gender, body water can vary between 49 to 84% of body weight (BW) (4). The body has developed mechanisms to maintain water balance under conditions of mildly fluctuating availability. Generally, consumption of 1.5 L of liquid per day, in conjunction with the liquid ingested as a component of food, is recommended to replace the water lost throughout the day (5). The practice of physical exercise implies increased water requirements, especially when people are performing at high temperatures. Following current public health guidelines (6), more and more children and adolescents should come into regular sport practice, additionally to those who are already engaged in youth sports and athletics. They should be made aware about the importance of establishing an adequate hydration plan before, during, and after exercise. Dehydration may cause early fatigue, irritability or a sudden decline in performance (7) and in a more advanced state, heat injuries, heat illness or even heat stroke (3, 8, 9).

Research regarding optimal sports nutrition and hydration performed in children and adolescents is not so abundant than that performed in adults as has been recently stated by Nemet & Eliakim (2009) (10) and therefore adds some limitations to the current review. Nevertheless, it seems convenient to review the available information regarding physiology of thirst and thermoregulation, describing the common problems linked to dehydration and proposing the best rehydration solution for this population group and some future research lines.

Involuntary dehydration in children and adolescents

Thirst is the physiological defence mechanism that makes us drink, which is stimulated by increases in cellular tonicity (cellular dehydration) and decreases in extracellular fluid volume (reduction in the amount of total body water, or extracellular dehydration) (1). This means that thirst is a bad indicator during physical activity because it appears when extracellular osmolality increases between 2 and 3% (11). A 1% decrease in BW from exercise-induced sweating decreases endurance in children (12) and a deficit of 2 – 3% BW is already considered as dehydration. Both the American College of Sports Medicine and the American Academy of Pediatrics advice not to depend on thirst as an adequate indicator of total fluid needs while practicing sports (3, 9).

It has been generally stated that people exposed to prolonged exercise and allowed to drink *ad libitum*, do not drink sufficient amounts of fluids to replenish their fluid losses, since with this strategy they only replace 1/3 of the water losses or, in the best case 2/3 (13-15). The result is known as involuntary dehydration. It is very frequent among children and adolescents who exercise in hot environments without being forced to drink (16-18), although children and adolescents rarely exhibit involuntary dehydration for activities less than 45 minutes (19). Involuntary dehydration appears to be controlled by more than one factor including social customs that influence what is consumed, the capacity and rate of fluid absorption from the gastrointestinal system, the level of cellular hydration involving the osmotic-vasopressin interaction with sensitive cells or structures in the central nervous system, and, to a lesser extend, hypovolemicangiotensin II stimuli (20-22). Other external factors, such as flavour, temperature, sodium and carbohydrate content of the beverage seem to have an influence on the drinking response and will be commented below. All in all, maintenance of euhydration, urine specific gravity and osmolality ≤1.020 gml^{-1} and ≤700 mOsmol, respectively, and plasma osmolality ≤ 290 mOsmol, (3) during exercise will depend on several factors, including hydration state previous to exercise. Some studies have indicated that children and young people tend to begin the training or exercise in a mild dehydration state (23, 24). Studies performed on children and adolescents regarding involuntary dehydration are summarized on Table 1.

Dehydration related adverse effects

The information about the effect of hypohydration in children is scarce because, for ethical reasons, dehydration levels in the experiments with these subjects did not exceed 2 – 3% of initial BW. Dehydration negatively affects the body and the thermoregulation system (3, 25, 26). One percent BW loss in children is equivalent to an increase of 0.28º C in body temperature, while in adults the increase will be only 0.1-0.2º C (27). Most of the older studies showed that children do not adapt to heat as effectively as adults (9, 28-31), and as a result, they were presumed to overheat faster than adults (26, 29). However, recent investigations which have directly compared thermoregulatory responses to exercise in the heat in children and adults have challenged these traditional concepts. In general, these investigations conclude that children employ a different thermoregulatory strategy, which is as efficient as in adults under most ambient conditions (32, 33), or perhaps even better (34). These findings imply that no maturational differences exist in thermal balance or endurance performance during exercise in the heat, nor that child athletes are more vulnerable to heat injury than adults.

