Centre for Research in Occupational Safety and Health

Guide to Thermal Stress in the Workplace

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CROSH
CRSST
centre for research in occupational safety and health
at Laurentian University
centre de recherche sur la santé et sécurité au travail
à l'Université Laurentienne

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Introduction

There are many occupations and occupational tasks that are required to be performed in thermally-challenging environments. Hot and cold environments can be present in both indoor and outdoor settings and exposure can directly, and indirectly, create or magnify hazards in the workplace through both physiological and psychological changes[17], resulting in occupational illnesses[71]. This guidebook will: inform workers and workplaces on how to identify environmentally-challenging workplaces; 'who' is prone to influence by thermal stress; the types of injuries that can occur; the effects on work functions; and finally, mitigating strategies to lower risks in the workplace for those working in both hot and cold environments.

Disclaimer

The information contained in this material is provided as a guide only. Laurentian University (LU) recognizes that individual companies must develop health and safety policies and programs that apply to their workplaces and comply with appropriate legislation. This material does not constitute legal advice. While information provided, including references to legislation and established practice, is current at the time of printing, it may become out-of-date or incomplete with the passage of time.

No warranty, guarantee or representation is made by LU as to the absolute correctness or sufficiency of any information contained in this material. LU assumes no responsibility in connection therewith; nor can it be assumed that all acceptable safety measures are contained in this material, or that other or additional measures may not be required in particular or exceptional circumstances.

Acknowledgements

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About CROSH

The Centre for Research in Occupational Safety and Health (CROSH) is a research centre at Laurentian University in Sudbury, Ontario. It was established to provide a formalized structure for industry, safe workplace associations, labour groups, government organizations and researchers to share workplace injury and disease problems and solutions. CROSH envisions a Northern Ontario where workplaces partner to ensure every worker gets home safe and healthy every day. CROSH will be an agent for innovation and discovery to solve relevant and critical problems facing northern industries so they can eliminate occupational injury and disease from their workplaces. CROSH is proud to fund the Guide to Thermal Stress in the Workplace.

About the Authors

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Objectives of this Guidebook

This Guidebook was developed to provide information about the health effects of workplace thermal hazards and safety measures or controls that can be implemented to prevent or manage exposure to them. However, it should be noted that it is the employer's responsibility to identify and implement controls for exposures. In many cases, measures including minor restructuring of the work environment or work schedule can ensure the safety of employees. Employers and employees need to decide what is in the best interest of the employees, on a case-by-case basis, using the information provided as a guideline. These suggestions may not encompass all possible ways of minimizing or preventing exposure to thermal hazards.

This Guidebook serves as an information resource for human resource managers, occupational therapists, industrial hygienists, employers, supervisors, and employees. It is intended to be used in conjunction with other resources, such as confidential interviews with trained health and safety professionals, in order to address all concerns in this area. The material contained in this Guidebook is for information and reference purposes only and not intended as legal or professional advice. The adoption of practices described in this Guidebook may not meet the needs, requirements, or obligations of individual workplaces.

Definitions

Acclimatization - Physiological changes that occur in response to several days of heat or cold exposure and make the body more accustomed to that thermal environment.

Acetylcholine - A chemical messenger that plays an important role in the normal functions of the brain and body. It is responsible for both voluntary and involuntary functions in the body, such as signalling muscle contraction, relaxation of the smooth muscle in blood vessels, and regulating heart rate. In the brain, acetylcholine acts in areas that influence arousal, memory, attention, and motivation.

Anticholinergics - A group of substances that block the action of the chemical messenger called acetylcholine (see 'Acetylcholine' definition).

Body Mass Index (BMI) - A measure of body fatness based on an individual's height and weight.

Cardiac Arrhythmia - An abnormal heart rhythm in which the heart beats too slowly, too quickly, or irregularly.

Cardiac Output - The amount of blood being pumped from the heart.

Cholinergic - A group of substances that enhance or mimic the action of the chemical messenger called acetylcholine (see 'Acetylcholine' definition).

Cognitive Function - Mental processes, or brain-based skills, that allow us to carry out tasks such as memory, orientation, attention, learning, reasoning, problem solving, and decision making.

Dehydration - Loss or deficiency of water in body tissues caused by sweating, vomiting, or diarrhea. Symptoms include excessive thirst, nausea, and exhaustion.

Blood Electrolytes - Minerals that carry an electric charge when they are dissolved in the blood. They help regulate nerve and muscle function and maintain acid-base balance and water balance in the body. They include sodium, potassium, chloride, and bicarbonate.

Hand-arm Vibration Syndrome - A condition associated with the use of handheld vibrating tools or machinery that affects blood flow and nerves in the fingers/hands. Symptoms include numbness with or without tingling, reduced sensation, whitening of fingers, loss of light touch and/or grip strength, and pain or cold sensations.

Heart Palpitations - The feeling of having a fast beating, fluttering, or pounding heart.

Heat Balance - The balance of body heat exchange that regulates the rate of heat production and rate of heat loss in order to maintain a fairly constant temperature.

Heat Illness - A spectrum of disorders, including heat cramps, heat exhaustion and heat stroke, caused by environmental exposure to heat.

Heat Retention - The amount of heat an object or material can store in itself.

Hyponatraemia - Low sodium concentration in the blood.

Hypotension - Low blood pressure.

Inflammation - A localized part of the body that becomes red, swollen, hot and/or painful, typically as a reaction to injury or infection.

Metabolic Rate - Rate of energy (heat) production of the body which varies with the level of activity.

Motor Control - The process of initiating, directing, and coordinating purposeful voluntary movement by the nervous system.

Postural Hypotension - A drop in blood pressure when an individual changes their body position (posture) from laying down or sitting to standing up.

Proprioception - The body's ability to perceive its own self-movement and position in space, including its sense of equilibrium and balance. It is based on feedback between sensory receptors throughout the body and the nervous system.

Relative Humidity - The ratio of the water vapour content of air to the maximum possible water vapour content of air at the same temperature and air pressure.

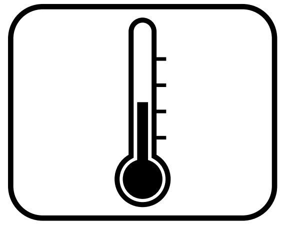
Thermoregulation - Process that allows the body to maintain its core internal temperature by tightly controlled self-regulation, even when the environmental temperature is very different.

Vasodilation - The widening, or opening, of blood vessels to increase blood flow, resulting from the relaxation of smooth muscle within the vessel walls.

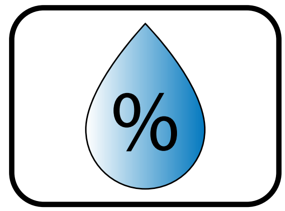
What is Thermal Stress?

Environmental thermal stress is assessed by quantifying the following factors:

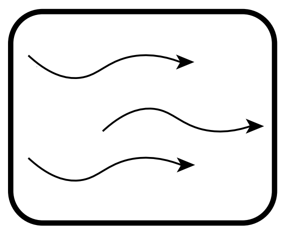
Air Temperature: The temperature of ambient air can be measured using a conventional thermometer. Individuals tend to feel most comfortable when the air temperature is between 20-27°C[13].



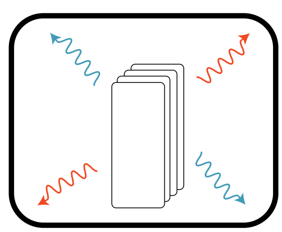
Relative Humidity: The amount of water vapour in the air directly determines the evaporative capacity of the environment (i.e. the ability for sweat to dissipate and reduce body heat). High humidity reduces the amount of sweat that can be evaporated from the skin in hot environments[48]; cold, humid air conducts heat away from the body 25 times faster than cold, dry air[11].



