CH5 M5.2 Response to exercise: Hot and Humid environments

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- Defining human thermal environment
- Sources of heat exchange during physical activity
- High intensity intermittent or prolonged sports activity in hot environment
- Heat acclimatization: its process and protocol
- Heat stress and heat disorders

Summary

Air temperature, radiant temperature, humidity and air movement are the four basic climatic variables that affect human response to thermal environments. The metabolic heat generated by the human activity and clothing worn by the person are other two parameters, providing six fundamental/basic parameters that define human thermal environment. The overall concept of heat balance in any human activity is expressed by involving three types of terms; i.e., heat production in the body, heat transfer and heat storage. The metabolic rate (M) provides energy for the human body to perform certain mechanical work (W), and the remainder is released as heat (M-W). Human body can store a very large amount of heat. First response to heat gain from external sources is to increase in the skin temperature and vasodilatation in subcutaneous region. This prevents increase in heat gain by reducing the temperature gradient between environment and the skin. When the environmental temperature is higher than the core temperature, heat loss via blood redistribution and other physical means is not possible. Sweating is the only option for heat loss under such condition. Effectiveness of heat loss through sweat is limited by the level of relative humidity of ambient environment, exposure of body surface area and air velocity. Increase in heart rate is observed in hot environment. High intensity sports activity always results in high metabolic heat production, in addition to heat load that arises from environmental heat exchanges. The effective heat load is the cumulative heat transfer from all avenues.

Introduction

Defining human thermal environment

The nature and degree of response to thermal environment depends on certain basic climatic variables. That is, air temperature, radiant temperature, humidity and air movement are the four basic climatic variables that affect human response to thermal environments. The metabolic heat generated by the human activity and clothing worn by the person are other two parameters, providing six fundamental / basic parameters that define human thermal environment.

Therefore, the feeling of environmental warmth is the combined influence of all the above stated six basic parameters. Among these, however, air temperature and humidity are the major contributors to heat exchange; for convenience of the readers, Table 1 is presented here, indicating coloured yellow and red zones of major heat stress or likely life threatening heat stroke.

Table 1:

	Ambient Air temperature (°C)									
Relative Humidity	21.1	23.9	26.7	29.4	32.2	35.0	37.8	40.6	43.3	46.1
	Temperature as felt °C)									
10%	18.3	21.1	23.9	26.7	29.4	32.2	35.0	37.8	40.6	43.9
20%	18.9	22.2	25.0	27.8	30.6	33.9	37.2	40.6	44.4	48.9
30%	19.4	22.8	25.6	28.9	32.2	35.6	40.0	45.0	50.6	57.2
40%	20.0	23.3	26.1	30.0	33.9	38.3	43.3	50.6	58.3	
50%	20.6	23.9	27.2	31.1	35.6	41.7	48.9	57.2	65.6	
60%	21.1	24.4	27.8	32.2	37.8	45.6	55.6	65.0		
70%	21.1	25.0	29.4	33.9	41.1	51.1	62.2			
80%	21.7	25.6	30.0	36.1	45.0	57.8	69.4			
90%	21.7	26.1	31.1	38.9	50.0	65.6	76.7			
100%	22.2	26.7	32.8	42.2	56.1	74.4				

Sources of heat during physical activity

The overall concept of heat balance in any human activity is expressed by involving three types of terms; i.e., heat production in the body, heat transfer and heat storage. The metabolic rate (M) provides energy for the human body to perform certain mechanical work (W), and the remainder is released as heat (M-W). As described elsewhere, about 3/4th of the total metabolic heat production is not utilized for physical activity. This quantity of heat is estimated by deducting the quantity of external work from metabolic heat production.

Heat transfer routes can be conduction (K), convection (C), radiation (R) and evaporation (E). By combining all these routes of heat production and loss gives the heat storage (S), which equals to zero when there is heat balance, i.e., at constant temperature. In case of net heat gain, S will be positive, causing body temperature to rise. On the other hand, if there is net heat loss, S will be negative, tending body temperature to fall.

The conceptual heat balance equation is:

$$M - W - E - R - C - K = 0 \quad \text{… (i.e., for heat balance S =0)}$$

where M-W is always positive, E,R, C and K are the rates of heat loss from the body in different routes (i.e., positive value is for heat loss and negative value if for heat gain). It is important that the units of expression for the components of heat alance equation are identical, and standardized against the unit body surface area.