Current available literature related to this topic has been recently reviewed by Rowland (2008) (35). However, in extreme temperatures or when dehydration is not prevented, children may be more vulnerable (32, 36). Moreover, their acclimatization process is slower than in young adults (37, 38). A child needs 8 to 10 exposures (30-45 minutes each) to the new climate in order to adequately acclimatize. Intense and prolonged exercise undertaken before acclimatization may be detrimental to the child's physical performance and well-being and may lead to heat-related illness, including heat exhaustion of fatal heat stroke (9). There are some individuals that can tolerate a 2% of BW loss without a significant risk to their health or endurance exercise performance in cold climates from 5–10° C, up to 20–22° C. But in hot environments, 30º C or above, a dehydration of 2% BW impairs exercise performance and increases the possibility of suffering a heat injury, or even a heat stroke (39, 40). Due to the climate change that is affecting globally, mean temperatures are rising and hot days are becoming more frequent, even in moderated-climate regions (41).

When a child gets dehydrated, the most affected function is the cardiovascular system, since heart rate increases between 5-8 beats·min^{-1} for each 1% BW (42) loss causing a decrease in cardiac output and stroke volume (43, 44) as well as a reduction in sweating rate. Furthermore, the increase in body temperature, as a result of deficient fluid intake, causes a rise of glucose utilization by the muscle and a gaining of fatty free acids (45). In addition, when children or adolescents are dehydrated, they easily achieve a fatigued state (9, 11, 13).

Cognitive function is also affected when children are mildly dehydrated (46, 47). Bar-David *et al.* (2005) investigated the influence of dehydration on physical and mental performance in fifty-one students, 10.1 – 12.4 years-old, from two classes in two elementary schools in Israel. They showed that mild dehydration has negative effects on short-term memory. Other negative effects have been documented in adults. Dehydration can impair performance on tasks such as perceptual discrimination, visual memory, arithmetic ability, visuomotor tracking, psychomotor skills and vigilance-related attention (26, 48-50). In children, dehydration leads to dizziness, lethargy, agitation, irritability, restlessness, and confusion (47, 51). Moreover, dehydration has been associated with reduced autonomic cardiac stability and reduced cerebral blood flow velocity (3). One recent investigation showed intracranial volume changes when six rugby players experienced up to 2.5% of dehydration increasing risk of brain damage (52).

Exercise performance is affected negatively when people are dehydrated in such aspects as endurance exercise performance, power and strength skills (40, 53-56). Muscle cramps are very frequent among athletes, especially when they lose large amounts of sodium via sweat (57, 58).

When the rehydration drink is a [Na^+] low beverage or when the amounts of sodium lost by sweat are high, the child can suffer hyponatraemia. Symptomatic hyponatraemia can occur when plasma concentrations of [Na^+] drop below 130 $mmol \cdot l^{-1}$. Symptoms of hyponatraemia are nausea, fatigue, confusion, apathy, swelling of hands and feet (12, 59). Children also can suffer hypernatraemia when plasma concentrations of [Na^+] are above 145 $mEq \cdot l^{-1}$. It can causes restlessness, altered mental status, confusion and fatigue (51).

Heat stroke occurs when the core body temperature exceeds 40º C (60). Some symptoms are cardiac arrhythmias, severe hyperthermia, dysfunction of the central nervous system, rhabdomyolysis, serum chemistry abnormalities, disseminated intravascular coagulation and death (61). Mortality for heat stroke ranges from 17% to 70% depending on severity and age of the patient (12, 62).

On the other hand, dehydration can increase the consequences of rhabdomyolysis increasing the severity of acute renal failure. Although exertional rhabdomyolysis is rare in young children, it can occur when exercise is excessive and there is an important dehydration or an untrained status (57, 63, 64).

Which is the best rehydration beverage for children?

Several studies have been performed in order to establish type, composition and amount of fluid that is best to set optimal conditions for exercise and to avoid dehydration. Most of them conclude that complete euhydration can not be maintained during exercise, but that water-electrolyte losses due to sweating should be replaced at least at a rate equal to the sweat rate (1, 2). After finishing the exercise, athletes should drink approximately 450-675 ml of fluid for every 0.5 kg of BW lost during exercise (65).

As stated above, to prevent dehydration during exercise will depend to a great extend on the desire to drink (6); therefore, to know which is the most suitable beverage composition to promote fluid intake in young athletes is of the utmost importance.