Air Velocity: The movement of air, through indoor ventilation or outdoor winds, plays an important part in quantifying thermal stress. Low air velocity in hot environments impairs evaporative heat loss, making the environment feel hotter. In cold environments, the combination of cold air and wind speed is expressed as Wind Chill. High air velocities in cold environments make the environment feel colder.



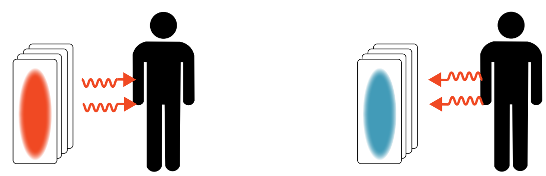
Radiant Heat: Objects or surfaces that are very hot or cold radiate that temperature to other objects or people in the surrounding area. This contributes to the overall environmental temperature. This factor is more prevalent in hot environments (i.e. black pavement).



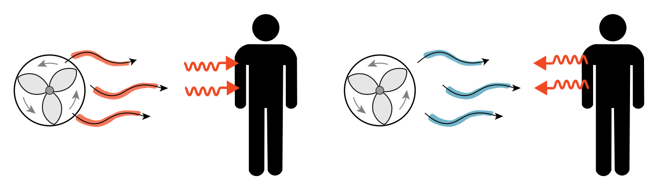
Methods of Heat Exchange

The body exchanges heat with its surroundings through different mechanisms. **Heat loss** refers to the transfer of heat from the body to the environment. **Heat gain** refers to heat transferred from the environment to the body. Both heat loss and heat gain mechanisms are important in cold and hot environments[9,13].

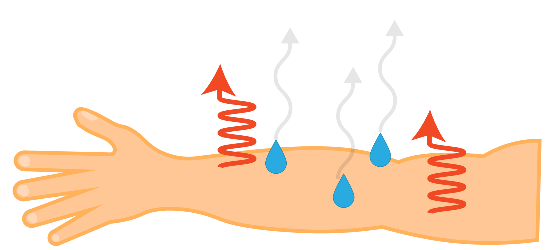
Radiation: The transfer of heat due to a temperature gradient without the body coming into contact with any surface or object. The body gains heat from nearby hot objects and loses heat to nearby cold objects.



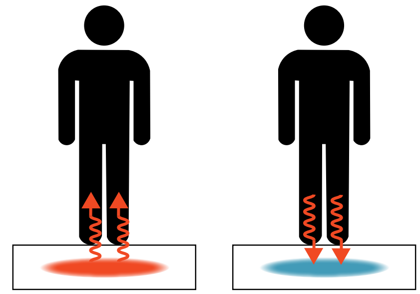
Convection: The transfer of heat with the surrounding air as air moves across the surface of the body. The body gains heat from hot air and loses heat to cold air, which comes into contact with the skin. The exchange of heat increases with greater air velocity.



Evaporation: The transfer of heat due to the conversion of liquid to gas. The evaporation of sweat from the skin surface dissipates heat from the body and occurs more quickly with low humidity and high wind speeds. The ability to evaporate sweat is a major determinant in heat balance and thermal injury risk.

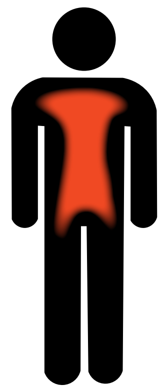


Conduction: The transfer of heat through direct contact with a surface or object. The body gains heat from surrounding hot objects and loses heat to cold objects. The body loses the greatest heat via conduction when it comes into contact with cold water.



The body is also capable of generating its own heat through **internal mechanisms**.

Metabolic heat: The heat produced by normal functioning biochemical processes in the body (e.g. chemical processes, hormone activity, digestion). This includes the energy produced during physical activity. Metabolic heat production rises with increased physical activity because both the energy expended in performing the work and the energy transformed into heat increase.



Shivering: The generation of heat through uncoordinated contraction of skeletal muscles, converting metabolic energy to heat with high efficiency.

In cold environments, heat loss can be counterbalanced with equal amounts of heat production. However, if the body cannot produce adequate amounts of heat, core body temperature will start to drop. Alternatively, in hot environments, if the rate of heat gain is greater than heat loss, the body's core temperature will begin to rise. An excessive drop or rise in core temperature increases an individual's risk of thermal-related injuries.

Physiological Responses to Thermal Stress

The human body maintains a relatively constant internal (core) temperature of approximately 37°C. Changes in core temperature by more than 1°C indicate that the body is unable to cope with the thermal stress[13]. Core body temperatures can rise substantially in hot conditions (2-3°C) while still maintaining functional work capabilities. Moderate increases in body temperature can benefit physical performance, as they enhance the speed of which chemical reactions occur, such as nerve conduction, cellular metabolism, and muscle contractions[72]. However, when body temperatures are excessively elevated (beyond 40°C), the body reaches a state of hyperthermia, which puts an individual at high risk of heat stroke. In the cold, functional changes are observed with smaller decrements in core body temperatures. A core body temperature drop by 1°C decreases coordination and manual function[18,44,91]; a drop by 2°C indicates the development of hypothermia[51].

Heat Stress

Heat stress is the total heat load a worker is exposed to, and arises from the combination of: high ambient temperatures, metabolic heat production from physical work and effort; and insulation from protective clothing[13,17]. When an individual is exposed to a hot environment, more blood is circulated towards the skin to transfer heat from the center of the body towards the surface, permitting the transfer of heat to the environment[49,95]. Sweat production is initiated when core temperature increases by 0.2-0.3°C, and will increase in proportion to elevations in body core temperature[29,48]. However, sweat only cools the body when it is evaporated from the skin surface, not when sweat drips from the body[48]. If core temperature continues to rise beyond 40°C, the risk of heat stroke, the most severe form of heat illness, increases[48,61].

Cold Stress

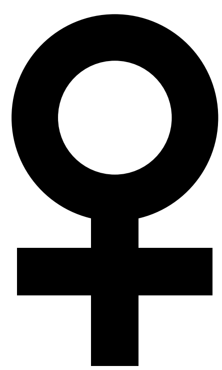
Cold stress occurs due to the combination of low ambient temperatures, passive work, with minimal body movement, and inadequate/insufficient clothing[17]. Cold environments are often coupled with other environmental factors, including: snow, ice, and darkness[45]. When an individual is exposed to a cold environment, blood flow to the extremities is reduced in order to keep internal organs warm and decrease heat loss[9,17]. Over time, cold-related injuries may take place. Lower body temperature also lowers the muscles' ability to function and produce work. With continued exposure to the cold environment, the body will begin actively generating heat through shivering[17], further challenging a worker's ability to perform work.

Who is Affected by Thermal Stress?

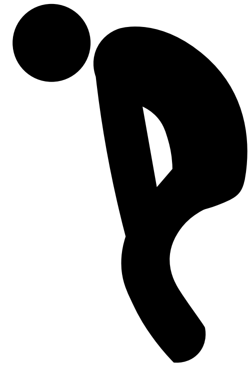
A person's general health impacts how well they can adapt to hot and cold environments. Certain characteristics or conditions can influence individuals: heat retention, thermal tolerance, and their response to thermal stress. These factors may increase the risk of thermal injury. They include:

Age: Older individuals (~40 years or older) may be more susceptible to the effects of thermal stress and have more difficulty adapting to thermal stress[13,71]. Beyond the age of 50, the body's thermoregulatory capacity steadily declines[85] due to reduced responses and functions of sweat glands[95]. Older individuals may also be more susceptible to dehydration, due to reduced thirst perception, or blunted thirst[92,97]. The prevalence of indirect hazards in the workplace may be magnified due to age-related decreases in strength, proprioception, motor control, and/or cognitive function[17].

