a review article
received: 2014-11-11

UDC: 796.012-053.2:612.5

THERMOREGULATION IN CHILDREN: EXERCISE, HEAT STRESS & FLUID BALANCE

Shawnda A. MORRISON[1,2], Stacy T. SIMS[3,4]

[1]University of Primorska, Faculty of Mathematics, Natural Sciences and Information Technology, Koper, Slovenia
[2]University Medical Centre, Institute of Clinical Neurophysiology, Division of Neurology Ljubljana, Slovenia
[3]Stanford University School of Medicine, Stanford Prevention Research Centre Stanford, CA, USA
[4]OSMO Nutrition, Inc. 725 Center Blvd, Fairfax, CA, USA

Corresponding author:
Shawnda A. MORRISON
University of Primorska, Titov trg 4, 6000 Koper, Slovenia
Tel: +386 5 6117500, Fax: +386 5 6227530
e-mail: shawndamorrison@hotmail.com

Co-author contact information:
Stacy T. SIMS
OSMO Nutrition, Inc. 725 Center Blvd, Fairfax, CA, USA, 94930
Tel: 415-258-1613,
e-mail: stsims@stanford.edu

ABSTRACT

This review focuses on the specific physiological strategies of thermoregulation in children, a brief literary update relating exercise to heat stress in girls and boys as well as a discussion on fluid balance strategies for children who are performing exercise in the heat. Both sport performance and thermoregulation can be affected by the body's water and electrolyte content. The recommendations for pre-pubertal fluid intake have been generalized from adult literature, including a limited concession for the physiological differences between adults and children. Considering these body fluid shifts, carbohydrate-electrolyte drinks are thought to be an essential tool in combating dehydration as a result of active hyperthermia (i.e. exercise), thus we examine current *hydration practices in exercising children. Finally, this review summarizes research which examines the relationship between cognition and hypohydration on young athletes' performance.*

Keywords: *childhood, cognition, fluid replacement, heat stress, hyponatremia, sweat rate, work*

URAVNAVANJE TEMPERATURE PRI OTROCIH: VADBA, VROČINSKI STRES IN URAVNOVEŠANJE TEKOČIN

POVZETEK

Članek se osredotoča na specifične fiziološke strategije termoregulacije pri otrocih, obsega pa tudi kratek povzetek iz novejše literature, ki se nanaša na vadbo in vročinski stres pri dekletih in fantih, ter razpravo o strategijah uravnovešanja tekočin pri otrocih, ki telovadijo v vročini. Na športne dosežke in termoregulacijo lahko vplivata voda v telesu in vsebnost elektrolitov. Priporočila glede vnosa tekočine v obdobju pred puberteto so posplošena in izhajajo iz literature, ki proučuje odrasle, omejenost se pa kaže pri upoštevanju fizioloških razlik med odraslimi in otroki. Glede na spremembe v količini telesnih tekočin so ogljikohidratne-elektrolitske pijače ključno orodje v boju proti dehidraciji, ki nastopi kot posledica aktivne hipertermije (tj. vadbe), s čimer preučujemo sedanje prakse hidracije pri otrocih, ki telovadijo. V zaključku tega članka pa povzemamo rezultate raziskave, ki proučuje odnos med kognicijo in hipohidracijo ter vplive na dosežke mladih športnikov.

Ključne besede: *otroštvo, kognicija, nadomeščanje tekočin, vročinski stres, hiponatriemija, delež znojenja*

INTRODUCTION AND REVIEW METHODOLOGY

To assist in the compilation of up-to-date, relevant information, we utilised a semi-structured review of the literature beginning with the free-form question "what is the state of knowledge regarding child hydration needs in the case of exercise induced heat strain?" To this end, the population in question focused on children, generally defined as having a pre-pubertal chronological age range between 4 and 12 years old. The study interventions needed to include some form of exercise, or target a particular athletic training cohort, whilst outcomes could be defined in terms of performance, physiological or psychophysical outcome variables (Table 1). Capturing as many relevant sources as possible required using the common Medical Subject Headings (MeSH) from the PubMed database, accessed on Oct. 12th, 2014 (Figure 1). Review articles or non-novel methodology studies were excluded from the review criteria. With this literature as a background, the following information has been gleaned regarding exercise, heat stress and fluid balance in children.