Plain water vs. flavoured drinks

Water is considered as the first-choice rehydration drink, before, during and after exercise. However, most of the studies published in the literature conclude that water intake is ineffective to recover the hydric balance in a longer exercise in a hot climate (66, 67), because large amounts of plain water decrease plasma osmolality (68). Studies in children also conclude that unflavoured water induces less to drink (27, 38, 69, 70). Flavour is an important factor for inciting them to drink voluntarily (71). Meyer *et al.* (1994) have compared unflavoured water with orange, grape and apple flavours, in a group of twenty-four children while practicing exercise. Children preferred grape flavour to the other drinks while they cycled during 90 minutes.

Rivera-Brown *et al.* (1999b) provided to a group of twelve heat – acclimatized girls three kind of beverages, in three different sessions, while they carried out 180 minutes of intermittent exercise at 60% VO_{2max}. Drinks were unflavoured water, flavoured water and flavoured water plus CHO and electrolytes (E). Girls could not keep euhydration with any of the beverages but when they drank flavoured water plus CHO-E, their degree of dehydration was lower than with the other two beverages. This same study was carried out in twelve heat – acclimatized boys, but using only two drinks, unflavoured water and flavoured water plus CHO-E. The second drink resulted in an increased intake compared with water and it prevented voluntary dehydration (16). A more recent experiment was performed with 9 to 12 year old girls who exercised intermittently in a hot environment, cycling at 50% VO_{2max}. Exposure time in each of the three sessions was 3 hours. When they were given flavoured water plus CHO-E *ad libitum,* the girls drank more fluid than with plain water (72).

Relevance of electrolyte addition

Prolonged exercise in hot climates is not only associated with body water loss through sweating, but also causes a high loss of [Na^+] and potassium [K^+] (30, 69, 73). The needs of these electrolytes will depend on intensity and duration of the exercise, besides environmental conditions. The Institute of Medicine recommends that rehydration drinks should contain 20-30 $mEq \cdot l^{-1}$ [Na^+] and 2-5 $mEq \cdot l^{-1}$ [K^+] (74). However, these recommendations are for the general population, and children present some physiological differences that can alter them. Children and pre-adolescents sweat electrolyte concentration has lower amounts of [Na^+] and [Cl^-] than people older than twenty years. In contrast, sweat [K^+] content is higher than in adults (30).

The inclusion of both electrolytes in the rehydration drink helps to replace electrolyte losses, to increase fluid retention (75) and to stimulate voluntary drinking (76-78).

Most of the studies in children use 18 $mmol \cdot l^{-1}$ [Na^+] or NaCl as a content of rehydration drinks. Meyer *et al.* (1993) performed a study with nine children who intermittently cycled during 120 minutes. Three drinks were offered with different [Na^+] concentrations, 0, 8.8 and 18.5 $mEq \cdot l^{-1}$ [Na^+]. A negative balance was obtained with the three beverages, although results were better with the last composition (-0.22, -0.14, -0.12 $mEq \cdot kg^{-1} \cdot h^{-1}$, respectively). Furthermore, a solution containing 18 to 20 $mmol \cdot l^{-1}$ [Na^+] or NaCl would be emptied from the stomach as fast as water (24, 79). However, if salt concentration is higher than 20 $mmol \cdot l^{-1}$, it would retard gastric emptying (12).

Relevance of carbohydrate addition

Besides electrolytes, research has demonstrated the adequacy of the inclusion of CHO to the drink both during and after exercise (3). Adding carbohydrates to rehydration drinks permits maintenance of blood glucose oxidation rate during sports sessions and therefore delays fatigue (80, 81). Previous investigations have shown that children and adolescents use proportionally more fat and less endogenous CHO compared to adults, while they practice exercise. However, children and adolescents use higher amount of exogenous CHO than adults. This means that if young people use CHO drinks, this will slow down fat oxidation extending CHO utilization (82-85), probably a non-desired effect for children who need to loose BW.

Between 30 to 60 g CHO·h^{-1} are necessary to maintain blood glucose levels in children and adolescents. The optimal concentration for replacement drinks might be 6-7% CHO in a high-level sport activity context, due to (i) it's contribution to maintaining performance and (ii) it's enhancing gastric emptying, since higher CHO concentrations will retard it (3, 12).

