SHORT REPORT

Physiology of accidental hypothermia in the mountains: a forgotten story

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Hypothermia is a serious condition, often with fatal consequences. The physiology and mechanisms of hypothermia in mountainous areas are discussed. It is as important to facilitate heat loss, especially during periods of high exertion, as it is to maintain heat production and preserve insulation. This can be partly achieved by clothing adjustments.

Hypothermia has long been recognised as a most serious condition, often with fatal consequences for hill walkers, fell runners, and high altitude mountain climbers. The physiology and mechanisms of hypothermia have been well documented during cold water immersion.[1] However, research into hypothermia occurring in the mountainous environment has, at best, been limited. This is somewhat surprising when one considers the popularity of such mountainous pursuits. An intriguing scientific consideration therefore is entwined with the physiological considerations, and predisposing factors, of hypothermia occurring in the mountainous environment.

EXERCISE INTENSITY AND FITNESS

While walking in the mountains, participants normally operate at 30–55% of their maximal oxygen uptake, depending on the terrain.[2] When exercising at these levels, the body's heat production is generally sufficient to offset heat loss. Exercise intensities (and associated energy expenditures) of this order are sufficient to prevent a fall in core temperature in wet cold conditions with mean skin temperatures as low as 20℃ (normal mean skin temperatures are about 33℃). However, groups of people walking and climbing are not always well matched physically, and, when conditions are such that mean skin temperature falls to 25℃, there is a strong inclination to walk faster, thereby raising core temperature to a value that makes the low skin temperature tolerable.[3 4] In this way, less fit persons may become exhausted, most likely coinciding with a decrease in body carbohydrate stores. In this sense, fitness may be important when less fit walkers pace themselves with other walkers who possess superior fitness levels. As most walkers pursue this activity in groups, the less fit walkers may be more susceptible to fatigue when exercising at a higher relative intensity compared with their fitter counterparts. The best off-set for hypothermia is to maintain heat production by means of exercise, and so fatigue becomes a critical predisposing factor.

In adverse conditions, owing to the increased insulation of clothing and hence the decreased ability to lose heat, rectal temperatures of over 39℃ can be regularly encountered.[2] The body's responses to this exercise induced ''hyperthermia'' are sweating and dilation of the peripheral blood vessels—that is, mechanisms to lose heat. When a rest is taken during these adverse climatic conditions, rapid cooling and a decrease in core temperature occurs. The body responds to this decrease in core temperature by constricting the peripheral vessels in an attempt to limit its heat loss. Once this vasoconstriction is maximised, core temperature can only be maintained by an increase in heat production—that is, shivering—which is thought to be the major contributor to the cold induced increase in heat production.[5] However, shivering also induces vasodilation in the arterioles supplying the shivering muscles. As a result, muscle blood flow increases. The effect is that shivering reduces the insulating effect normally provided by the thickness and mass of the inactive skeletal muscle. It has been proposed[6 7] that vasoconstricted (non-perfused) muscle acts in series with fat and skin to provide insulation, such that 75% of the body's insulation is provided by the vasoconstricted muscle and only 25% by the subcutaneous fat and skin. As a result, during exercise or shivering, the ''variable'' resistance of muscle vasoconstriction is lost because of increased muscle perfusion, leaving only the ''fixed'' resistance of the subcutaneous fat and skin. Therefore signs of shivering, in the mountainous environment, should be used as a sign of imminent danger to the participant.