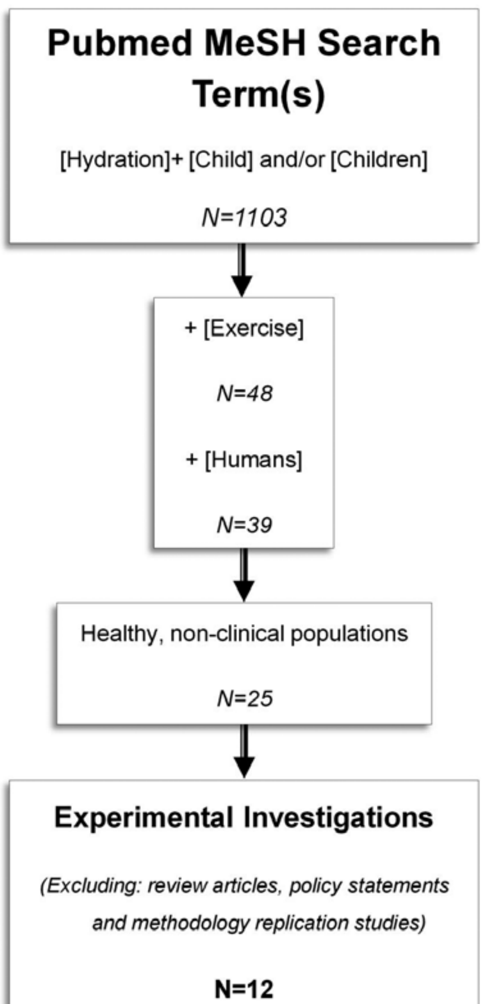

Figure 1: Literature search algorithm for identifying appropriate research articles to include in the present review.

THERMOREGULATION IN CHILDREN

Elevations in core temperature provide the principal stimulus for initiating and controlling heat loss mechanisms (Gisolfi, 1989), thus avoiding premature fatigue and thermal injury. These mechanisms are both autonomic and behavioural in nature. Autonomic responses include the release of vasoconstriction of cutaneous blood vessels, active vasodilation of shunt vessels, and activation of eccrine sweat glands (Gagge & Gonzalez, 1996). Heat is then dissipated primarily via dry (radiation, convection) and wet (evaporation) mechanisms. When exercising in a natural environment, the radiant energy from the sun can contribute a significant heat load to the exercising individual (Nielsen et al., 1988), whilst the increased production of heat from the working muscles further accentuates a rise in core temperature (Asmussen & Boje, 1945). Airflow can impact both dry and evaporative heat transfer, the coefficients of which have been previously established for various airflow velocities using naphthalene sublimation (Nishi & Gagge, 1970). Thus, the ability to maintain heat balance in a given environment is reliant on an individual's metabolic rate, their external work rate, convective, radiative, evaporative and conductive heat exchange, which can also depend on one's cardiovascular and sweating response capabilities.

The ability of pre-pubertal children to regulate their body temperature under thermoneutral conditions remains similar to adults, albeit via different cooling strategies. In a hot environment however, heat-related illnesses can vary from mild (heat rashes, cramps) to severe (heat exhaustion, heat stroke) for any age group. During exercise, core temperature increases relative to work output, and these increases are exacerbated by hot, humid environmental conditions (Reviewed in: Rowland, 2008). Thermoregulation is significantly altered in the paediatric population compared to adults (Bar-Or, 1989) in terms of both morphological and physiological differences between groups when exercising in the heat. Specifically, children rely more heavily on dry mechanisms of heat exchange (conduction, convection), since their sweat output is approximately half that of adults (Meyer et al., 1992), and even individual sweat drop size is smaller, with a gradual increase in drop area as the maturation process continues (Falk et al., 1992). Historically, children were thought to be at a thermoregulatory disadvantage when under environmental heat stress compared to their adult counterparts (Bytomski & Squire, 2003). This may be owing to a greater reliance on increased cutaneous blood flow, which may ultimately reduce cardiac output, especially in the heat. Evidence suggests that incidence rates of heat illness in children may be higher than in adult populations (Adcock et al., 2000; Nakai et al., 1999); however comparative-based research studies are often conducted in laboratory-based environments without the benefit of realistic airflow, or relative work rates, making generalizability to field-based activities difficult.

Exercise as external stressor

Prolonged exercise itself has a marked effect on the cardiovascular system, to such extent that increases in heart rate, decreases in stroke volume, and changes in the distribution of blood flow and volume are significant, ultimately lowering cardiac output and mean arterial blood pressure. An upward drift in the heart rate, known as cardiovascular drift, can occur after only ~10 min of exercise (Pitts et al., 1944). Traditionally, this drift has been attributed to a progressive increase in cutaneous blood flow, by up to eight L•min^{-1}, in attempt to attenuate the rise in core temperature (Rowell, 1993). An increase in the heart rate may be the underlying factor responsible for decreased stroke volumes during prolonged exercise (Fritzsche et al., 1999), although neither theory is mutually exclusive from the other. Indeed, decreases in cardiac filling time due to higher heart rates causing lower stroke volume with hyperthermia can theoretically reduce central blood volume, and central venous pressure, impairing cardiovascular function, especially in conditions where dehydration occurs (González-Alonso et al., 1999).