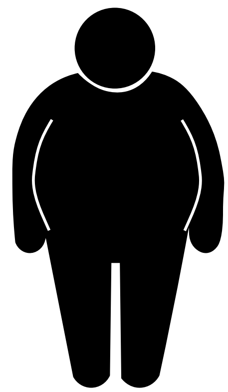
Sex: Though females cool more slowly, they generate less metabolic heat through exercise and shivering compared to males, leading to greater risk of cold-induced injuries. Females may also be less heat tolerant than males because females tend to have a lower sweat rate, resulting in higher body temperatures, than males of equal size, fitness, and acclimatization[31].



Low levels of fitness: Low aerobic and/or muscular fitness may further decrease physical work capacity when performing physically demanding tasks in hot and cold environments. Lower fitness reduces an individual's ability to manage the cardiac demands of thermal stress[8]. Low fitness levels may also make individuals less heat tolerant, more susceptible to feelings of extreme heat, and increase the incidence of thermal injury and illness[13,74,96,102].

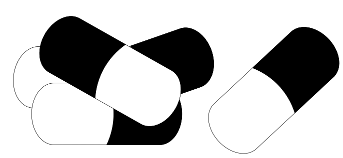


Body shape: An increased amount of body fat on an individual can cause difficulty in maintaining heat balance: heat transfer to the environment is slowed from the added fat tissue[89]. This may be advantageous in cold environments, as extra fat will act as a layer of insulation, but can be detrimental in hot environments as the insulative effect contributes to heat storage in the body[40]. Extra weight carried by an individual can also result in increased heat production from the added metabolic energy required to perform a task compared to a lean individual, increasing the risk of heat-related illness[52].



Medical conditions: Individuals with heart disease, high blood pressure, respiratory disease, Raynaud's disease, and uncontrolled diabetes may need to take extra precautions when exposed to thermal stress, as these conditions affect circulation of blood, sweat production, and cardiac capacity[93].

Use of drugs and medications: Many prescribed drugs can interfere with the regulation of body temperature[53], and are capable of decreasing an individual's ability to cope with thermal stress, specifically heat stress[9,93].



Drugs with anticholinergic activity: Altered central thermoregulation, sedation and cognitive impairment, leads to dry mouth and/or skin, fever, cessation of sweating, hypotension and reduced cardiac output may increase risk of fainting and falls.

Ex. atropine, antihistamines, tricyclic antidepressants, phenothiazines, butyrophenones

Hypotensive Drugs and Diuretics: Increase dehydration, impaired cardiac output, impaired blood volume (hypovolemia), postural hypotension increases risk of fainting or falls, reduced thirst sensation, renal impairments[93,100].

Ex. Chlorothiazide, bumetanide, triamterene

Sedatives and Antianxiety Drugs: Impaired behavioural responses to temperature, such as drinking fluids or taking cooling/heating actions, these drugs may also reduce the threshold for shivering[93].

Ex. Benzodiazepines, barbiturates, zolpidem, eszopiclone

Antipsychotics: Impaired sweating, reduced thirst sensation, hypotension, and reduced cardiac output may increase risks of fainting or falls, sedation and cognitive impairment, such as reduced alertness, judgment, and perception can occur[19,100].

Ex. Phenothizines, risperidone, olanzapine, quetiapine, haloperidol

Antidepressants:

Tricyclic antidepressants (ex. Amitriptyline): Have strong anticholinergic effects, hypotension and reduced cardiac output may increase risk of fainting and falls[100].

Selective serotonin reuptake inhibitors (SSRIs, e.g. Sertraline, citalopram, escitalopram): Impaired sweating, can be associated with hyponatraemia, increased cholinergic heat production, and inhibition of heat loss pathways[25], sedation and cognitive impairment, such as reduced alertness, judgment and perception can occur[100].

Serotonin and noradrenaline reuptake inhibitors (SNRIs, e.g. Venlafaxine, duloxetine, desvenlafaxine): Impaired sweating, enhanced cholinergic heat production, and inhibition of heat loss pathways[25].

Amphetamines: increased metabolic rate within the central nervous system[19,23], decreased blood flow and limited heat dissipation[19].

Ex. Dextroamphetamine, methylphenidate, dextroamphetamine/amphetamine combinations

Occupations and Workplaces with Increased Prevalence of Thermal Stress: Individuals involved in physically active occupations (both indoors and outdoors) can have difficulty balancing safety with their job requirements in challenging thermal conditions[48]. There are many occupations where individuals can be at risk to heat or cold stress.

Hot environments can be present in many workplaces, including areas where materials are extremely hot or molten (e.g. brick firing and ceramic plants, glass production facilities, smelters, steam tunnels, iron and steel foundries), mining sites, in outdoor occupations where there is prolonged exposure to the sun (e.g. Hydro and telecommunications line-persons, construction and road workers, outdoor recreation workers), and for emergency personnel (e.g. firefighters).

As well, occupational cold exposure can vary greatly. Examples of workers at risk for cold hazards include: individuals who work outdoors[46] (e.g. Hydro and telecommunications line-persons, construction and road workers, outdoor recreation workers), emergency personnel, fishers, hunters and trappers, individuals who work in the food industry (e.g. refrigerated warehouses, meat and seafood processing and packaging, and cold storage).

Thermal Injuries

Thermally-related occupational injuries and illnesses occur when the thermal load of the environment and metabolic demands exceeds the capacity of the body to maintain a constant internal temperature[71]. There are several potentially negative responses to both acute and prolonged exposure to extreme environments. It is important to be aware of the conditions, how to recognize the symptoms, and know what steps can be taken to avoid incidents of thermal-related injuries in the workplace, in order to keep yourself and those around you safe. Individuals are generally unable to notice their own symptoms; it often falls to their coworkers to recognize the symptoms and seek timely first aid or medical help[12,13].

Heat Stress Injuries

The following injuries and illnesses are listed from mild to severe.

Thermal Injury or Illness	Description	Signs and Symptoms	Acute Treatment
Heat Edema	Pooling of fluid in the hands and legs by gravity due to heat induced expansion (dilation) and permeability of blood vessels.	Swelling of soft tissue, most noticeably in the ankles and hands/fingers.	Move to a cooler temperature area, and elevate the affected body part. Compression sleeves can be worn to promote drainage. Will resolve with acclimatization.
Heat Rash	Rash on the skin due to inflammation of plugged sweat gland ducts with prolonged exposure to humid heat and skin continuously wet with sweat.	Clusters of tiny red bumps or blisters, itching.	Increase ventilation within clothing, avoid direct heating of skin, keep rash area dry.

Heat Stress Injuries

Thermal Injury or Illness	Description	Signs and Symptoms	Acute Treatment
Sunburn	Burning of the skin due to too much exposure to the sun.	Red and painful skin, may be blistered or peeling.	Applying an aloe or calamine lotion or a dampened cool towel to the area may be soothing. Use skin lotions to treat peeling skin. Cover affected area to prevent further burning, work in covered or shaded areas. If skin blisters, seek medical assistance.
Heat Cramps	Sharp muscle pains/ spasms due to salt imbalance. Often occurs with large amounts of water intake without sufficient salt (electrolyte) replacement.	Sharp muscular cramps, pain, or spasms in arms, legs, or abdomen.	Seek cool area, remove excess clothing, drink water, have a snack, or fluids with electrolytes.