PROBLEM OF FATIGUE

Once the walker, runner, or mountain climber fatigues and starts to slow or stops walking altogether, the rate of heat production falls dramatically.[8] This alone predisposes to the development of hypothermia. These processes, in adverse weather conditions, will be accelerated. Likewise, if activity is pursued in conditions of hypobaric hypoxia—that is, at altitude—by virtue of a reduced inspiratory partial pressure of oxygen and hence oxygen consumption, the ability to produce heat will be decreased, further increasing the likelihood of hypothermia. The critical point for this heat loss to occur is at cessation of activity when participants take a rest or stop for fluid/food intake, during exercise when the level of exertion is low (with low heat production)—for example, when walking downhill—or during periods of navigation/group control. During these critical points, especially when participants have become wet because of adverse weather and/or high levels of exertion, heat loss will be unavoidable.[2 9] Once the walker or runner becomes too tired to continue exercising in cold, wet, and windy conditions either because he or she is already developing hypothermia or because of the onset of exhaustion, the development of hypothermia will only be prevented if most of the following steps are undertaken. The hypothermic subject is taken rapidly to buildings or geographical features that provide shelter from the wind and rain and there is an external source of heating, a source of food, and an opportunity to change into clothes that are dry and water repellent. More clothing is required because the change from running or walking to the resting state has a considerable effect on the rate of heat production and thus the amount of clothing needed to maintain body temperature even at relatively mild effective temperatures. For example, clothing with at least four times as much insulation is required to maintain body temperature at rest at an effective air temperature of 0℃ as when running at 16 km/h at the same temperature.[9] For this reason it is essential that extra clothing including water repellent outer clothing, both jacket and overtrousers, is always taken when exercising in cold and potentially wet and windy conditions. Although in the past, both poor clothing and equipment may have been factors in the increased physiological strain and likelihood of injury,[8] this lack of adequate equipment cannot be considered the case today. Indeed, recent analysis of the Scottish Mountain Rescue Services indicates a decline in the number of deaths compared with previous years.[10] This favourable change may reflect many developments including improvements in clothing worn by casualties, their overall skill/awareness level, and improvements in rescue provision, particularly faster response times by the rescue teams as a result of mobile phone use.[10] Despite the substantial work carried out in fabric technology, enabling greater regulation of both temperature and water vapour management in adverse weather, a continued problem is that clothing able to provide 4 CLO units of insulation may weigh as much as 10–15 kg, making it unfeasible for general participants to carry.

BEHAVIOURAL MEASURES

During typical cold conditions, behavioural adjustments can be far more effective for maintaining thermal balance than physiological reflexes. These include all voluntary actions to increase thermal comfort. In cold climates, extra clothing is worn, exercise is undertaken, and, where possible, shelter and warmth are sought, as well as a source of food. These behavioural measures give the greatest independence from the environment and permit survival in even the most demanding of climates. However, during increased walking intensity, the clothing worn increases the evaporation required for the maintenance of thermal balance. This increase creates a difficult balance for walkers. On the one hand, they require increased insulation from clothing for protection from the environmental weather conditions. On the other hand, they need to keep the insulation relatively low to aid evaporative heat loss. The failure to achieve this balance results in increased heat strain leading to an increased likelihood of dehydration.[11] From a thermoregulatory point of view, this balance will always be difficult to achieve for the walker, especially when high insulation levels are required. Furthermore, when high insulation levels are required, a situation will arise in which the clothing will restrict airflow to the skin. This restriction will promote the increased saturation of water vapour from air close to the skin. Because effective evaporation is prevented if the vapour pressure gradient between the skin and the environment is low,[12] as in the case when high insulation is required, the ability of the body to evaporate water from its skin surface may become severely compromised. The significance of this decreased ability to evaporate sweat creates a paradoxical situation whereby the participant may initially, in adverse weather conditions, be at risk from increased heat strain. Therefore, in an attempt to maintain thermal balance, it is as necessary to facilitate heat loss, especially during periods of high exertion, as it is to maintain heat production and preserve insulation. By means of clothing adjustments, the anatomical areas of high heat exchange (head/face, axilla, sides of chest, groin) are areas to ventilate during activity and insulate when inactive.

Take home message

To maintain thermal balance it is as necessary to facilitate heat loss, especially during periods of high exertion, as it is to maintain heat production and preserve insulation. By means of clothing adjustments, the anatomical areas of high heat exchange (head/face, axilla, sides of chest, groin) should be ventilated as much as possible during activity and insulated during inactivity.

MANAGEMENT ISSUES

Therefore, during activity in the mountains, improper management of energy expenditure and clothing leads to sweating and fatigue. Dehydration may be a consequence of this increased rate of sweating, and, in addition to low fluid intakes, may increase this thermal stress. This likelihood of dehydration may lead to decreased thermoregulatory, circulatory, and cognitive functioning.[11] In a recent study of strenuous hill walking, older age walkers were particularly prone to dehydration and decreased physical and mental performance compared with younger counterparts.[13] Competitiveness may keep the walker from admitting to his or her condition, and he or she may reach a rather severe state of exhaustion and wetness before calling for a rest stop.[4 14] At this point the individual's peripheral circulation will be dilated, so, on sitting down for a rest, heat loss occurs rapidly.[2] Sweating may cease, but the wet clothing continues to dry, chilling the vasodilated vessels of the skin and adding to the increase in heat loss.

Paradoxically, it would appear that the prevention of overheating is likely to be a major factor in the prevention of hypothermia. Therefore prevention of overheating, and hence hypothermia, requires proper management of energy expenditure, clothing, fluid intake, and evaporation.