Dehydration and high core temperature can not only worsen each other, but can independently and additively raise heart rate and decrease stroke volume and cardiac output during upright exercise (González-Alonso et al., 1997). Although sweating is a powerful mechanism of dissipating heat, accounting for up to 600 kcal• hr^{-1} in warm, dry conditions, losses of water can be in excess of two L•hr^{-1} (Rowell, 1983), or more, depending on the training status and the age of the individual. Additional cardiovascular responses include marked changes in regional blood flow, triggering significant volume changes in the central blood reservoir and splanchnic bed due to a reduction in central blood volume, while total blood volume slowly decreases due to sweat and respiratory losses. To exacerbate matters, large amounts of blood continue to be shunted to the periphery with cutaneous vasodilation in attempt to attenuate the rise of core temperature, and subsequent reductions in blood flow to some tissues result from lower blood volume in total, as the thermoregulatory and cardiovascular systems compete for less fluid.

Exercising heat stress in children

Many young athletes train and compete in conditions that place high demands on their body's thermoregulatory mechanisms, in particular high ambient and/or humid conditions. These environmental conditions, coupled with metabolic costs of exercise, can place children at risk for fluid imbalance (i.e. perturbations in body water content within the intra- and extracellular compartments, as well as whole-body electrolyte concentrations). Hypohydration, namely a decrease in whole-body water stores due to combined water and electrolyte losses in sweat, is usually the major health concern during exercise in the heat, whereas hyperhydration is typically a less frequent concern. For the exercising adult, it has been well demonstrated that hypohydration per se can increase skin and core temperature (Cheuvront et al., 2003; Inbar et al., 2004; Horswill et al., 2005), leading to increased cardiovascular strain, especially in the heat. Elevated heart rate and blood pressure during exercise can contribute to a number of physiologically deleterious effects, including: decreased physical performance (primarily during endurance exercise), increased fatigue and the perception of effort, decreased motivation, coupled with increased propensity for injury, including both musculoskeletal and total heat illness (Sawka et al., 2007; Horswill et al., 2005; Sawka et al., 1998; Meyer et al., 1992).

In prepubescent children, there is still a question of the extent to which hypohydration directly contributes to these stressors. Indeed, compared to adults, prepubescent children experience greater proportional increases in core and skin temperatures as they become dehydrated (Inbar et al., 2004; Falk et al., 2008; Meyer et al., 2012). Although heat acclimatization can naturally occur with repeated exposure to hot environments throughout a hot summer season, heat acclimatization occurs more slowly in children (Inbar et al., 2004; Falk et al., 2008), possibly predisposing them to overt heat illness(es). Factors which contribute to increased thermal strain in children include: a lower sweat rate and a higher metabolic cost of locomotion (to such extent that there is more heat produced and less dissipated for a given activity), in addition to a higher surface area to body mass ratio. Finally, there is an emerging concern of an increased possibility of hyponatremia in active children, especially in the view of the popular "drink lots of water" recommendation(s) espoused in the popular literature. Clinically, hyponatremia is defined as a serum sodium level of $<135 \text{mEq L}^{-1}$, which includes a rapid lowering of blood sodium. Note that blood sodium concentrations usually rest between ~140-145 mEq L^{-1}; thus, with the rapid ingestion of plain water, blood sodium dilution is a technical, if not rare, possibility for exercising children.

Table 1: Overview of the studies (N = 12) which include pre-pubertal child populations, and an exercise/or a hydration component to their experimental investigations.

