KEY POINTS
1. Because of their larger ratio of surface area to body mass, children are more prone than adults to heat loss in cold climates.
2. Extreme heat loss in children is particularly apparent in aquatic activities because of the high thermal conductivity of water.
3. During land-based activities, children compensate for their large relative surface area by an enhanced metabolic heat production and by greater cutaneous vasoconstriction.
4. Small children and those with little subcutaneous fat are at particular risk of hypothermia and frostbite.
5. Cold air increases the risk for exercise-induced asthma.

INTRODUCTION
Exercise and climatic heat both induce heat stress. Their synergistic effect, when excessive, may impair physical and cognitive performance, cause hyperthermia, and be detrimental to a child's well-being and health. In contrast, when the body is exposed to a cold environment, exercise-induced thermogenesis will help to prevent excessive body cooling. Therefore, hypothermia (core body temperature of 35°C or less) is more likely to occur during rest than during exercise. In fact, during moderate and intense physical activities in the cold, the rate of metabolic heat production often exceeds the rate of heat loss to the environment. The net result is that, even with exposure to very cold environments, core temperature often rises during exercise. One example is ice-hockey (MacDougall, 1979; Paterson et al., 1977), during which a child's metabolic heat production is so high that profuse sweating develops, even when the child is lightly dressed.

This is not the case, however, when the activity is performed in water. Although air is considered an effective thermal insulator, water is an excellent conductor. Specific heat (the number of calories required to heat 1g of a substance by 1°on) of water is approximately 4,000 times that of air, and the thermal conductivity of water is approximately 25 times that of air. The result is that body heat loss may be 25-30 times faster during swimming than during cycling or running at equivalent ambient temperatures (Nielsen, 1978). The greater the temperature gradient between the skin and the environment, the greater the rate of heat loss.

Another important factor to consider is the thickness of the subcutaneous fat layer. Because fat is an effective thermal insulator, the thicker the subcutaneous fat layer, the better the preservation of body heat, particularly in the water (Bergh et al., 1978; Keatinge, 1978). This is particularly true when the cutaneous blood supply is shut down, thus markedly reducing convection of heat from body core to the periphery. The rate of heat loss from the body is then limited by the slow conduction through the fat layer.

The rate of heat loss from the body depends also on the skin surface area (SA). The smaller a person, the larger the SA per body mass unit. For example, an 8-year-old child whose body height and mass are 128 cm and 25 kg, respectively, has a SA-to-mass ratio of 380 cm²/kg. This compares with a SA to mass of 280 cm²/kg in a 20-year-old adult, with a body height and mass are 177 cm and 64 kg, respectively. Based on this geometric difference alone, assuming no differences in physiological responses, one would predict that the child would have a faster heat loss (via convection, conduction, and radiation) to a cool environment when compared with the adult.
**RESEARCH REVIEW**

The first study that compared age-related differences in physiologic responses to exercise in the cold showed that children were at a considerable disadvantage. Sloan & Keatinge (1973) monitored 8- to 19-year-old girls and boys who swam in a 20.3°C pool at a speed of 30m/s-1. They were all proficient club swimmers. The rate of body cooling was inversely related to age; although the young adults had little or no decrease in oral temperature by the end of the swim, most of the youngest participants had a decrease of 2.0°C or more. Moreover, the older swimmers managed to keep swimming for about 30 min, but the youngest swimmers had to be taken out of the water after 18-20 min because of a marked cold-related discomfort. Most of the variance in the rate of body cooling could be explained by the SA-to-mass ratio and by the reciprocal of skinfold thickness.

It took nearly 20y until another study was performed comparing responses of children and adults to exercise in the cold. Smolander et al. (1992) exposed 11- to 12-year-old boys and 19- to 34-year-old men to 5°C air for 60 min. Subjects wore shorts, socks, and sneakers. They first sat in a cold chamber for 20 min and then cycled at 30% of their predetermined maximal 02 uptake for 40 min. Based on the previous findings by Sloan & Keatinge, the authors hypothesized that the rate of body core cooling would be faster in the children than in the adults. The results were surprising: although the adults sustained their rectal temperature throughout the 60-min exposure, the boys had a mild increase in rectal temperature. In compensation for their larger SA-to-mass ratio (320 vs 250 cm²/kg-1), the boys had a greater increase in heat production per kg body mass, as reflected by a greater increase in 02 uptake. In addition, they had a more effective peripheral vasoconstriction to the limbs (reflected by a greater reduction in skin temperatures) than did the men. This ability of children to compensate for a larger SA per unit mass was shown also in studies in which children and adults rested in milder (< 10°C) conditions (Araki et al., 1980; Mecklenburg et al., 1974; Wakeling & Russell, 1970) suggests that their average low resting core temperature of approximately 36°C in a thermoneutral environment drops further when they rest in a cool environment (and rises during heat exposure). As shown by Davies et al. (1978), the increase in the rectal temperature of anorexia patients during exercise at 65% V02 max lags behind that of healthy controls. It has been suggested (Mecklenburg et al., 1974) that the above deficiency in maintaining a constant core temperature not only reflects their low subcutaneous fat insulation but also hypothalamic dysfunction.