In summary, while such hypothermic events provide an intriguing scientific consideration for the environmental physiologist, such knowledge should be made applicable to both participants and the rescue services.

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Reliability of heart rate variability measures at rest and during light exercise in children

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Objectives: To investigate the reliability of heart rate variability (HRV) measures at rest and during light exercise in children.
Methods: Short term (five minute) HRV was assessed in 12 children (11–12 years of age). HRV measures were collected at rest with the children supine, breathing at 12 breaths/min, and during exercise on a cycle ergometer while exercising at 25% of peak oxygen uptake. Both resting and exercise data were collected twice from each child.
Results: Intraclass correlation coefficients were low to moderate for most measures with wide confidence intervals for each variable in both resting and exercise conditions. Random variation (typical error) within repeated measurements ranged from 31% to 187%.
Conclusions: These preliminary findings suggest that HRV measures are unreliable at rest and during light exercise in children aged 11–12 years. Tighter control of extraneous influences is recommended.

Variations in heart rate period arise through the balance of sympathetic and parasympathetic nervous modulation of heart rate. Through differences in the physiological response of the myocardium to the neurotransmitters acetylcholine and noradrenaline (norepinephrine), a greater variation in heart rate period arises when the parasympathetic nervous system predominates than with predominant sympathetic modulation.[1 2] Analysis of this natural variation in heart rate period (heart rate variability (HRV)) is considered a valuable tool in providing a non-invasive window to sympathovagal regulation of heart rate.[3]

Time and frequency domain statistical procedures are used to analyse HRV data,[4 5] with the following measures being calculated from short term—less than five minute—heart rate recordings: in the time domain, square root of the mean of the sum of the squares of the differences between adjacent R-R intervals (RMSSD), the proportion of pairs of adjacent intervals differing by more than 50 ms (pNN50), and standard deviation of all the R-R intervals (SDNN); in the frequency domain, low frequency power (LF), high frequency power (HF), and total power (TP).

In adults, the HRV response to exercise has been previously documented.[2] In addition, the relation of HRV to peak oxygen uptake (peak $\dot{V}O_2$) and physical activity levels and the effects of exercise training on HRV are widely understood,[3 6 7] yet their use with children has largely focused on the neonate,[4] and data on the reliability of HRV are restricted to adult subjects.

In healthy adult subjects, there exists a wide interindividual variation in HRV measures at rest. Between subject variance is reported to be in the range 12–15% for mean R-R interval, 41–155% for LF, and 70–163% for HF, although the cause(s) of such a wide variation is unclear.[8 9]

Within individual resting HRV measures in adults are considered reliable: RMSSD (r = 0.20–0.98), pNN50 (r = 0.43–0.97),[5 10] HF (r = 0.48–0.96), LF (r = 0.60–0.97), and TP (r = 0.52–0.97).[5 10 11]

Although group mean reliability data may indicate no significant difference between HRV measures, on an individual basis significant day to day variation exists for each person: mean (SD) variation of 23.5 (14.6)% for pNN50 and 10.7 (6.8)% for SDNN.[12] There appear to be no published data on the reliability of short term resting HRV measures in healthy children.

HRV measures during exercise have been investigated previously in adults. Data are sparse, but indicate that exercise HRV measurements are reliable. Tulppo *et al*[13] reported the limits of agreement between repeated measures[14] during cycling at intensities of 50 and 75 W. The range of differences for HF expressed as a coefficient of variation was 4.4%. The reliability of HRV measures in children during exercise is not known and must be established to evaluate the use of this technique with young people.

The purpose of this study was therefore to assess the reliability of HRV measures in children during rest and light exercise.

METHODS

Twelve children (seven girls, five boys) volunteered for the study. Written informed consent was obtained from the participants and their legal guardians. The institutional ethics committee granted approval for the study. All children were healthy, and none were taking any prescription medications. Participants were fully habituated to equipment, protocols, and experimenters. Stature was measured using a Holtain stadiometer (Holtain, Crymych, Dyfed, UK), and body mass

Abbreviations: HRV, heart rate variability; RMSSD, square root of the mean of the sum of the squares of the differences between adjacent R-R intervals; pNN50, the proportion of pairs of adjacent intervals differing by more than 50 ms; SDNN, standard deviation of all the R-R intervals; LF, low frequency power; HF, high frequency power; TP, total power; ICC, intraclass correlation coefficient