

Environmental Conditions

SSE #49: Children's Responses to Exercise in Hot Climates: Implications for Performance and Health

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CHILDREN'S RESPONSES TO EXERCISE IN HOT CLIMATES:
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KEY POINTS

1. Compared with adolescents and adults, children produce more heat relative to body mass during activities such as walking and running, they have a low sweating capacity, and their body core temperature rises at a higher rate during dehydration.
2. These differences do not interfere with children's ability to sustain exercise unless climatic heat stress is extreme.
3. There are no adequate scientific comparisons of the incidence of heat-related illness in children and adults, but certain childhood diseases enhance the risk for a heat-related illness.

INTRODUCTION

Children's physiologic responses to exercise are generally similar to those of adults, but there are several age and maturation-related differences in their responses. For example, children respond to the combined stresses of exercise and climatic heat differently than do adults (Table 1).

While some of the characteristics of children's responses to exercise in the heat (e.g., low sweating rate per gland, high concentrations of lactic acid in sweat and lower cardiac output) are of theoretical interest, others (e.g., high metabolic heat of locomotion, shorter exercise tolerance time, slower acclimatization rate, rapid increase in core temperature during dehydration) are of practical importance to the child's performance, well-being, and health. The purpose of this article is to focus on the latter characteristics, highlighting the implications of these factors for performance and health. Although such implications are important to all children, they are of particular relevance to children with certain conditions and diseases that put them at a high risk for heat-related illness.

Characteristic	Typical for Children, vs Adults
Metabolic heat of locomotion	Higher
Sweating rate per m ² skin	Lower
Sweating rate per gland	Much lower
Sweating threshold	Higher
Population density of HASG	Higher
Cardiac output/L O ₂ uptake	Lower
Blood flow to skin	Higher
Sweat NaCl content	Lower
Sweat Lactate and H ⁺	Higher
Exercise tolerance time	Shorter
Acclimatization to heat	Slower
Core temp. rise with dehydration	Faster

¹HASG = heat-activated sweat glands

RESEARCH REVIEW

Physiologic Responses. For detailed reviews of children's responses to the combined stresses of exercise and climatic heat, see Bar-Or (1980; 1983; 1989). The following is an overview of the main findings of numerous studies which suggest that, compared with adults, children are at some disadvantage when they exercise in a hot environment.

The need to dissipate heat from the body is amplified during exertion because of the metabolic heat that is created during muscle contraction. For reasons not entirely clear, children's metabolic heat production per kg body mass is greater than in adults during walking and running (Astrand, 1952; MacDougall et al., 1983); this imposes an extra load on their thermoregulatory systems. The smaller the child, the greater is the excess in heat production. For example, there may be as much as a 25-30% excess heat production in an 8-year-old child.

The rate of heat exchange between the body and the environment increases with increasing body surface area. Children's surface area-to-mass ratio is greater than in adults and, as a result, they are exposed to a faster influx of heat when environmental temperature exceeds skin temperature.

During exercise in hot climates, evaporation of sweat is the main avenue for heat dissipation. It is the only means for cooling the body when ambient temperature exceeds skin temperature. Children have a lower sweating rate per sweat gland than do adults (Bar-Or, 1980; Falk et al., 1992a). Even though the number of heat-activated sweat glands per unit skin area is much higher in children

(Falk et al., 1992a; Inbar 1978) the total sweating rate, even when calculated per unit surface area, is lower in children (Araki et al., 1979; Falk et al., 1992a). This difference may result from a lower anaerobic energy turnover in children's sweat glands (Falk et al., 1991). Also, under certain conditions the sweating threshold (i.e., the core temperature at which sweating starts) is considerably higher in children than in adults (Araki et al., 1979). The transition from a childhood sweating pattern to that of adulthood occurs during the early stages of puberty (Falk et al., 1992a; 1992c).

The most efficient way of moving heat from body core to the skin is by convection through the blood. To increase the rate of convection, blood flow to the skin must increase. While the percentage of cardiac output that goes to the skin may be higher in children than in adults during exercise in the heat (Drinkwater et al., 1977; Falk et al., 1992b), the overall cardiac output per unit of oxygen uptake is somewhat lower in children (Bar-Or, 1983).