Heat Stress Injuries

Thermal Injury or Illness	Description	Signs and Symptoms	Acute Treatment
Heat Syncope	Heat induced dizziness and fainting caused by temporary insufficient blood flow to the brain while an individual is standing. Often caused by fluid loss through sweating and lowered blood pressure from pooling of blood in the legs. Most common in unacclimated individuals.	Light-headedness, fainting (for short durations), headache, nausea.	Lay individual down in cool area, remove excess clothing, have them sip water. Actively cool the person. Get medical help if: vomiting, symptoms worsen or do not improve within an hour.
Heat Exhaustion	Prolonged exposure to, or physical exertion in high temperatures, causing the body to overheat. Loss of body water and salt content through excessive sweating. Without prompt treatment, Heat Exhaustion can progress to Heat Stroke. A person who has experienced Heat Exhaustion or Heat Stroke previously will be more sensitive, and less tolerant, to the heat for up to a week. Recurrence of a second heat-stress event is common during this time.	Pale and clammy skin, heavy sweating, weakness, dizziness, body temperature above 38-39°C, visual disturbances, intense thirst, nausea, headache, vomiting, diarrhea, muscle cramps, breathlessness, heart palpitations, numbness of hands and feet, irritability.	Seek medical assistance, as this can progress to Heat Stoke. Move to cooler or shaded location, removing as much clothing as possible (socks, shoes), apply cool, wet clothes or ice to head, face or neck, spray with water, encourage fluid intake.

Heat Stress Injuries

Thermal Injury or Illness	Description	Signs and Symptoms	Acute Treatment
Heat Stroke	The most serious type of heat illness. Prolonged exposure to, or physical exertion in high temperatures, causing the body to overheat. Death can occur in minutes. A person who has experienced Heat Exhaustion or Heat Stroke previously will be more sensitive, and less tolerant, to the heat for up to a week. Recurrence of a second heat-stress event is common during this time.	High heart rate, erratic breathing, body temperature greater than 40°C, confusion, slurred speech, seizures, complete or partial loss of consciousness. "Classical" heat stroke: hot dry skin, with little to no sweating. "Exertional" heat stroke: sweating is usually present due to strenuous exercise or work.	Seek medical assistance immediately. Apply same aggressive cooling maneuvers as 'Heat Exhaustion', apply cold to person's armpits, groin, wet their skin and clothing with cool water, increase air circulation, do not try to force the person to drink liquids.

Cold Stress Injuries - Non-Freezing Injuries

The following injuries and illnesses are listed from mild to severe.

Thermal Injury or Illness	Description	Signs and Symptoms	Acute Treatment
Chilblain	Mild cold injury cause by prolonged and repeated exposure to cold (0°C - 16°C) for several hours. Recurrence is common.	Affected skin area will be red, swelling, tingling, blisters, pain.	Move person to warm area. Will resolve on its own (1-3 weeks after cold exposure), especially in warmer conditions. Seek medical care to check for complications if the pain is unusually severe, if infection is suspected, or if symptoms aren't improving after one to two weeks.
Immersion Foot	Injury to nerve and muscle tissue cause by feet that have been wet, but not cold, for days or weeks.	Tingling, numbness, itching, pain, swelling in legs and feet, blisters. Skin can be red, but may turn blue/purple as injury progresses. Gangrene can develop in severe cases.	Move person to a warm area, remove wet clothing, dry affected area, apply gentle rewarming* (apply warming packs, or hold the affected area to another warm area on the body). Seek medical advice to prevent gangrene.

* **Do not** attempt to rewarm areas while on site, or while still in a cold environment. The thawed area may refreeze, causing further injury. **Do not** rub or massage the affected area[14].

Cold Stress Injuries - Non-Freezing Injuries

Thermal Injury or Illness	Description	Signs and Symptoms	Acute Treatment
Trenchfoot	Injury to nerve and muscle tissue cause by prolonged exposure to cold and damp or wet environment.	Tingling, numbness, itching, pain, swelling in legs and feet, blisters. Skin can be red, but may turn blue/purple as injury progresses. Gangrene and/or permanent nerve damage can develop in severe cases.	Move person to a warm area, remove wet clothing, dry affected area, apply gentle rewarming* (apply warming packs, or hold the affect area to another warm area on the body). Seek medical advice to prevent gangrene.

* **Do not** attempt to rewarm areas while on site, or while still in a cold environment. The thawed area may refreeze, causing further injury. **Do not** rub or massage the affected area[14].

Cold Stress Injuries - Freezing Injuries

The following injuries and illnesses are listed from mild to severe.

Thermal Injury or Illness	Description	Signs and Symptoms	Acute Treatment
Frostnip	Mildest form of freezing injury. Occurs when an area (typically toes, fingers, cheeks, noses or ear lobes) is exposed to the cold, and the top layers of the skin freeze.	Affected skin will be paler than surrounding area, pain, stinging, numbness. As progresses, skin can appear shiny, rosy, and hardened.	Move person to a warm area, remove cold clothing, apply gentle rewarming* (apply warming packs, or hold the affect area to another warm area on the body).
Frostbite	Injury to tissue, blood vessels and nerves, typically in toes, fingers, cheeks, noses or ear lobes, caused by prolonged exposure to cold, or by direct contact with cold objects. Previously frostbit areas are more susceptible to recurrent frostbite.	Skin appears waxy, cold, and hard to the touch. <u>Mild cases:</u> Inflammation accompanied with pain, burning, or prickling. <u>Severe cases:</u> no pain, burning or prickling sensations, blisters.	Move person to a warm area, remove cold or wet clothing, apply gentle rewarming* (apply warming packs, or hold the affect area to another warm area on the body), loosen/remove constricting clothing, wrap in blankets, cover head and neck, if alert give liquids. If possible, cover affected area with sterile dressing. Seek medical assistance.

* **Do not** attempt to rewarm areas while on site, or while still in a cold environment. The thawed area may refreeze, causing further injury. **Do not** rub or massage the affected area[14].

Cold Stress Injuries - Freezing Injuries

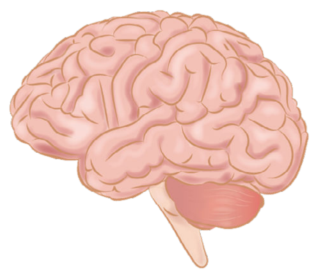
Thermal Injury or Illness	Description	Signs and Symptoms	Acute Treatment
Hypothermia	The most severe cold injury due to excessive heat loss. The body is unable to compensate for this heat loss and core temperature falls critically low.	<u>Mild:</u> vigorous shivering, sensation of cold, decreased physical function, difficulty caring for self. <u>Moderate:</u> weak and intermittent shivering, feelings of cold and pain diminish, lack of coordination or speech, confused or unusual behaviour, impaired judgement. <u>Severe:</u> no shivering, no sensation of pain, unresponsiveness, diminished consciousness, dilated pupils, no pulse, body feels stiff. May lead to death.	Seek medical assistance immediately. Check airways, breathing and circulation, lay person down, move to a warm place, remove wet clothing**, insulate the individual, rewarm slowly*** (apply warm water bottles, heating pads, blankets, heat from another individual). If individual stops breathing, perform CPR until medical assistance is available.