Another group with a high risk for hypothermia is children of small body size. As discussed above such children, due to their large body SA-to-mass ratio, are particularly prone to fast heat losses when in the water.

Frostbite. Although any person may sustain frostbite in skin areas that are exposed to the cold (mostly the cheeks, chin, nose and ears) or even those that are covered by clothes (mostly fingertips, toes, nipples, and male genitalia), some individuals are more prone to frostbite than others. Although there are no epidemiologic data about the prevalence of frostbite at different ages children, because of their enhanced peripheral vasoconstriction, may be more prone then adolescents and young adults. In addition, there are individuals with an inadequate cutaneous blood flow, mostly to the extremities. Although this condition is more prevalent among adults and the elderly, it sometimes occurs in adolescents, females in particular.

**PRACTICAL IMPLICATIONS**

The potentially deleterious effects of exercising in the cold on children’s health are all preventable. The following steps are recommended:

1. Whenever possible, water temperature for child swimmers should be warmer (by 1-2°C) than for adults.
2. During swim practice, children should be allowed to come out of the water every 15-20 min to avoid hypothermia.
3. Small and lean children should be especially well supervised.
4. Because cold sensation is most unpleasant, it is likely that a child who feels cold in the water will want to go out. However, it is possible that a highly ambitious young athlete may ignore perceptual cues of cold discomfort and will opt not to leave the water unless told to do so.
5. In long-distance swimming in cool water, a 1 to 2 mm layer of lanolin or petroleum jelly should be applied over the skin.
6. Use several layers of dry clothing for activities performed in near-freezing or below-freezing conditions. Particular protection must be given to fingers and toes. Whenever the windchill factor is minus 15-20°C or lower, the child's face should be covered.
7. The mouths and noses of children with asthma should be covered with a surgical mask or a scarf when exercising in cool air (10°C or below). The additional pocket of air thus created will help to humidify and warm the inspired air (Schachter et al., 1981). While inhalation through the nose rather than the mouth also increases the
humidity and temperature of the inspired air, this is an impractical strategy during moderate and intense activity because the high rate of air flow cannot be accommodated through nasal breathing.

8. The child with asthma should be advised to reduce the intensity of outdoor exertion on cold days.

SUMMARY

Because of their higher surface area-to-body mass ratio, children’s rate of body heat loss is faster than that of adults. When a child exercises in cool ambient air (as low as 5° C), this handicap is compensated for by enhanced peripheral vasoconstriction and metabolic heat production. However, when the child is immersed in water, the high thermal conductivity of water induces very high body heat losses via conduction. This may result in hypothermia, particularly when the child is small and lean. The enhanced peripheral vasoconstriction in children’s extremities is a potential risk factor for frostbite. Cold air may facilitate exercise-induced asthma.

References


CHILDREN'S RESPONSES TO EXERCISE IN COLD CLIMATES: HEALTH IMPLICATIONS

INTRODUCTORY BACKGROUND
Although children's physiologic responses to exercise are similar to those of adults, there are some important age- and maturation-related differences in their responses. These are apparent, for example, when the body is trying to prevent excessive cooling (hypothermia) during exercise in a cold environment. The rate of heat loss from the body depends on the surface area of contact between the skin and the environment. Children have a larger surface area than adults, when calculated per unit of body mass, e.g., m²/kg⁻¹. As a result, the smaller the child, the greater is the risk of excessive heat loss. This is particularly important when exercise is done in the water, an excellent heat conductor. In contrast, during land-based exercise children compensate for their large surface area by increasing their metabolic heat production and by reducing the blood flow to thin skin. The end result is that in air temperatures of 5o C or higher, children maintain their body core temperatures adequately while exercising at mild to moderate intensities. More research is needed regarding children's performance in lower air temperatures. Because fat is an excellent insulator, the thickness of fat tissue under the skin affects the child's success in preventing excessive heat loss—the thicker the fat pad, the greater is the protection.

PRACTICAL IMPLICATIONS
To prevent hypothermia, children who swim or play in the water should be encouraged to leave the water periodically. If possible, water temperature should be kept warmer (by 1-2o C) for children than for adults. For long-distance or cool-water swimming, apply a thin layer of lanolin or petroleum jelly over the child's skin. When exercise is performed in cold air, use multilayer clothing and try to prevent wetting of the clothes. To prevent frostbite, pay special attention to covering the fingers, toes and face. Children with asthma should be encouraged to wear a scarf or a surgical mask over their mouths and noses when they exercise outdoors on a cold day.