Other differences between children and adults are in the composition of sweat. As shown by Meyer et al. (1992), the concentrations of Na⁺ and Cl⁻ are higher in preand mid-pubescent girls and boys than in young adult women and men, respectively. On the other hand, concentrations in sweat of lactate, H⁺ and K⁺ are higher in children (Falk et

al., 1992b; Meyer et al., 1992).

PRACTICAL IMPLICATIONS

Implications to Physical Performance. Do the above physiologic characteristics of children impede their ability to perform exercise under climatic heat stress? Regretably, there are not enough studies that allow us to answer this question definitively. It seems that when children are exposed to mild temperatures (Davies, 1981), or even to moderate hot-dry conditions, e.g., 42°C, 20% relative humidity, (Falk et al, 1992b), they manage to thermoregulate effectively. Nor does moderate climatic heat stress impede their performance in high-intensity short-term exercise (Dotan & Bar-Or, 1980). There are, however, laboratory and field-based observations which suggest that, when the climatic heat stress is severe, children's exercise tolerance time is shorter than that of adults (see Bar-Or, 1980; 1989 for review).

Upon transition from a cool to a warm or hot climate, it usually takes several exposures to the new climate until acclimatization takes place. When 8-10 year old boys were exposed in a climatic chamber to a hot-dry environment (80min exposures to 43°C, 21% relative humidity, 3 times weekly) they managed to acclimate. However, the rate of acclimation was considerably slower in the children than in young adults (Bar-Or, 1980; Inbar, 1978): the adults needed one week to achieve a reasonable acclimation; the children required two weeks. Likewise, boys aged 11-14 years acclimated less effectively to 47.7-49°C, 17% relative humidity than did adolescents and young adults (Wagner et al., 1972). The practical implication is that when young sports participants are confronted with warmer climatic conditions, their training dosage should first be reduced and then increased at a more gradual rate than for the more mature competitor. When untrained children were given aerobic training (60-min sessions at 85% HR max) in a thermoneutral environment for two weeks, the average rise in their core temperatures during exercise in the heat was attenuated following training in a manner similar to that seen following acclimation (Inbar et al., 1981). This suggests that training per se can decrease the physiologic strain experienced by children during exercise in hot climates.

Implications to Health. Ellis et al. (1976) stated that during climatic heat waves, young children (and elderly people) are at a high risk for heat-related illness. Furthermore, Knochel (1975) stated that heat-related illness ranks second to head injury as a cause of death in secondary school youths. However, in spite of apparent relative deficiencies in children's physiologic responses to combined metabolic and climatic heat stresses, there are no epidemiologic data that document a higher susceptibility to heat-related illness among children compared to adults.

There are, though, certain groups of children and adolescents who are at a particularly high risk of heat illness. The conditions and diseases listed in the table in the supplement section are presented alphabetically and not in order of prevalence or severity. One common denominator among several of these conditions is that they may induce hypohydration, either through excessive fluid loss or insufficient drinking. Conditions that may induce excessive fluid loss include: bulimia, congenital heart disease, diabetes mellitus, diabetes insipidus, gastroenteritis, high fever, obesity, and vomiting. Insufficient drinking may exist in anorexia nervosa, cystic fibrosis, mental retardation, and renal failure. It is beyond the scope of this article to describe the mechanisms by which hypohydration impedes the child's ability to dissipate heat. One should realize, however, that a reduction in plasma volume consequent to hypohydration may reduce sweating rate and the flow of blood (and heat) to the skin.

Conversely, there are conditions in which sweating rate is low, and this may impede the child's evaporative cooling. For example, an unacclimatized young athlete who exercises in a warm environment is at high risk for heat-related illness, including fatal heatstroke (Barcenas et al., 1976; Fox et al., 1966; Redfearn, 1969), presumably because of a low sweating rate. In adults, low aerobic fitness, which is accompanied by a relatively low sweating rate and a high core temperature during exercise, is considered a risk for heat-related illness. However, it is controversial whether children's aerobic fitness affects their core temperature (Araki et al., 1979; Docherty et al., 1986; Inbar et al., 1981; Matsushita & Araki, 1980) and, thus, their well-being in hot climates.