Study	Sample Population	Study Intervention	Main Study Outcome(s)
Bergeron, MF et al, 2009	N = 24 athletes (age 12 −13, N = 6 boys, N = 6 girls, and age 14 - 16 y, N = 6 boys, N = 6 girls)	Two 80-min intermittent exercise bouts (treadmill 60 %, cycle 40 % peak oxygen uptake) in 33° C, 49 % relative humidity	Sweat loss, core temperature, physiological strain index and thermal sensation were not different between either age groups or between girls/boys. RPE higher in 16 − 17 y group on exercise bout 2 compared to bout 1. One-h rest between bouts with hydration matched to mass loss was adequate recovery for second exercise bout.
Hewitt, MJ et al 1993	N = 28 healthy children (5 − 10 y), N = 31 young adults (22 − 39 y), N = 62 older adults (65 − 84 y)	Determination of water : FFM via $2H_2O$ dilution method and Siri 2-component modelling	Prepubescent children (72.7 +/- 1.6 %) and older adults (72.5 +/- 1.4 %) have significantly higher ($P < 0.01$) mean W/FFM than young adults (70.8 +/- 1.2 %).
Hill et al, 2008	Rest and exercise groups	Comparison of 3 sports drinks with water [rest + exercise (55 % max HR on treadmill)] using deuterium dilution technique. Rest = 0.05g/kg of deuterium (gelatine capsules), saliva samples collected every 5 min for 1 h. kinetics modelled to derive hydration data.	NS differences in max absorption rate at rest or by the end of exercise; concluded that the sports drinks studied did not hydrate the body at a faster rate compared to water.
Kavouras et al, 2012	N = 92 children (age 13.8 ± 1.2 y), N = 31 control (N = 13 boys,18 girls) N = 61 intervention (INT) (N = 30 boys, 31 girls)	Educational intervention in schools where the intervention group attended a lecture on hydration and urine colour charts placed in bathrooms	Hydration status (USG) improved from 1.031 to 1.023 in INT group. Endurance run time for 600 m distance improved in INT group only (from 189 to 167 s)

Study	Sample Population	Study Intervention	Main Study Outcome(s)
Rivera-Brown et al, 2008	N = 12 trained, heat-acclimatized girls (11 y)	Three 3-h sessions of four 20-min cycling bouts (60 % $\dot{V}O_{2peak}$), alternating w 25 min rest. One of three beverages (ad libitum): unflavored water (W), flavored water (FW) or flavored water plus 6 % carbohydrate and 18 mmol/l NaCl (CNa).	Sweat loss, HR, rectal temperature not different between trials; urine produced was 73 and 68% lower [corrected] during CNa compared to [corrected] FW and W (W = 269.8 +/- 85.9; FW = 320.8 +/- 87.2; CNa = 85.6 +/- 9.3 g). Flavoured water and 6 % CHO + 18 mmol/l NaCl do not prevent mild hypohydration
Riviera-Brown et al, 1999	N = 12 trained, heat-acclimatized boys (13 y)	Two 3-h exercise sessions of four 20 min cycling at 60 % $\dot{V}O_{2peak}$, alternating 25 min rest. One of two beverages was assigned: unflavored water (W) or flavored water plus 6 % CHO and 18 mmol/l Na (CNa) ad libitum.	Total intake was higher with CNa (1,943 6 190 g) v W (1,470 6 143 g). Euhydration was maintained with CNa; mild dehydration with W. Flavored CHO-electrolyte drink prevents voluntary dehydration in boys exercising in the heat despite sweat losses.
Rowland et al, 2008	N = 8 boys, Tanner stage 11 y	Cycle at 63 % $\dot{V}O_{2peak}$ to exhaustion (~41 min) in a thermoneutral environment to characterize cardiovascular drift	Rectal temperature (fm 37.6° C to 38.1° C. HR +13 %, Q +15 %, systemic vascular resistance fell by 10.5 %, SV remained stable. Concluded that similar pattern of CV strain as adult men.
Rowland et al, 2007	N = 8 healthy non-acclimatized, highly physically active prepubertal boys	Steady-load cycling [65 % $\dot{V}O_{2peak}$ to exhaustion in cool (20°C, 66 % rh) and hot (31° C, 57 % rh)	Endurance time significantly shorter in the heat (29 ± 6 v 41 ± 6 min). NS in circulatory markers, hydration status or RPE between conditions. Rate of rise of Tre greater in the heat, but NS in Tre at exhaustion. Authors argue that rises in core temperature and/or brain perception (RPE) rather than circulatory insufficiency may be the critical factors defining limits to exercise in the heat for prepubertal boys.
Wang, S et al 2013	N = 102 (age 5 −60 y) divided into 5 groups	Exercise-induced sweating on facial sebum, changes in skin surface pH at rest, beginning of sweating, excessive sweating and 1-h post sweating	Excessive sweat from exercise did not impair the surface pH of facial skin; no consequential differences between age groups
Wilk et al, 2007	N = 12 physically active girls (9 − 12 y)	Assess the influence of drink flavor and composition on voluntary drinking and hydration status in girls; exercise intermittently in the heat (35° C , 45 − 50 % rh)	Difference in body mass between water (-0.15 %) and grape-flavored water +6 % CHO, and 18 mmol l NaCl trial (-0.45 %); NS between any other physiological or psychophysical variable between trials. Euhydration maintained by adequate intake of unflavored water.