The metabolic heat production of a person can be determined with reasonable accuracy, however, calculation of external work done is a challenge specially in level walking and running. Unless a chance of gradient in the surface occurs the physical work in level walking / running remains zero according to the physical laws. Tucker (2008) expressed heat production during running as (4 x mass x velocity).

Heat Storage:

Heat balance given above can quantify the storage of heat in the body. As a matter fact, human body can store a very large amount of heat. The total body heat content can be estimated from the product of mean body temperature (Tb) and body heat capacity (Sawka and Castellani, 2007). Heat capacity is a function of body mass and specific heat of tissue. In a standard body composition the specific heat would be constant. It is interesting that diurnal increase in body heat content and any influence of heavy physical activity in the total heat content are dissipated during the night and every morning starts with low body heat content (Webb, 1995). This would happen provided that night environmental temperature is cooler than the day temperature. Under conditions permitting full sweat evaporation, body heat storage is lower with warm water ingestion, because of modulations in sweat output arising from warm-sensitive sensors in the esophagus/stomach (Bain et al., 2012).

Response of human body in hot environment

When the human thermal environment provides a tendency for body heat storage, the body thermoregulatory system sets in to increase heat loss. The consequent bodily strain may become unacceptable and eventually leading of heat illness and heat disorder of fatal in nature.

a) First response to heat gain from external sources is to increase in the skin temperature and vasodilatation in subcutaneous region. This prevents increase in heat gain by reducing the temperature gradient between environment and the skin. Circulation to cooler region of skin also helps in heat loss;

b) When the environmental temperature is higher than the core temperature, heat loss via blood redistribution and other physical means is not possible. Sweating is the only option for heat loss under such condition. Human body has about 2.5 million sweat glands (for a man of tropical climate). It is possible to produce sweat at the rate of 1.6 litre an hour and remove 900 kcal of heat from the body;

c) Effectiveness of heat loss through sweat is limited by the level of relative humidity of ambient environment, exposure of body surface area and air velocity. In dry hot weather, humidity is low and sweat evaporates readily;

d) Increase in heart rate is observed in hot environment. This happens to meet higher circulatory load. In an average each ºC increase in ambient temperature raises heart rate by 1 beat/min;

e) Most people have the ability to physiologically acclimatize to hot conditions over a period of days to weeks. The salt concentration of sweat progressively decreases while the volume of sweat increases; and

f) Urine volume also reduces. It takes about 7 days to become acclimatized in hot environment. The adjustment is very rapid and is achievable in about 7 to 10 days if regular daily exercise for 90 minutes is undertaken. (Goswami, 2012).

High intensity intermitted sports activity (soccer/hockey) in hot environment

High intensity sports activity always results in high metabolic heat production, in addition to heat load that arises from environmental heat exchanges. The effective heat load is the cumulative heat transfer from all avenues. As mentioned, depending on the heat storage the body temperature responses are elicited. Due to intense physical activities, the elevated muscle or body temperature can elicit fatigue through altering the capacity of the neuromuscular system. In intermittent or prolonged sports and exercises, the contractile behavior of motor units vary in its muscle response, through the central activation and recruitment of force, and the conduction of signal along the central and peripheral nervous system (Cheung, 2008).

The act of imposing an effective cooling intervention in lowering skin, muscle and core temperature is beneficial in endurance and intermittent exercise performance. It is unclear, however, in case of events of strength performances. The ergogenic benefits of pre-cooling for prolonged exercise seem to be evident and documented (Duffield, 2008), the actual mechanisms responsible for these improvements are somewhat equivocal. Regardless of the mechanisms, there are evidences to emphasize that pre- and post-exercise cooling as an important ergogenic aid and to recommend the use of such procedures in the protection and recovery of exercise-induced heat stress. Many football teams adopt this pre-cooling technique, prior to their events.

Prolonged physical activity (marathon) in hot environment

Research on exercise protocols by subjecting individuals to volitional exhaustion in the heat has led to the development of the theory that fatigue is the direct result of hyperthermia. High body or brain temperatures are responsible for a failure to maintain skeletal muscle activation at the required level. Also, both constant workload performance and self-paced exercise performance are impaired in hot environment, as compared to temperate and cool environments. Exercise is regulated in advance of such a thermoregulatory ‘failure’, and that the rate of heat storage and possibly afferent inputs from the skin are responsible in mediating changes in muscle activation and work output. The consequence of these changes is that the exercising athlete is able to complete exercise safely, though with impaired performance (Tucker, 2008).