Obesity is an advantage in the cold, but a liability in hot climates. Most of the available information on this topic is related to adults. As shown by Haymes et al. (1975), rectal temperature and heart rate rose faster in mildly obese (31.2% fat) boys than in leaner controls during 70-min of intermittent exercise and rest at 40-42°C, 25% relative

humidity. Possible reasons for the relatively deficient thermoregulation ability in the obese include the following: 1) Fat has a low specific heat, which means that a relatively small amount of heat is needed to increase the temperature of a given mass of fat. 2) Fat has a lower water content than most other tissues. As a result, any given level of hypohydration denotes a relatively higher percentage of water loss in obese than in lean persons. 3) Obese children, as a group, have a low maximal aerobic capacity. Thus, when they exercise at the same intensity as their nonobese peers their relative effort is greater and, on average, the rise of their core temperature is higher.

Voluntary Dehydration and its Prevention. Children, like adults, do not drink enough when offered fluids ad libitum during exercise in the heat (Bar-Or et al., 1980; 1992). However, one important difference is that for any given level of hypohydration, children's core temperatures rise faster than those of adults (Bar-Or et al., 1980). The moral is that one should try to prevent, or markedly reduce, "voluntary dehydration" in children. This can be achieved by instructing and encouraging children to drink above and beyond thirst at frequent intervals, e.g., every 20 minutes (Bar-Or et al., 1980; 1992). A rule of thumb based on our experience is that a child 10years-old or younger should drink until he or she does not feel thirsty and should then drink an additional half a glass (100-125 mL). Older children and adolescents should drink a full glass extra. When relevant, regulations for competition should be modified to allow children to leave the playing field periodically in order to drink.

To enhance a child's willingness to drink, beverages should be palatable and should stimulate further thirst. Prepubertal and early pubertal girls and boys prefer grape flavor to apple and orange flavors or water (Meyer et al., 1994). This preference was apparent at rest, following a maximal aerobic test, and during a rehydration stage after prolonged exercise in a hot-dry environment. It is not clear whether the lower NaCl content in children's sweat (Meyer et al., 1992) justifies the use of more dilute beverages for children than for adults. More research is needed to identify the optimal beverage content for the exercising child.

SUMMARY

There are several physiological characteristics, mostly related to sweating pattern and to the production of metabolic heat, that put children at a thermoregulatory disadvantage compared to adults when they exercise in a hot or humid environment. While children thermoregulate effectively during exercise in thermoneutral or moderately hot environments, their exercise tolerance time is reduced, compared with adults, when the climatic heat stress is extreme.

There is no conclusive evidence that the incidence and severity of heat-related illness are greater in children than in adolescents or adults. There are, however, certain diseases that put the child patient at excessive risk for heat-related illness. Because such consequences are all preventable, recognizing how they originate and identifying the children at high risk are of utmost importance. Special attention should be paid to securing optimal fluid intake during prolonged exercise in the heat, because hypohydration can promote heat-related illness, including fatal heatstroke. A drinking regimen should be encouraged and enforced in which the child periodically drinks more than the volumes dictated by thirst alone.

References

- Araki, T., Y. Toda, K. Matsushita, and A. Tsujino (1979). Age differences in sweating during muscular exercise. *Jap. J. Phys. Fitness Sports Med.* 28: 239-248.
- Astrand P.O. (1952). *Experimental Studies of Physical Working Capacity in Relation to Sex and Age*. Copenhagen: Munksgaard.
- Barcenas, C., H.P. Hoeffler, and J.T. Lie (1976). Obesity, football, dog days and siriasis: a deadly combination. *Am. Heart. J.* 92: 237-244.
- Bar-Or, O (1980). Invited review climate and the exercising child. *Int. J. Sports Med.* 1: 53-65.

Bar-Or, O. (1983). *Pediatric Sports Medicine for the Practitioner. From Physiologic Principles to Clinical Applications*. New York: Springer Verlag.

Bar-Or, O. (1989). Temperature regulation during exercise in children and adolescents. In: C. Gisolfi and D.R. Lamb (eds.) *Perspectives in Exercise*

Science and Sports Medicine. Vol 2: Youth, Exercise, and Sport. Indianapolis: Benchmark Press, pp. 335-367.

Bar-Or, O., C.J.R. Blimkie, J.A. Hay, J.D. MacDougall, D.S. Ward, and W.M. Wilson (1992). Voluntary dehydration and heat intolerance in patients with cystic fibrosis. *Lancet* 339: 696-699.

Bar-Or, O., R. Dotan, O. Inbar, A. Rotshtein and H. Zonder (1980). Voluntary hypohydration in 10 to 12 year old boys. *J. Appl. Physiol.: Resp. Environ. Exerc. Physiol.* 48: 104-108.