Study	Sample Population	Study Intervention	Main Study Outcome(s)
Wilk et al, 1998	N = 12 healthy boys (10 − 12 y)	Six 70-min intermittent exercise sessions [three 20-min cycling (50 % $\dot{V}O_{2peak}$ 5 min rest in between)] at 35° C, 50 % or 60 % rh.	NS between the six sessions in: drink intake (765 − 902 g), hydration level (+0.75 to +1.07 % BM), sweat rate (245 − 263 $g.m^{-2}.hr^{-1}$), all other physiological + perceptual variables. Grape-flavored CHO-NaCl beverage sufficient to prevent dehydration during repeated exercise in the heat.
Wilk & Bar-Or, 1996	N = 12 boys (9-12 y)	Three 3-h sessions [four 20 min cycling (50 % VO2, followed by 25-min rest) in 30° C , 45 − 50 % rh]. One of three beverages (Latin-square sequence): unflavored water (W), grape-flavored water (FW), and grape-flavored water plus 6 % CHO + 18 mmol/l NaCl (CNa).	NS between trils in BM, HR, rectal and skin temperatures, thirst, stomach fullness; hypohydration seen with W (-0.65 % BM) and FW (-0.32 % BM), and CNa = slight overhydration (+0.47 % BM).

Notes: BM, body mass; CHO, carbohydrate; CV, cardiovascular; FFM, fat-free mass; HR, heart rate; NS, no significance; RH, relative humidity; RPE, ratings of perceived exertion; USG, urine specific gravity; VO_{2peak}*, aerobic capacity; y, years.*

CURRENT HYDRATION PRACTICES IN EXERCISING CHILDREN

The clinical paediatrics profession and the World Health Organisation (WHO) each have specific recommendations addressing rehydration/hydration strategies for combating illness-induced dehydration which are defined as body water losses > 4 % (Bergeron et al., 2011; Popkin et al., 2010), but there are no such recommendations for exercise-induced body water losses of <3 %. The majority of body water losses seen during active play and even intense physical activity in children rarely exceeds 3 % of the total body mass. To address this concern, the scientific and medical literature recently published guidelines to describe what and how much an active, pre-pubescent child should drink (Bergeron et al., 2011), although it is admittedly difficult to formulate a single hydration guideline which can encompass all young athletes. Relative to their body size, children demonstrate less total sweat water and sodium losses during exercise than adults (0.25 – 0.65L h^{-1} and 0.19-0.27 g h^{-1} Na^+ loss vs 1.5-3.0L h^{-1} and 0.8-4.0 g h^{-1} Na^+ loss, in children vs. adults, respectively) (Meyer et al., 1992; Meyer et al., 2012).

Although the percentage levels of incurred dehydration are similar in pre- and post-pubertal athletes, there are differences in levels of hypohydration and subsequent performance decrements in children. For example, a 2 % or greater body mass loss in adults can result in significant, measurable decreases in aerobic and muscular performance (Cheuvront et al., 2003; Sawka & Noakes, 2007), whereas only a 1 % loss in pre-pubertal children has been shown to elicit similar performance decrements (Meyer et al., 2012). In contrast to adults, if children are given adequate opportunity to drink during exercise, the fluid volume intake driven by thirst alone is expected to prevent significant levels of dehydration in the young athlete. This is primarily due to the children's lower sweat rates compared to their adult counterparts (Falk & Dotan, 2008; Meyer et al., 1992). Required fluid intake for children during exercise training can be conservatively calculated as an hourly fluid intake volume of 13 mL/kg bodyweight (Rowland, 2011).

Equally important is post-exercise fluid replenishment (approximately 4 mL/kg) for each hour of the completed exercise. This rehydration strategy would avoid initiating subsequent exercise bouts in a dehydrated state (Rowland, 2011; Unnithan et al., 2004). Given the above-mentioned factors differentiating young athletes from their adult counterparts (less sweat-sodium and fluid losses during activity, concomitant lower body mass loss impacting performance), additional research into the composition of hydration products and optimal fluid ingestion strategies are needed.