Heat acclimatization

With repeated exposures to heat, human's defense mechanism undergoes progressive changes, and these adjustments are characterized as acclimatization/ acclimation. Acclimatization is induced by repeated exposures to natural hot environments, while acclimation refers to experimentally induced physiological adaptation.

With heat acclimatization, a human being demonstrates an increased ability to perform physical activity in heat, reduced cardiovascular stress and responds to acute heat stress with a pronounced sudomotor response. The responses, however, depend on a variety of conditions, e.g., the degree of exposure, type of physical exercises performed, the state of acclimatization and training to work in heat.

It is likely that heat acclimatization is better maintained by individuals who are physically fit. Increase in cardiac output after acclimation is attributable to an increased stroke volume. Acclimation reduces the threshold for vasodilation. The splanchnic and renal blood flow, which is reduced during acute heat exposure, increases after acclimation. Blood flow to exercising muscle increases after acclimation. The principal physiological benefit appears to result from an increased sweating efficiency, e.g., an increased sensitivity and a lower threshold for onset of sweating with acclimation. It is possible that heat acclimatization shifts thermo-neutral zone and set point in temperature regulation.

Acclimatization to heat is an unsurpassed example of enormous physiological and psychological potentials to combat environmental adversities. It does not necessarily mean that individuals can work at widely different hot environments. Complete acclimatization of a person is rarely possible. Caution is raised that acclimatization may be specific to the level of heat exposure (hot-dry and hot-humid) to which a person is exposed and may not respond well above the level of exposure. It is important to recognize that training to work in heat may not be taken as an adequate substitute of heat acclimatization, since there may be individual differences in physical abilities, and regularity of heat exposure. The degree of exposure to combined load of work and heat, may reflect differently on the cardio-respiratory and thermoregulatory capacities.

Fluid intake in hot environment

The physical activity in hot environment is a potential health hazard to persons who are exposed beyond the acceptable limit of bodily strain. Because of profuse sweating, dehydration may occur for persons engaged in physical exercises. The increased level of dehydration disturbs the homeostasis of body fluid when there is inadequate replenishment of fluid. This might lead to decreased skin blood flow, elevated body core temperature, decreased sweat rate, decreased exercise tolerance, and increased risk of heat injury. Since the active humans do not voluntarily replace all the water lost during the prolonged work and heat stress, choosing the efficacious means of rehydration is critical to prevent the development of dehydration.

The fluids of choice are very many, such as water, electrolyte, carbohydrate and glycerol supplements, which have been suggested to modify the euhydration levels, and assist in thermoregulation and exercise performance. Better skin perfusion results in better thermoregulation, and better muscle perfusion results in better maintenance of energy supply for the muscle. The summated effect of fluid intake in preventing blood volume losses reflects in overall exercise performance in hot environment.

A fluid supplement is chosen to promote a state of hyperhydration; that is, the chosen fluid, after ingestion should evenly distribute in the body space, and better preserve cardiovascular and thermoregulatory functions.

Heat disorders and illnesses

Heat disorders occur for one or more of the following reasons:

a) The existence of factors such as dehydration or lack of acclimatization;
b) The lack of understanding of the dangers of heat; and
c) Accidental or unforeseeable circumstances leading of sudden exposure to very high heat stress.

There is ample body of literature available that describes different kinds of heat illnesses and disorders. There are evidences of extreme events and fury of heat claiming lives at every coming summer seasons, in the tropical and other geographical regions. For the benefit of the students, different heat illnesses are tabulated, in terms of category of illness or disorder, its predisposing factors, physiological disturbances, treatment and prevention. The following table gives details of different predisposing factors, physiological disturbances and treatment of the condition are given below.