Davies, C.T.M. (1981). Thermal responses to exercise in children *Ergonomics* 24: 55-61.

Docherty, D., J.D. Eckerson, and J.S. Hayward (1986). Physique and thermoregulation in pre-pubertal males during exercise in a warm, humid environment. *Am. J. Phys. Anthropol.* 70: 19-23.

Dotan, R., and O. Bar-Or (1980). Climatic heat stress and performance in the Wingate Anaerobic Test. *Eur. J. Appl. Physiol.* 44: 237-243. Drinkwater B.L., I.C. Kuppert, J.E. Denton, J.L. Crist, and S.M. Horvath (1977). Responses of prepubertal girls and college women to work in the heat. *J. Appl. Physiol.* 43: 1046-1053.

Ellis, F.P., A.N. Exton-Smith, K.G. Foster, and J.S. Weiner (1976). Eccrine sweating and mortality during heat waves in very young and very old persons. *Isr. J. Med. Sci.* 12: 815-817.

Falk, B., O. Bar-Or, R. Calvert, and J.D. MacDougall (1992a). Sweat gland response to exercise in the heat among prepubertal and late-pubertal boys. *Med. Sci. Sports Exerc.* 24:313-319.

Falk, B., O. Bar-Or, and J.D. MacDougall (1992b). Thermoregulatory responses of prepubertal and late-pubertal boys to exercise in dry heat. *Med. Sci. Sports Exerc.* 24:688-694.

Falk, B., O. Bar-Or, J.D. MacDougall, C.H. Goldsmith, and L. McGillis (1992c). Longitudinal analysis of the sweating response of prepubertal and late-pubertal boys during exercise in the heat. *Am. J. Human Biol.* 4:527-535

Falk, B., O. Bar-Or, J.D. MacDougall, L. McGillis, R. Calvert, and F. Meyer (1991). Sweat lactate in exercising children and adolescents of varying physical maturity. *J. Appl. Physiol.* 71:1735-1740.

Fox, E.L., D.K. Mathews, W.S. Kaufman, and R.W. Bowers (1966). Effects of football equipment on thermal balance and energy cost during exercise. *Res. Quart. Am. Assoc. Health Phys. Ed.* 37: 332-339.

Haymes, E.M., R.J. McCormick, and E.R. Buskirk (1975). Heat tolerance of exercising lean and obese prepubertal boys. *J. Appl. Physiol.* 39: 457-461.

Inbar, O. (1978). *Acclimatization to Dry and Hot Environment in Young Adults and Children 8-10 Years Old*. EdD dissertation, Columbia University.

Inbar, O., O. Bar-Or, R. Dotan, and B. Gutin (1981). Conditioning vs. work-in-the-heat as methods for acclimatizing 8-10 year old boys to dry heat. *J. Appl. Physiol.: Respirat. Environ. Exerc. Physiol.* 50:406-411.

Knochel, J.P. (1975). Dog days and siriasis: how to kill a football player. *J. Am. Med. Assoc.* 233: 513-515.

MacDougall, J.D., P.D. Roche, O. Bar-Or, and J.R. Moroz (1983). Maximal aerobic capacity of Canadian school children: prediction based on age-related oxygen cost of running. *Int. J. Sports Med.* 4:194-198.

Matsushita, K., and T. Araki (1980). The effect of physical training on thermoregulatory response of pre-adolescent boys to heat and cold. *Jap. J. Phys. Fit. Sports Med.* 29: 69-74.

Meyer, F., O. Bar-Or, J.D. MacDougall, and J.F. Heigenhauser (1992). Sweat electrolyte loss during exercise in the heat: effects of gender and maturation. *Med. Sci. Sports Exerc.* 24:776-781.

Meyer, F., O. Bar-Or, A. Salsberg, and D. Passe (1994). Hypohydration during exercise in children: Effect on thirst, drink preferences, and rehydration. *Int. J. Sports Nutr.* 1:22-35.

Redfearn, J.A. Jr. (1969). History of heat stroke in a football trainee (question). *J. Am. Med. Assoc.* 208: 699.

Wagner, J.A., S. Robinson, S.P. Tzankoff, and R.P. Marino (1972). Heat tolerance and acclimatization to work in the heat in relation to age. *J. Appl. Physiol.* 33: 616-622.