** If help is less than 30 minutes away, **do not** remove wet clothing and insulate immediately[14].

*** **Do not** rewarm too quickly. Ensure the individual is rewarmed slowly[14].

Thermal Effects on Work Function and Performance

Cognitive Function



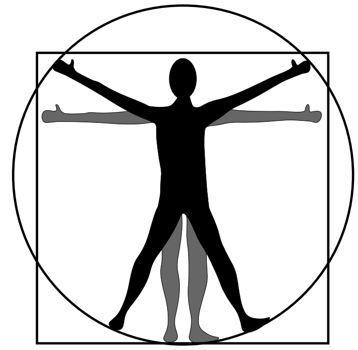
Impairments in cognitive function, decision making, and task performance can increase the risk of accidents in the workplace[39,77] and can be influenced by both cold and hot environments.

Small increases in body core temperature have the ability to influence cognitive tasks[90]. Increased sweating and hot thermal sensations associated with increased core temperatures can cause discomfort and sometimes distress, leading to increased distraction, irritability, and changes in behaviour[48]. However, the degree of cognitive impairment may be based on the type of cognitive task being performed. Tasks that are less attention-demanding are typically less vulnerable to heat effects than tasks requiring greater concentration or skill, such as mathematical or perceptual tasks[36,38,48,77,82,83].

With acclimatization, core temperature does not usually rise as much under regular conditions, and has been shown to improve heat-related decrements in cognitive performance[2,20,81].

Impairments in cognitive ability can also occur in cold environments, particularly when cold conditions are uncomfortable, as they tend to lead to lower work efficiency[9]. Intellectual function, reaction speeds, decision making, and control of mental ability become slower when working in a cold environment. Additionally, superficial cooling can cause discomfort in low temperature conditions, which may alter mental attentiveness, arousal, and ability to concentrate[3,24,62].

Physical Function



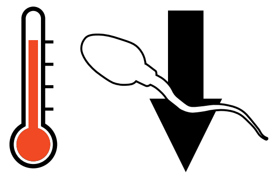
As a whole, heating and cooling reduces total work capacity and increases the risk for chronic injuries, such as repetitive strain injuries[17,76]. Reduction in manual performance is more commonly associated with cold environments. However, both heat and cold can influence whole body functions and accelerate the onset of fatigue[48].

Increased sweating can affect tasks that require grip and manual dexterity[65]. Like cognitive tasks, heat-related deficits in manual tasks vary depending on the type of task being performed, as well as the duration of exposure to the hot environment[39]. More complex motor tasks (i.e. tasks involving coordinated effort from both muscles and the brain) have greater deficits than simple motor tasks[78]. Exposure to heat for less than 60 minutes is associated with greater reductions in performance than exposure durations of 2 hours or longer[77]. This is because individuals who are exposed to heat for a long period of time may adjust to working in those conditions, improving overall performance as exposure time increases (i.e. worse performance is expected at the beginning of the day rather than later in the day)[77].

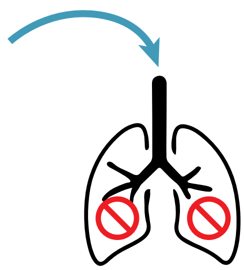
Cooling of the extremities (e.g. hands and feet) occurs quickly in cold environments because they have a high surface to volume ratio, they lack large muscles to produce heat, and they are more likely to come in contact with cold surfaces compared to other areas of the body[10]. Profound cooling of the extremities can impair proper functioning of hands, fingers, and feet[44]. Cooling of tissues in the hands and fingers can rapidly decrease tactile sensation of the skin as well as impair neuromuscular functions, affecting manual dexterity of the fingers[18,44,91]. Tasks that require more precise and controlled finger movements (e.g. tying a knot, screw tightening) are more likely to be compromised by cold exposure compared to tasks using hand, arm, and shoulder movements (e.g. hammering, pulling wire or rope)[84]. This may increase the risk of mistakes and accidents as the hands can become weak, senseless, and clumsy in the cold[3]. Thick clothing can further decrease movements and make functioning of the hands difficult. Additionally, cooling of tissues deeper than the skin surface can reduce muscular strength and increase stiffening of the joints. This can increase the work involved in maintaining balance and posture[63]. Cold feet can affect balance[75] and walking, both increasing the risk of slips, trips ,and falls[32], particularly when snow or ice are present[3].

Other Considerations

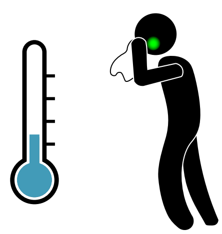
Heat exposure can be associated with temporary infertility in both males and females, however the effects are more pronounced in males[59,80]. When the temperature of the groin area increases above normal temperatures, sperm density, mobility, and numbers of normally shaped sperm decrease[42,50,66,79].



Continuous breathing of cold air can irritate the respiratory system, potentially eliciting asthma incidents and bronchospasms in susceptible individuals[15,17]. Prolonged cold air exposure has also been associated with other respiratory issues such as emphysema and chronic obstructive pulmonary disorder (COPD)[98].



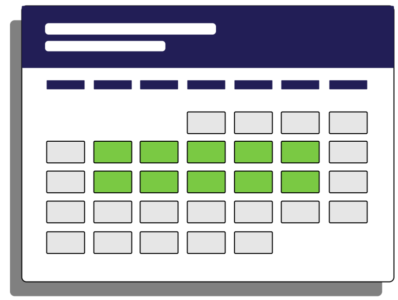
Exposure to cold stress can elevate hormonal and immune stress markers and potentially impair immune functions[17,30,55]. This may increase the risk of becoming sick and/or developing infections[69].



Simultaneous cooling of extremities with exposure to vibration have been shown to be correlated with the risk of development, as well as the severity, of hand-arm vibration syndrome[16].

Mitigating Strategies to Lower Thermal Risks in the Workplace

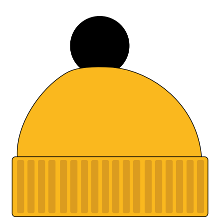
Acclimatization



One way to lower the risk of thermal injury is to acclimatize to the environment. Acclimatization is the development of resistance to, or enhanced tolerance for, an environmental change with repeated exposure to that environment[12,48]. Over time, generally six to fourteen days, individuals will acclimatize to the thermal stress[6,22,94]. However, some individuals may need a longer period of time. Acclimatization to heat occurs through physiological changes, including lower heart rate, lower core temperature, and greater amounts of sweat production to elicit greater evaporative cooling capacity[5,33,70,94]. Cold acclimatization is a diminishing of a perceptual response and desensitization to a frequently repeated stimulus, rather than physiological changes[17]. Individuals typically acclimatize more easily to a hot environment compared to cold environments[9].

New employees should be given enough time to acclimate to the new thermal conditions before assuming a full workload[11]. Some workplaces may benefit from implementing acclimatization programs. These programs can be used to increase work ability, decrease the risk for heat-related illness and enhance heat tolerance times[48]. General acclimatization protocols involve 1-2 hours a day of heat exposure while performing physical activity for 7-14 days[17].

Clothing



Protective clothing can be an effective way to prevent thermal injuries, particularly in cold environments. Clothing should be selected to suit the ambient temperature, weather conditions (e.g. wind, rain), the job design, as well as the level and duration of activity[11]. Choosing clothing according to these factors can help regulate the amount of heat and perspiration produced and retained during work in hot and cold conditions.