Additionally, it has many benefits for performance; for example, by increasing effort time in high intensity exercise (86-88), increasing explosive strength and speed (56) and decreasing the rating of perceived exertion (RPE) in healthy adolescents (87), although controversy exist about this last aspect (89, 90).

On the other hand, CHO intake is important immediately after exercise because, at that moment muscles have more capacity to capture glucose, and muscular glycogen resynthesis is the highest during the two hours after exercise (91). Moreover, CHO addition favours voluntary hydration and enhances water absorption (92).

Table 2 summarizes studies about CHO and electrolyte beverages and their effects in children and adolescents during exercise practice.

To sum up, water is meant to be ingested before, during and after physical exercise in order to prevent dehydration in children and adolescents. In order to minimize the effects of water and electrolytes loss and the depletion of the body's carbohydrate reserve a sport beverage can be chosen. The flavour as well as CHO and electrolyte addition into rehydration drinks acquires a great deal of importance since they improve the palatability of the beverage increasing voluntary hydration in this population. However, in an equilibrated diet context, beverages with a lower level of CHO are the most recommended for sport-practicing children.

Table 3 summarizes hydration strategies for physically active children and adolescents before, during and after sport practice.

Discussion and Conclusion

Current available research seems to establish that there is no thermoregulatory difference between children and adults when practicing sports as was presumed some years ago (35), even though children's physiological responses and performance outcomes during exercise, specifically in the heat, are far from complete. Nevertheless, involuntary dehydration among young people is reported in the literature in different scenarios, like exercising for more than 45 minutes (93), exercising in hot climates (94) or attending a summer camp (95). In the middle of the last century, thirst was already considered as a bad indicator of total fluid needs at all ages and drinking *ad libitum* seems only replenish 2/3 of body water loss, in the best case. Evidence exists to suggest that a good rehydration drink must contain electrolytes ([Na^+] and [K^+]) and 6-7% CHO for a correct fluid intake and to increase voluntary hydration. Furthermore, to add CHO to replacement fluids has many benefits such as increasing endurance performance or improving explosive strength. There is a high consensus in the literature that dehydration has a negative effect on health, physical and cognitive performance.

From a public health perspective, more and more children and adolescents should practice sports on a regular basis. Parents, teachers and trainers must be aware of the importance of correct fluid intake and optimal hydration strategy by all children and adolescents while being physically active, attending summer camps, exercising, playing on the play ground, etc. In regard to more competitive sports, for the youth athlete, proper nutrition and adequate liquid intake is of essence. Unfortunately, most of the knowledge in this field is based on adult literature. Additional research is necessary respect to the kind and best composition of rehydration beverages, and the influence of dehydration on performance. Intrinsic parameters need to be approached with caution: the thermoregulation system and gastric emptying in children should be checked, although extrinsic parameters, such as daily dietary context, have also to be taken into account to recommend the best formulation.

In summary, until more specific recommendations are available, current fluid replacement guidelines for adults with the mentioned specifications could be taken into account by children and adolescents while being physically active and practising sports.

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TABLES

Table 1. Involuntary dehydration in children and adolescents.

Study	Subjects and age	Climate	Exercise task	Drink	Dehydration
(38)	Eleven acclimatized boys. 10 – 12 yr	39º C 45% RH	Cycled at 45% VO_{2max} intermittently for 210 min.	a) Unflavoured water.	a) 1 – 2% BW
(96)	Thirty-one physically active boys A) 12±0.3 yr B) 13.6±0.4 yr C) 16.7±0.6 yr	41–43º C 18–22% RH	Twenty min cycling at 50% VO_{2max} alternating with 10 min rest and 5 min rest last bouts periods for 95 min.	a) Unflavoured water.	A) -0.29±0.22% BW B) -0.23±0.12% BW C) 0.00±0.35% BW
(66)	Nine untrained children (6 males and three females). 13.3 ± 1.9 yr	27–31º C	Twenty min cycling at 60% VO_{2max} alternating with 25 min rest periods for 180 min each under four conditions: SuVD, SuFD, ShVD and ShFD	a) Unflavoured water.	SuVD = -1.7±0.4% BW SuFD = -1.5±0.4% BW ShVD = -2.1±0.2% BW ShFD = -1.3±0.3% BW
(67)	1) 19 basketball male players. 2) 12 basketball female players. 3) 32 soccer male players. 16 – 18 yr.	Summer >20º C Winter <10º C	Two weight training sessions, two matches and four training sessions in summer and winter.	a) Unflavoured water.	Winter: 1) -0.4, -1.2, -1.0% BW 2) -0.4, -1.0, -0.7% BW 3) -0.3, -0.8,-1.4% BW Summer: 1) -0.4, -1.0, -0.9% BW 2) -0.5, -0.7, 0.7% BW 3) -0.4, -1.2, -1.4% BW
(97)	Thirty-two triathletes (16 girls and 16 boys). 1) 15.0 – 17.1 yr. 2) 12.5 – 14.8 yr.	NA	a) 2-km run, 12-km ride and 4-km run. b) 1-km run, 8 km-ride and 2-km run.	a) Unflavoured water.	1-♂) -1.95% $BW \cdot hr^{-1}$ 1-♀) -1.34% $BW \cdot hr^{-1}$ 2-♂) -1.32% $BW \cdot hr^{-1}$ 2-♀) -1.04% $BW \cdot hr^{-1}$
Study	**Subjects and age**	**Climate**	**Exercise task**	**Drinks**	**Dehydration**