CATEGORY	PREDISPOSING FACTORS	PHYSIOLOGICAL DISTURBANCES	TREATMENT

Thermoregulation **(Heat stroke)** Hot dry skin; body core temp. 40.5ºC & over; loss of consciousness, convulsions; may be fatal if treatment is delayed.	Sustained heat exposure by unacclimatized persons; lack of physical fitness; obesity; alcohol intake; dehydration; heat susceptibility; chronic cardiovascular disease.	Failure of central drive for sweating; minimal evaporative cooling; rise in body core temp.	**Treatment:** Rapid cooling by immersion in chilled water or wrapping in wet sheet; vigorous fanning, but avoid overcooling. **Prevention:** Select person, based on health & physical fitness; acclimatize for 5-7 days by combined exposure to work & heat; carefully monitor persons in severe heat.
Circulatory Hypostasis **(Heat Syncope)** Fainting while standing in heat.	Lack of acclimatization.	Pooling of blood in dilated vessels (skin surface & lower parts of body).	**Treatment:** Remove to cooler area; rest in recumbent position. **Prevention**: Acclimatization; Intermittent physical activity to assist venous return to heart.
Water & salt depletion **(Heat Exhaustion)** Fatigue; nausea, headache, giddiness; complexion pale; Skin clammy & moist; fainting; rapid heart rate; low blood pressure; body core temperature elevated (38-38.5 ºC); concentrated urine.	Sustained exertion in heat; lack of acclimatization; failure to replace water lost in sweat.	Dehydration from deficiency of water; Depletion of circulating blood volume; Circulatory strain for demands of blood flow to skin and muscles.	**Treatment:** Remove to cooler place; rest in recumbent position; administer fluid by mouth; keep at rest until urine volume indicates that water balance is restored. **Prevention**: Acclimatize person for 5 to 7 days; supplement dietary salt during acclimatization; allow drinking water frequently during work day.
Water & salt	Heavy	Loss of body	**Treatment**:

depletion **(Heat Cramps)** Spasms of muscles during work.	sweating during hot work; Drinking large volumes of water without replacing salt loss.	salt in sweat; water intake dilutes electrolytes; water enters muscles, causing spasm.	Salted liquids by mouth; for prompt relief, infuse I-V. **Prevention**: Adequate salt intake; for unacclimatized persons supplement salt in food & drinks.
Skin Eruptions **(Heat Rash -prickly heat)** Profuse blister-like red vesicles on affected areas; pricking sensation in heat.	Unrelieved exposure to humid heat; skin continuously wet with unevaporated sweat.	Plugging of sweat gland ducts; inflammatory reaction	**Treatment**: Mild drying lotions; skin cleanliness to prevent infection. **Prevention:** Rest in cool places to allow skin to dry between heat exposures.
Skin Eruptions **(Anhidrotic Heat Exhaustion)** Extensive areas of skin which do not sweat on heat exposure, and associated incapacitation in heat	Long periods of constant exposure to high heat with previous history of heat rash and sunburn.	Skin trauma (heat rash; sunburn) causes sweat retention deep in skin; reduced evaporative cooling causes heat intolerance.	**Treatment:** No effective treatment available for anhidrotic skin; recovery occurs gradually, with rest in a cooler climate. **Prevention**: Treat heat rash; avoid further skin trauma by sunburn; periodic relief from sustained heat.
Behavioural Disorders (Heat Fatigue - Transient) Impaired performance in sensorimotor, mental or vigilance tasks.	Performance decrement greater in unacclimatized person.	Discomfort and physiological strain.	**Treatment**: Immediately withdraw from heat exposure; treat for other heat illness. **Prevention**: Acclimatization and training for work in the heat.
Behavioural	Persons at risk	Psychosocial	**Treatment**:

Disorders (Heat Fatigue - Chronic) Reduced performance capacity; lowering of self-imposed standards of social behaviour; inability to concentrate, *etc.*	come from temperate climates, for long stay in tropical latitudes.	stress; probable adrenal hormonal imbalance.	Medical treatment for serious cases, speedy relief of symptoms on returning home. **Prevention:** Orientation on life in hot regions (customs, climate, living, *etc.*).

Some basic steps in heat stress management

1. Wear light clothing during physical activity. Nature of cloth is important.
2. Carry out outdoor work at cooler times of the day (e.g., early morning and late afternoon). Major competitions involving prolonged activity, like marathon running should not be conducted in high environmental temperature conditions.
3. Allow 2 weeks for acclimatization. This is a must for sports persons who are inhabitants at different environmental zones.
4. Drink lot of fluids before and after workout. Fluids can also be taken during the workout in a limited quantity. Long distance runners should take water in small sips even during running.
5. Occasional pouring of cold water on the head and the body is helpful in reducing acute heat illness.

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