While clothing is a common preventative measure to prevent heat loss in cold environments, bulky and heavy clothing can affect performance by interfering with movement, increasing muscular strain and workload. It may also inhibit the perception and sensation needed in detailed work[45,56,73].

The following guidelines should help you choose suitable clothing for cold environments:

- Protective clothing should be worn for work at, or below, 4°C.

- Clothing should be worn in layers, and the layers should not be tight to one another. The air between garments provides insulation[11].

- Layers provide the option of removing clothing before getting too warm, or adding clothing when cooling down or taking a break[11]. Layers allow workers to accommodate to changes in environmental conditions.

- Inner layers should "wick" moisture away from the skin. Materials that have this property include polyesters or polypropylene.

- Ensure clothing remains dry, and change clothing if it becomes wet. When clothing becomes wet (e.g. snow, rain, sweat) the insulative properties of the clothing decrease, potentially increasing the risk of cold injury.

- Avoid cotton-based fabrics, as they get wet quickly and lose insulative properties. Try wool or synthetic fabrics, as they retain heat when wet.

- Leather-topped safety boots and shoes are best suited for cold weather because the material is porous, allowing air flow and evaporation of moisture within the boot[11].

- In high winds, goggles are recommended to prevent the corneas of the eyes from freezing.

- Clothing is recommended to be removed in the following order to prevent excessive sweating while working in cold environments[11]:

    » Mittens or gloves
    » Headgear and/or scarf
    » Opening jacket at the waist, wrists, or underarms
    » Removal of layer(s)

In hot environments, the insulative and evaporative resistance of some protective clothing can hinder heat transfer through convection, radiation, and evaporation[33]. The following guidelines should help provide suggestions for suitable clothing for hot environments:

- Light coloured clothing is suggested when exposed to the sun.

- When safe to do so, clothing should be loose fitting.

- Wear reflective clothing when in high radiant-heat environments.

- Cover your head when exposed to direct sunlight.

- Inner layers should "wick" moisture away from the skin. Materials that have this property include polyesters or polypropylene.

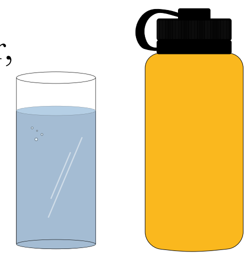
- When physical work rate, protective equipment, or the environment cannot be modified, auxiliary cooling garments can be used. These include: ice vest systems and circulating liquid or air-cooling systems.

Screening

Susceptibility to development of thermal illness and injury, as well as tolerance to a thermal environment can be assessed before individuals start working in a thermally challenging environment[26,71]. Screening criteria can include age, anthropometry (e.g. BMI, body fat percentage, body surface area), and cardiovascular fitness or physical work capacity[26]. Previous medical history should also be included during screening, as workers who have experienced previous thermal-related illnesses may be less heat tolerant[4,58].

Nutrition

Balanced meals and adequate fluid intake are essential for acquiring thermal balance in hot and cold environments. There is also an important connection between body fluid levels, fluid loss, and heat loss. As moisture is lost from the body, circulating blood volume is reduced, influencing the amount of sweat production[35,43], which can lead to dehydration. Meals should provide enough energy to maintain work capacity while fluids are required for preventing dehydration.



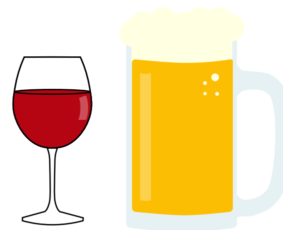
When water and electrolytes are lost at a rapid rate in the heat through sweat evaporation, loss of water, salt, and potassium should be compensated for by increasing food and fluid intake. Fluid intake should equal fluid loss. However, thirst is a poor indicator of hydration status and normal thirst mechanisms are often not sensitive enough to ensure sufficient water intake[35,64]. Individuals need to be encouraged to drink fluids in small quantities, at frequent intervals[64]. It is important to not overdrink water in hot and humid environments. Overdrinking water, in combination with significant sodium loss from sweating, can decrease the concentration of sodium in the blood". Known as hyponatremia, this further exaggerates sodium imbalance[1,17,57,68]. This is a primary concern for individuals working in hot environments for prolonged periods of time[87]. Salt and potassium in a normal diet should be sufficient to maintain electrolyte balance in acclimatized individuals, however additional salt and potassium-rich foods may need to be added for unacclimated workers[12,22]. Salt tablets can irritate the stomach and are not recommended to be used[22,71].

Sports drinks, fruit juices, and other drinks designed to replace electrolytes and fluids should only be used in moderation[12,67]. These types of drinks often add unnecessary sugar and/or salt to the diet.

Caffeinated drinks (e.g. coffee, tea, soft drinks) have been shown to not substantially alter heat balance[23,88], but doses should be consumed in moderation. Caffeinated drinks that contain high doses of caffeine (e.g.

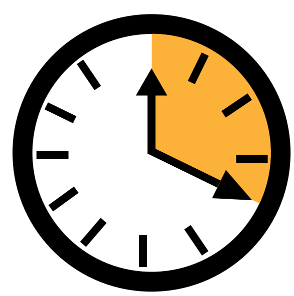
energy drinks) can increase urine production and increase skin blood flow, which can contribute to dehydration and increase loss of body heat[11]. High doses of caffeine are capable of inducing cardiac arrhythmias[99], especially when combined with heat stress.

Alcohol consumption can alter the body's thermoregulatory functions in both hot and cold environments. Alcohol ingestion can give an individual a 'false sense of warmth', in which they report less sensation of cold and discomfort during cold exposure even though body core temperature is lowered[27,104]. Alcohol consumption increases vasodilation of skin blood vessels[27], increasing skin blood flow and enhancing body heat loss in cold environments. An increase in blood alcohol levels may also decrease blood glucose concentration, which can reduce or eliminate the shivering response to cold exposure, reducing metabolic heat produced by the body[28,34,37]. These factors increase the risk of hypothermia. Increased heat loss can also occur in the heat, as skin blood flow, heart rate, and sweating rate significantly increase with alcohol consumption[103]. Individuals will also have greater sensation of the heat, feeling hotter even though core temperature is not elevated[103]. Alcohol also increases body fluid loss and urine production, leading to dehydration[11].



Work-Rest Cycles

When continuous work is being completed in hot and cold temperatures, frequent rest periods should be taken[54]. In the cold, heated warming shelters should be provided for these rest periods, while in the heat, cooled observation booths can allow workers to cool down and monitor equipment simultaneously[11]. Implemented work-rest cycles are important to limit excessive heat loss, or accumulation of body heat storage, in cold and hot environments, respectively.



Individuals should also ensure they get adequate sleep (approximately 7 hours). Both sleep deprivation and shortened sleep can influence body temperature, in addition to cognitive function and alertness[41,86]. Skin temperature gradients can be significantly affected by lack of sleep, enhancing heat loss in the feet and legs, and heat gain in the hands and arms[86]. Shortened sleep times (3.5-4 hours) can also reduce body core temperatures during the day[7,41], likely due to decreased metabolic rate, which also increases the risk of future weight gain.