THE HYDRATION − COGNITION LINK

The effect of hypohydration in the paediatric *athletic* population has not been well studied. It is well documented that hypohydration is associated with disruptions in mood and cognition, in both adults and non-athletic children. Specifically, alterations in concentration, alertness and short-term memory, and psychomotor skills are observed. Cognitive and reaction abilities (in addition to physical conditioning) can significantly affect performance outcomes in both game and team sport situations. When examining the relationship between cognition and the impact hypohydration may have on young athletes' performance, the evidence appears to be equivocal. Edmonds and Burford (2009) observed children (7 to 9 year old boys) who were randomly allocated into two groups; an experimental group that received additional water (211.7 ± 62 ml) 20 min prior to cognitive testing, and a control group, which received no additional water. The group given additional water showed improvements in visual attention, although visual memory was unaffected. In research described by Benton and Burgess (2009), memory performance was improved by provision of water, but sustained attention was not altered in the same group of children. Bar-David et al. (2005) observed children (10 to 12 years old) who were identified as either euhydrated or dehydrated in the morning of testing. Regardless of hydration status, results from the cognition tasks were not significantly different between groups. However, by midday, the euhydrated group did perform significantly better on short-term memory, verbal analogy and visual attention tasks than the (initially) dehydrated group. Moreover, Fadda et al. (2012) also observed significant improvements in short-term memory in 9 to 10 year old children who were provided 1000 ml supplementary water throughout the school day. Taken together, these results indicate a connection between hydration status and cognitive function abilities in children, especially throughout the school day, and that giving children an opportunity to drink may enhance certain cognitive abilities, including but not limited to: short-term memory, visual attention, verbal analogy, and perhaps visual memory.

The possibility exists that children are particularly susceptible to hypohydration due to inadequate fluid intake, given their large surface area to volume ratio, and higher levels of activity and immature thirst mechanisms. For example, one study asked 10 to 12 year olds to cycle in 39° C; in one trial they drank when they were thirsty, whilst in the second trial they drank enough water to replace fluid losses. It was only when drinking to thirst that the children became progressively dehydrated (Bar-Or et al., 1980), data which was consistent to the theory that children's thirst mechanisms are not being fully operational at this age (Kenney & Chiu, 2001). Indeed, drinking attitudes and the amount of fluid active children ingest are influenced by a number of factors, primarily: sport modality, the type of competition, practice duration, fluid availability, and the characteristics (flavour, temperature) of the beverage available (Broad et al., 1996; Meyer et al., 1994; Rivera-Brown et al, 1999). As the aforementioned factors can influence the hydration practices of the pre-pubescent athlete, sufficient and appropriate fluid should be provided on-site (with education around hydration status), and children should be encouraged to create appropriate hydration strategies with their coaches encompassing before, during and after sporting activity to promote euhydration and overall fluid balance in young athletes.

REFLECTIONS AND RECOMMENDATIONS

We chose to examine a "snap-shot" of the current literature regarding exercising children, heat stress and hydration practices. Although this work used a semi-systematic approach, utilising one major electronic search engine, we believe this method was robust enough to reveal a paucity of research data in the sport science child-hydration field in general, and a lack of experimental data in particular within this population.

CONCLUSIONS

A greater focus on children's hydration status and specific hydration requirements for peak performance (either for physical or cognitive development) is a research area with a dearth of high-quality, peer-reviewed experimental investigations. In contrast to adults, if children are given adequate opportunity to drink during exercise, the fluid volume intake driven by thirst alone is expected to prevent significant levels of dehydration in the young athlete. This is primarily due to the children's lower sweat rates compared to their adult counterparts.

Acknowledgements and Disclosures

No external funding was used for manuscript preparation. A portion of this work was presented as an invited keynote address for "A Child in Motion" Conference in Portorož, Slovenia on Oct 3rd, 2014. Dr. Morrison's research has been supported by the Gatorade Sport Science Institute (2002, 2004); funds were used to purchase research consumables related to various exercise-thermoregulation projects. The company had no input on study research design, or access to data or any manuscript preparations. Dr. Sims is a co-founder and a Chief Research Officer of OSMO nutrition, an exercise performance-based nutrition company.

REFERENCES

Adcock, M. P., Bines, W. H., & Smith, F. W. (2000). Heat-related illnesses, deaths, and risk factors–Cincinnati and Dayton, Ohio, 1999, and the United States, 1979–1997. Morbidity and Mortality Weekly Report, 49, 470–473.

Asmussen, E., & Boje, O. (1945). Body temperature and capacity for work. Acta Physiologica Scandinavica, 10, 1–22.

Bar-David, Y, Urkin, J., & Kozminsky, E. (2005). The effects of voluntary dehydration on cognitive functions of elementary school children. Acta Paediatrica, 94, 1667–1673.

Bar-Or, O. (1989). Temperature regulation during exercise in children and adolescents. In C. V. Gisolfi, & D. R. Lamb (Eds.), Perspectives in Exercise Science and Sports Medicine. Youth, Exercise and Sport (Vol. 2, pp. 335–362). Indianapolis: Benchmark.

Bar-Or, O., Dotan, R., Inbar, O., Rotshtein, A., & Zonder, H. (1980). Voluntary hypohydration in 10- to 12-year-old boys. Journal of Applied Physiology, 48, 104–108.