Study	Subjects and age	Climate	Exercise task	Drinks	Dehydration
(76)	Twelve boys (9 recreational sports and 3 competitive athletes) 10 – 12 yr.	35±1º C 60±5% RH	Twenty min cycling at 50% VO_{2max} alternating with 5 min rest periods for 70 min.	a) Flavoured water plus CHO-E.	a) 0.75% to 1.07% BW
(16)	Twelve heat - acclimatized trained boys. 11 – 14 yr.	30.4±1.0º C 56.4±1.9% RH	Twenty min at 60% VO_{2max} alternating with 25 min rest periods for 180 min.	a) Unflavoured water. b) Flavoured water plus CHO-E.	a) -0.94% BW b) 0.18% BW
(18)	Twelve heats acclimatized trained girls. 10.6 ± 1.1 yr.	30.9±1.0º C	Twenty min at 60% VO_{2max} alternating with 25 min rest periods for 180 min.	a) Unflavoured water. b) Flavoured water. c) Flavoured water plus CHO-E.	a) -1.12% BW b) -0.95% BW c) -0.74% BW
(24)	Thirteen football male players. 16.6±0.4 yr	15.5 – 25º C 38 – 45% RH	Two-a-day training football sessions for 5 days.	NA	a) -1.12 ± 0.74% BW
(17)	Twenty-four players (9 female netball players, 7 female basketball players and 8 male basketball players). 17.8 ± 1.1 yr.	17.8±0.9º C 40.4±8.1% RH	Nine usual training sessions.	a) Unflavoured water. b) Flavoured water plus CHO-E. c) Flavoured water plus low kilojoules CHO-E.	a) -156.4ml·h^{-1} FB b) -11.3 ml·h^{-1} FB c) -29.5 ml·h^{-1} FB
(23)	Fourteen tennis players (9 male and 5 female). 15.1 ± 1.4 yr.	79.3 – 79.9º F	Tennis specific training sessions for 120 min.	a) Unflavoured water. b) Flavoured water plus CHO-E.	a) -0.9±0.6% BW b) -0.5±0.7% BW
(72)	Twelve physically active girls. 9-12 yr.	35±1º C 45 -50% RH	Twenty min cycling at 50% VO_{2max} alternating with 25 min rest periods for 180 min.	a) Unflavoured water. b) Flavoured water. c) Flavoured water plus CHO-E.	a) -0.15% BW b) 0.16% BW c) 0.45% BW

(33)	Eight boys 11.7 ± 0.4 yr.	a) 31.0±0.3º C 57±2% RH b) 19.6±0.6º C 66±11% RH	Cycling to exhaustion at 65% VO_{2max} in a constant-load test.	a) Unflavoured water.	a) 0.11±0.17% BW b) 0.28±0.15% BW
(75)	Twelve heat-acclimatized girls 10.6±0.2 yr.	30.9±0.2º C	Twenty min at 60% VO_{2max} alternating with 25 min rest periods for 180 min.	a) Unflavoured water. b) Flavoured water. c) Flavoured water plus CHO-E.	a) -1.12% BW b) -0.95% BW c) –0.74% BW

NA = not available; RH = relative humidity; BW = body weight; CHO-E = carbohydrates and electrolytes; SuVD = sun exposure with voluntary drinking; SuFD = sun exposure with forced drinking; ShVD = shaded with voluntary drinking; ShFD = shaded with forced drinking; FB = Fluid Balance [FB= fluid intake (ml)-Sweat loss (ml)].