Work-rest cycles are important when scheduling shifts. It should also be noted that a decrease in thermal tolerance, specifically to heat stress, can occur in as short as 3-4 days[12]. De-acclimatization can occur with absence from the environment for a week or longer[71]. Physically fit individuals maintain heat acclimatization to a greater degree than less fit individuals[74]. Workers may need to re-acclimatize if they are absent from the thermal conditions for an extended period of time. Additional caution should be taken on the first day of a shift change as the individual may have diminished acclimation during days off[71]. However, re-acclimatization can usually be regained in 3-5 days upon return to the thermal environment, depending on the amount of time away from the thermal stress[6,60,101]. Various organizations and agencies have put forth industry-specific recommendations for exposure and acclimatization (e.g. American Conference of Governmental Industrial Hygienists, Mine Safety and Health Organization, International Organization for Standardization, Canadian Centre for Occupational Health and Safety), but the general recommendation for individuals returning to the same job after a prolonged leave (~9 days or longer) is as follows: 50% of usual duration of work under thermal stress on Day 1, 60% on Day 2, 80-90% on Day 3, and 100% on Day 4[71].

Control or Reduce Exposure

When possible, the reduction of the thermal source in the workplace should be implemented.

Convective Controls:

- Increased local ventilation and air velocity through the use of electric fans[47]
    - When air temperature is less than worker's skin temperature, increasing local ventilation will increase the rate of heat loss[71].

- When air temperature is greater than worker's skin temperature, air speeds should be reduced to levels that still allow evaporative heat loss, but also reduce conductive heat gain[71].

- Reduction of ambient air temperature through localized air conditioning.

- Reduce cold drafts through doorways and passageways through curtains.

- Provide tents when work is completed in cold and windy environments[3].

Radiant Controls:

- Shielding of local, industrial-radiated heat sources from workstations. Bright metal surfaces can be used to reflect heat back towards the source, while absorbent shields can effectively absorb and carry heat away.

- Insulating hot surfaces can reduce heat exchange between the source and the work environment.

- Avoidance of direct sunlight by working in shaded areas[33].

- Use of local radiator or infrared heaters in cold workplaces[3].

Evaporative Controls:

- Reduction of humidity through dehumidification and elimination of open hot water baths, drains, and leaky steam valves.

- Increase air movement (see *Convection Controls*).

Administrative Controls:

- Hot Environments: Schedule more strenuous jobs or tasks to cooler times of the day (e.g. early morning, later afternoon, evening).

- Cold Environments: Schedule more strenuous jobs or tasks to a warmer time of the day (e.g. mid-day).

- Schedule routine maintenance and repairs in hot areas for cooler seasons.

- Implement work/rest schedules (see *Work-Rest Cycles*).

- Reduce heat produced by the body by automation and mechanization of tasks involving heavy physical work.

- Add extra personnel to the task to reduce work and exposure time.

- Implement heat or cold-acclimatization programs (see *Acclimatization*).

References

1. Almond CS, Shin AY, Fortescue EB, Mannix RC, Wypij D, Binstadt BA, Duncan CN, Olson DP, Salerno AE, Newburger JW, Greenes DS. Hyponatremia among runners in the Boston marathon. N Engl J Med 2005;352:1550-1556.

2. Amos D, Hansen R, Lau WM, Michalski JT. Physiological and cognitive performance of soldiers conducting routine patrol and reconnaissance operations in the tropics. Mil Med 2000;165:961-966.

3. Anttonen H, Pekkarinen A, Niskanen J. Safety at work in cold environments and prevention of cold stress. Industrial Health 2009;47:254-261.

4. Armstrong LE, De Luca JP, Hubbard RW. Time course recovery and heat acclimation ability of prior exertional heatstroke patients. Med Sci Sports Exerc 1990;22:36-48.

5. Armstrong LE, Maresh CM. The induction and decay of heat acclimatisation in trained athletes. Sports Med 1991;12:302-312.

6. Ashley CD, Ferron J, Bernard TE. Loss of heat acclimation and time to re-establish acclimation. J Occup Environ Hyg 2015;12:302-308.

7. Bach V, Maingourd Y, Libert JP, Oudart H, Muzet A, Lenzi P, Johnson LC. Effect of continuous heat exposure on sleep during partial sleep deprivation. Sleep 1994;17:1-10.

8. Buskirk E, Lundegren H, Magnusson L. Heat acclimatization patterns in obese and lean individuals. Ann NY Acad Sci 1965;131:637-653.

9. Canadian Centre for Occupational Health and Safety. Cold environments: General, https://www.ccohs.ca/oshanswers/phys_agents/cold_general.html. 2019.

10. Canadian Centre for Occupational Health and Safety. Cold environments: Health effects and first aid, https://www.ccohs.ca/oshanswers/phys_agents/cold_health.html. 2019.

11. Canadian Centre for Occupational Health and Safety. Cold environments: Working in the cold, https://www.ccohs.ca/oshanswers/phys_agents/cold_working.html. 2019.

12. Canadian Centre for Occupational Health and Safety. Hot environments: Control measures, https://www.ccohs.ca/oshanswers/phys_agents/heat_control.html. 2016.

13. Canadian Centre for Occupational Health and Safety. Hot environments: Health effects and first aid, https://www.ccohs.ca/oshanswers/phys_agents/heat_health.html. 2016.

14. Canadian Red Cross. Cold-Related Emergencies: Staying Warm and Safe in Canadian Winters, https://www.redcross.ca/training-and-certification/first-aid-tips-and-resources/first-aid-tips/cold-related-emergencies-staying-warm-and-safe-in-canadian-winters.

15. Carlsen KH. Sports in extreme conditions: The impact of exercise in cold temperatures on asthma and bronchial hyper-responsiveness in athletes. Br J Sports Med 2012;46:796-799.

16. Carlsson IK, Dahlin LB. Self-reported cold sensitivity in patients with traumatic hand injuries or hand-arm vibration syndrome – an eight year follow up. BMC Musculoskelet Disord 2014;15:83.

17. Cheung SS, Lee JKW, Oksa J. Thermal stress, human performance, and physical employment standards. Appl Physiol Nutr Metab 2016;41:S148-S164.

18. Cheung SS, Montie DL, White MD, Behm D. Changes in manual dexterity following short-term hand and forearm immersion in 10 °C water. Aviat Space Environ Med 2003;79:990-993.

19. Cuddy MLS. The effects of drugs on thermoregulation. AANC Clinical Issues 2004;15:238-253.

20. Curley MD, Hawkins RN. Cognitive performance during a heat acclimatization regimen. Aviat Space Environ Med 1983;54:709-713.

21. DOD. Occupational and environmental health: prevention, treatment, and control of heat injury. Washington, DC: Departments of the U.S. Army, Navy, and Air Force 1980.

22. DOD. Technical bulletin: heat stress control and heat casualty management. TB MED 507/AFPAM 48-152 (I). Washington, DC: Departments of the U.S. Army, Navy, and Air Force 2003.

23. Ely BR, Ely MR, Cheuvront SN. Marginal effects of a large caffeine dose on heat balance during exercise-heat stress. Int J Sport Nutr Exerc Metab 2011;21:65-70.

24. Enander A. Effects of moderate cold on performance of psychomotor and cognitive tasks. Ergonomics 1987;30:1431-1445.

25. Epstein Y, Albukrek D, Kalmovitc B, Mora DS, Shapiro Y. Heat intolerance induced by antidepressants. Ann NY Acad Sci 1997;813:553-558.

26. Flouris AD, McGinn R, Poirier MP, Louie JC, Ioannou LG, Tsoutsoubi L, Sigal RJ, Boulay P, Hardcastle SG, Kenny GP. Screening criteria for increase susceptibility to heat stress during work or leisure in hot environments in healthy individuals aged 31-70 years. Temperature (Austin) 2018;5:86-99.