Benton D., & Burgess N. (2009). The effect of the consumption of water on the memory and attention of children. Appetite, 53(1), 143–146.

Bergeron, M. F., Devore, C., & Rice, S. G. (2011). Policy Statement: Climatic heat stress and the exercising child and adolescent. Pediatrics, 128(3), e741–e747.

Bergeron, M. F., Laird, M. D., Marinik, E. L, Brenner, J. S., & Waller, J. L. (2009). Repeated-bout exercise in the heat in young athletes: physiological strain and perceptual responses. Journal of Applied Physiology, 106(2), 476–485.

Broad, E. M., Burke, L. M., Cox, G. R., et al. (1996). Body weight changes and voluntary fluid intakes during training and competition sessions in team sports. International Journal of Sport Nutrition, 6, 307–320.

Brown, M. B., Millard-Stafford, M., & Casner, M. R. (2008). Sweat rates in circumpubertal children versus adults matched by fitness [abstract]. Medicine and Science in Sport and Exercise, 40, S187.

Bytomski, J. R., & Squire, D. L. (2003). Heat illness in children. Current Sports Medicine Reports, 2, 320–324.

Cheuvront, S. N., Carter, R., & Sawka, N. (2003). Fluid balance and endurance performance. Current Sports Medicine Reports, 2, 202–208.

Edmonds, C. J., & Burford, D. (2009). Should children drink more water? The effects of drinking water on cognition in children. Appetite, 52(3), 776–779.

Fadda, R., Rapinett, G., Grathwal, D., et al. (2012). Effects of drinking supplementary water at school on cognitive performance in children. Appetite, 59, 730–737.

Falk, B., & Dotan, R. (2008). Children's thermoregulation during exercise in the heat: a revisit. Applied Physiology Nutrition Metabolism, 33, 420–427.

Falk, B., Bar-Or, O., Calvert, R., & MacDougall, J. D. (1992). Sweat gland response to exercise in the heat among pre-, mid-, and late pubertal boys. Medicine and Science in Sports and Exercise, 24, 313–319.

Fritzsche, R. G., Switzer, T. W., Hodgkinson, B. J., & Coyle, E. F. (1999). Stroke volume decline during prolonged exercise is influenced by the increase in heart rate. Journal of Applied Physiology, 86, 799–801.

Gagge, A. P., & Gonzalez, R. R. (1996). Mechanisms of heat exchange: biophysics and physiology. In M. J. Fregly, & C. M. Blatteis (Eds.), Handbook of Physiology: Environmental Physiology (Vol. 1, pp. 45–84). New York: Oxford University Press.

Gisolfi, C. (1987). Influence of acclimatization and training on heat tolerance and physical endurance. In J. R. S. Hales, & D. A. B. Richards (Eds.), Heat Stress: physical exertion and environment (pp. 335–366). Amsterdam: Elsevier.

González-Alonso, J., Mora-Rodriguez, J. R., Below, P. R., & Coyle, E. F. (1997). Dehydration markedly impairs cardiovascular function in hyperthermic endurance athletes during exercise. Journal of Applied Physiology, 82(4), 1229–1236.

González-Alonso, J., Mora-Rodriguez, J. R., & Coyle, E. F. (1999). Supine exercise restores arterial blood presure and skin blood flow despite dehydration and hyperthermia. American Journal of Physiology, 277, H576–H583.

Hewitt, M. J., Going, S. B., Williams, D. P., & Lohman, T. G. (1993). Hydration of the fat-free body mass in children and adults: implications for body composition assessment. American Journal of Physiology, 265(1 Pt 1), E88–95.

Hill, R. J., Bluck, L. J., & Davies, P. S. (2008). The hydration ability of three commercially available sports drinks and water. Journal of Science and Medicine in Sport, 11(2), 116–123.

Horswill, C. A., Horn, M. K., Stofan, J. R., et al. (2005). Adequacy of fluid ingestion in adolescents and adults during exercise. Pediatric Exercise Science, 17, 41–50.

Inbar, O., Morris, N., Epstein, Y., et al. (2004). Comparison of thermoregulatory responses to exercise in dry heat among prepubertalboys, young adults and older males. Experimental Physiology, 89, 691–700.

Iuliano, S., Naughton, G., Collier, G., et al. (1998). Examination of the self-selected fluid intake practices by junior athletes duringa simulated duathlon event. International Journal of Sports Medicine, 8, 10–6.

Kavouras, S. A., Arnaoutis, G., Makrillos, M., Garagouni, C., Nikolaou, E., Chira, O., et al. (2012). Educational intervention on water intake improves hydration status and enhances exercise performance in athletic youth. Scandinavian Journal of Medicine Science and Sports, 22(5), 684–689.