Table 2. Effects of CHO and E drink intake in children and adolescents.

Study	Subjects and Age	Drink composition		Exercise task	Effects of CHO and E intake
		CHO	Electrolytes		
(77)	Nine children (5 boys and 4 girls). 9 – 12 yr.	NA	a) 0 $mEq \cdot l^{-1}$ Na^{+} b) 8.8 $mEq \cdot l^{-1}$ Na^{+} c) 18.5 $mEq \cdot l^{-1}$ Na^{+}	Cycled 20 min and two 15 min bouts at 50% VO_{2max} with 10 min rests between and a 4th period at 90% VO_{2max}.	18.5 mEq/l diminished $[Na^{+}]$ deficit more than other two drinks.
(89)	Twelve recreational swimmers children (6 boys and 6 girls). 9 – 12 yr.	a) 4% S plus 2% F. b) 4% S plus 2% F. c) 4% S plus 2% F.	a) 0 $mEq \cdot l^{-1}$ b) 8.8 $mEq \cdot l^{-1}$ Na^{+}, 7.1 $mEq \cdot l^{-1}$ Cl^{-}, 3 $mEq \cdot l^{-1}$ K^{+}. c) 18.5 $mEq \cdot l^{-1}$ Na^{+}, 15.5 $mEq \cdot l^{-1}$ Cl^{-}, 3 $mEq \cdot l^{-1}$ K^{+}.	Cycling one 20 min and two 15 min bouts at 50% VO_{2max} followed by a 90% VO_{2max} bout until exhaustion and 10 min rest between bouts.	CHO ingestion had no effect on RPE. Drink composition had no effect on intensity of thirst or stomach fullness sensations or voluntary drinking.
(78)	Twelve boys 9 – 12 yr.	a) 6%	a) NA	Four 20 min cycling bouts at 50% VO_{2max} with a 25 min rest in between and after the last bout.	CHO drink prevents dehydration.
(27)	Twelve recreational sports boys. 9 – 12 yr.	a) 6%	a) 18 $mmol \cdot l^{-1}$ NaCl	Twenty min cycling at 50% VO_{2max} alternating with 25 min rest periods for 180 min.	CHO-E drink prevents dehydration.
(76)	Twelve boys (nine recreational sports and three competitive athletes). 10 – 12 yr.	a) 2% G plus 4% S.	a) 18 $mmol \cdot l^{-1}$ NaCl.	Twenty min cycling at 50% VO_{2max} alternating with 5 min rest in between for 70 min.	CHO-E drink prevents dehydration.

Study	Subjects and Age	Drink composition		Exercise task	Effects of CHO and E intake
		CHO	Electrolytes		
(16)	Twelve heat-acclimatized trained boys. 11 – 14 yr.	a) 6%	a) 18 $mmol \cdot l^{-1} Na$.	Twenty min at 60% VO_{2max} alternating with 25 min rest periods for 180 min.	CHO-E drink prevents dehydration.
(18)	Twelve heats acclimatized trained girls.	a) 6%	a) 18 $mmol \cdot l^{-1} Na^{+}$.	Twenty min exercise at 60% VO_{2max} alternating with 25 min rest periods for 180 min.	Lower fluid loss with the CHO-E drink.
(86)	Twelve habitually active boys 11 – 14 yr.	a) 0% b) 6% G. c) 3% G plus 3% F.	a) 18 $mmol \cdot l^{-1}$ NaCl b) 18 $mmol \cdot l^{-1}$ NaCl c) 18 $mmol \cdot l^{-1}$ NaCl	Thirty min cycling at 55% VO_{2max} alternating with 5 min rest, and performance ride to volitional exhaustion at 90% $VO_{2max.}$	Glucose and fructose intake increase the exercise time to volitional exhaustion after 90 min of prolonged moderate exercise.
(17)	Twenty-four junior elite (9 female netball players, 7 female basketball players and 8 male basketball players). 17.8±1.1	a) 6.8% b) 1%	a) 18.7 $mmol \cdot l^{-1}$ Na+, 3 $mmol \cdot l^{-1} K^{+}$. b) 18.7 $mmol \cdot l^{-1} Na^{+}$, 3 $mmol \cdot l^{-1} K^{+}$.	Nine usual training sessions.	CHO drinks enhance fluid balance.
(90)	Ten recreationally active boys. 9 – 10 yr.	a) 4% S plus 2% G. b) 4% S plus 2% G.	a) 18 $mmol \cdot l^{-1} Na^{+}$ and ~3$mmol \cdot l^{-1} K^{+}$. b) 18 $mmol \cdot l^{-1} Na^{+}$ and ~3$mmol \cdot l^{-1} K^{+}$.	Thirty min at 70% VO_{2max} alternating with 5 min rest periods for 70 min.	CHO ingestion had no effect on RPE.
(23)	Fourteen young tennis players (9 male and 5 female). 15.1±1.4 yr.	a) 6%	a) 21.1 $mmol \cdot l^{-1} Na^{+}$	Tennis specific training sessions for 120 min.	CHO-E drink increases fluid intake and fluid retention and mild lower core body temperature.