Kenney, W. L., & Chiu, P. (2001). Influence of age on thirst and fluid intake. Medicine and Science in Sport and Exercise, 33, 1524–1532.

Meyer, F., Bar-Or, O., MacDougall, D., et al. (1992). Sweat electrolyte loss during exercise in the heat: effects of gender and maturation. Medicine and Science in Sport and Exercise, 24, 776–81.

Meyer, F., Bar-Or, O., Passe, D., & Salberg, A. (1994). Hypohydration during exercise in children: effect on thirst, drink preferences, and rehydration. International Journal of Sport Nutrition, 4, 22–35.

Meyer, F., Volterman, K. A., Timmons, B. W., & Boguslaw, W. (2012). Fluid balance and dehydration in the young athlete: Assessment considerations and effects on health and performance. American Journal of Lifestyle Medicine, 6, 489–501.

Nakai, S., Itoh, T., & Morimoto, T. (1999). Death from heat-stroke in Japan: 1968–1994. International Journal of Biometeorology, 43, 124–127.

Nielsen, B., Kassow, K., & Aschengreen, F., E. (1988). Heat balance during exercise in the sun. European Journal of Applied Physiology, 58, 189–196.

Nishi, Y., & Gagge, A. P. (1970). Direct evaluation of convective heat transfer coefficient by naphthalene sublimation. Journal of Applied Physiology, 29(6), 830–838.

Pitts, G. C., Johnson, R. E., & Consolazio, F. C. (1944). Work in the heat as affected by intake of water, salt and glucose. American Journal of Physiology, 142, 253–259.

Popkin, B. M., D'Anci, K. E., & Rosenberg, I. H. (2010). Water, Hydration and Health. Nutrition Reviews, 68(8), 439–458.

Rivera-Brown, A. M., Gutiérrez, R., Gutiérrez, J. C., Frontera, W. R., & Bar-Or, O. (1999). Drink composition, voluntary drinking, and fluid balance in exercising, trained, heat-acclimatized boys. Journal of Applied Physiology, 86(1), 78–84.

Rivera-Brown, A. M., Ramírez-Marrero, F. A., Wilk, B., Bar-Or, O. (2008). Voluntary drinking and hydration in trained, heat-acclimatized girls exercising in a hot and humid climate. European Journal of Applied Physiology, 103(1), 109–116.

Rowell, L. B. (1993). Human cardiovascular control. New York: Oxford University Press.

Rowland, T., Garrison, A., & Pober, D. (2007). Determinants of endurance exercise capacity in the heat in prepubertal boys. International Journal of Sports Medicine, 28(1), 26–32.

Rowland, T., Pober, D., & Garrison, A. (2008). Cardiovascular drift in euhydrated prepubertal boys. Applied Physiology Nutrition and Metabolism, 33(4), 690–695.

Rowland, T. (2008). Thermoregulation during exercise in the heat in children: old concepts revisited. Journal of Applied Physiology, 105, 718–24.

Rowland, T. (2011). Fluid replacement requirements for child athletes. Sports Medicine, 41(4), 279–288.

Sawka, M. N., Latzka, W. A., Matott, R. P., & Montain, S. J. (1998). Hydration effects on temperature regulation. International Journal of Sports Medicine, 19 (Suppl 2), S108–S110.

Sawka, M. N., & Noakes, T. D. (2007). Does dehydration impair exercise performance? Medicine and Science in Sport and Exercise, 39, 1209–1217.

Unnithan, V. B., & Goulopoulou, S. (2004). Nutrition for the pediatric athlete. Current Sports Medicine Reports, 3(4), 206–211.

Wilk, B., & Bar-Or, O. (1996). Effect of drink flavor and NaCL on voluntary drinking and hydration in boys exercising in the heat. Journal of Applied Physiology, 80(4), 1112–1117.

Wilk, B., Kriemler, S., Keller, H., & Bar-Or, O. (1998). Consistency in preventing voluntary dehydration in boys who drink a flavored carbohydrate-NaCl beverage during exercise in the heat. International Journal of Sport Nutrition, 8(1), 1–9.

Wilk, B., Rivera-Brown, A. M., & Bar-Or, O. (2007). Voluntary drinking and hydration in non-acclimatized girls exercising in the heat. European Journal of Applied Physiology, 101(6), 727–734.

Wang, S., Zhang, G., Meng, H., & Li, L. (2013). Effect of Exercise-induced sweating on facial sebum, stratum corneum hydration, and skin surface pH in normal population. Skin Research and Technology, 19(1), e312–317.