Study	Subjects and Age	Drink composition		Exercise task	Effects of CHO and E intake
		CHO	Electrolytes		
(88)	Eleven adolescent wrestlers. 16.1 ± 0.8 yr.	a) 6% b) 0%	a) 18mEq·l^{-1} Na^+ and 3 mEq·l^{-1} K^+. b) 18mEq·l^{-1} Na^+ and 3 mEq·l^{-1} K^+.	After training, they performed 6 min of intermittent, high-intensity arm cranking.	CHO-E ingestion during training may enhance high-intensity intermittent arm work.
(56)	Fifteen male basketball players. 12 – 15 yr.	a) 6% b) 0%	a) 18.0 mmol·l^{-1} Na^+. b) 18.0 mmol·l^{-1} Na^+.	Two hours continuous basketball drills to simulate a game.	Euhydration with a CHO-E improves shooting performance and on-court sprinting.
(72)	Twelve physically active girls. 9-12 yr.	a) 6%	a) 18 mmol·l^{-1} NaCl.	Twenty min cycling at 50% VO_{2max} alternating with 25 min rest for 180 min.	CHO-E drink mildly enhanced voluntary drink.
(75)	Twelve heat-acclimatized girls. 10.6±0.2 yr.	a) 6%	a) 18 mmol·l^{-1} NaCl	Twenty min at 60% VO_{2max} alternating with 25 min rest periods for 180 min.	Lower fluid loss with the CHO-E drink.

NA= not available; CHO = carbohydrates; F = fructose; G = glucose; S = sucrose; E = electrolytes; RPE= rating of perceived exertion.

Table 3. Hydration strategy for physically active children and adolescents

	Before being active	During sport practice	After sport practice
Hydration aim	Euhydration at start*	Prevent > 2% BW dehydration and changes in electrolyte balance	450-675 ml/0.5 kg BW.
Type of beverage	Water + food or Beverage with sodium	Water/Sport beverage	Water + food or sport beverage
Flavour	Beverage with accepted taste (orange, grape, apple…) favours voluntary drinking and rehydration		
Composition of the beverage	~20 – 50 mEq/l [Na^+]	~20 – 30 mEq/l [Na^+] (18-20 mmol/l [NaCl]) ~2 – 5 mEq/l [K^+] ~6 – 7% CHO (30 – 60 g/h)	~20 – 30 mEq/l (1,5 g/l [Na^+]) 3 mEq/l [K^+] (1-2 g/l [K^+]) ~4 – 6 % CHO (0,35 g/kgBW/h during the first 4 – 6 hours).
Temperature of the beverage	15 – 21 ºC	10 – 15 ºC	15 – 21 ºC
Hydration strategy	5 y 7 ml/kg BW (4 hours before the event). 300 – 400 ml, 30 or 40 min before warming-up.	400 – 800 ml/h, drinking in small amounts (i.e.. 100 ml/15 min), beginning to drink after the first 15 or 20 min of exercise. If high sweating rates, recommendations can be higher	Recover optimal hydration status and favour glycogen synthesis in order to avoid a fatigue state.

* Euhydration = urine density ≤1.020 gml^{-1} and osmolarity ≤700 mOsmol, plasma osmolarity ≤ 290 mOsmol.