27. Freund BJ, O'Brien C, Young AJ. Alcohol ingestion and temperature regulation during cold exposure. J Wilderness Med 1994;5:88-98.

28. Fox GR, Hayward JS, Hobson GN. Effect of alcohol on thermal balance of man in cold water. Can J Physiol Pharmacol 1979;57:860-865.

29. Gagge AP, Gonzales RR. Mechanisms of heat exchange. Handbook of physiology. Environmental physiology. Bethesda, MD: American Physiological Society 1996;45-84.

30. Gagnon DD, Gagnon SS, Rintamäki H, Tormäkangas T, Puukka K, Herzig KH, Kyroläinen H. The effects of cold exposure on leukocytes, hormones, and cytokines during acute exercise in humans. PLoS ONE 2014;9:e110774.

31. Gagnon D, Kenny GP. Sex modulates whole-body sudomotor thermosensitivity during exercise. J Physiol 2011;589:6205-6217.

32. Gao C. Slip and fall risks on ice and snow (Ph.D.). Technical University, Luleå 2004.

33. Gao C, Kuklane K, Östergren PO, Kjelistrom T. Occupational heat stress assessment and protective strategies in the context of climate change. Int J Biometeorol 2018;62:359-371.

34. Graham T, Dalton J. Effect of alcohol on man's response to mild physical activity in a cold environment. Aviat Space Environ Med 1980;51:793-796.

35. Greenleaf JE, Harrison MH. Water and electrolytes. ACS Symp Series 1986;294:107-124.

36. Grether WF. Human performance at elevated environmental temperatures. Aerosp Med 1973; 44:747-755.

37. Haight JSJ, Keatinge WR. Failure of thermoregulation in the cold during hypoglycaemia induced by exercise and ethanol. J Physiol 1973;229:87-97.

38. Hancock PA. Task categorization and the limits of human performance in extreme heat. Aviat Space Environ Med 1982;53:778-784.

39. Hancock PA, Ross JM, Szalma JL. A meta-analysis of performance response under thermal stressors. Hum Factors 2007;49:851-877.

40. Hanna EG, Tait PW. Limitations to thermoregulation and acclimatization challenge human adaptation to global warming. Int J Environ Res Public Health 2015;12:8034-8074.

41. Hibi M, Kubota C, Mizuno T, Aritake S, Mitsui Y, Katashima M, Uchida S. Effect of shortened sleep on energy expenditure, core body temperature, and appetite: a human randomised crossover trial. Sci Rep 2017;7:39640.

42. Henderson J, Baker HW, Hanna PJ. Occupation-related male infertility: a review. Clin Reprod Fertil 1986;4:87-106.

43. Henschel A. The environment and performance. In: Simonson E, ed. Physiology of work capacity and fatigue. Vol 14. Springfield, IL: Charles D Thomas 1971.

44. Heus R, Daanen HA, Havenith G. Physiological criteria for functioning of hands in the cold: A review. Appl Ergon 1995;26:5-13.

45. Holmér I. Evaluation of cold workplaces: An overview of standards for assessment of cold stress. Industrial Health 2009;47:228-234.

46. Holmér I, Granberg PO, Dahlström G. Cold. In: Encyclopedia of Occupational Health, Stellman J (Ed.), ILO, Geneva 1997;42.29-42.43.

47. Jay O, Cramer MN, Ravanelli NM, Hodder SG. Should electric fans be used during a heat wave? Appl Ergon 2015;46:137-143.

48. Jay O, Kenny GP. Heat exposure in the Canadian workplace. Am J Indust Med. 2010;53:842-853.

49. Johnson JM, Minson CT, Kellogg DL. Cutaneous vasodilator and vasoconstrictor mechanisms in temperature regulation. Compr Physiol 2014;4:33-89.

50. Jung A, Schuppe HC. Influence of genital heat stress on semen quality in humans. [Review]. Andrologia 2007;39:203-215.

51. Kanzenbach TL, Dexter WW. Cold Injuries. Postgraduate Medicine 1999;105:72-78.

52. Kenny GP, Yardley J, Brown C, Sigal RJ, Jay O. Heat stress in older individuals and patients with common chronic diseases. CMAJ 2010;182:1053-1060.

53. Khagali M, Hayes JSR. Heatstroke and temperature regulation. Sydney: Academic Press 1983.

54. Kjellstrom T, Holmer I, Lemke B. Workplace heat stress, health and productivity – an increasing challenge for low and middle-income countries during climate change. Global Health Action 2009;2;46-51.

55. LaVoy EC, McFarlin BK, Simpson RJ. Immune responses to exercising in a cold environment. Wilderness Environ Med 2011;22:343-351.

56. LeBlanc J, Dulac S, Cote J, Girard B. Autonomous nervous system and adaptations to cold in man. J Appl Physiol 1975;39:181-186.

57. Lee JKW, Ang WH, Nio AQX, Johnson C, Aziz AR, Lim CL, Hew-Butler T. First reported cases of exercise-associated hyponatremia in Asia. Int J Sports Med 2011;32:297-302.

58. Leithead CS, Lind AR. Heat stress and heat disorders. London: Cassell 1964.

59. Levine RJ. Male fertility in hot environment. JAMA 1984;252:3250-3251.

60. Lind AR, Bass DE. Optimal exposure time for development of acclimatization to heat. Fed Proc 1963;22:704-708.

61. LoVecchio F, Pizon AF, Berrett C, Balls A. Outcomes after environmental hyperthermia. Am J Emerg Med 2007;25:442-444.

62. Mäkinen TM, Palinkas L, Reeves D, Pääkkönen T, Rintamäki H, Leppäluoto J, Hassi J. Effect of repeated exposures to cold on cognitive performance in humans. Physiol Behav 2006;87:116-176.

63. Mäkinen TM, Rintamäki H, Korpelainen JT, Kampman V, Pääkkönen T, Oksa J, Palinkas LA, Leppäluoto J, Hassi J. Postural sway during single and repeated cold exposures. Aviat Space Environ Med 2005;76:947-953.

64. McArdle WD, McArdle FI, Katch VL. Exercise physiology. In: McArdle WD, McArdle FI, Katch VL, eds. Exercise physiology: nutrition, energy, and human performance. 7th ed. Philadelphia: Lippincott Williams & Wilkins 2010.

65. Meese GB, Kok R, Lewis MI, Wyon DP. A laboratory study of the effects of moderate thermal stress on the performance of factory workers. Ergonomics 1984;27:19-43.

66. Mieusset R, Bujan L, Mansat A, Pontonnier F, Grandjean H. Effects of artificial cryptorchidism on sperm morphology. Fertil Steril 1987;47:150-155.

67. Montain SJ, Cheuvront SN. Fluid, electrolyte and carbohydrate requirements for exercise. In: Taylor NAS, Groeller H, eds. Physiological bases for human performance during work and exercise. Edinburgh: Churchhill Livingstone Elsevier 2008.

68. Montain SJ, Cheuvront SN, Sawka MN. Exercise associated hyponatraemia: quantitative analysis to understand the aetiology. Br J Sports Med 2006;40:98-105; discussion, 198-105.

69. Mourtzoukou EG, Falagas ME. Exposure to cold and respiratory tract infections. Int J Tuberc Dis 2007;11:938-943.

70. Nielsen B. Heat acclimation – mechanisms of adaptation to exercise in the heat. Int J Sports Med 1998;19:S154-S156.

71. NOISH. Criteria for a recommended standard: occupational exposure to heat and hot environments. Cincinnati, OH: U.S. Department of Health and Human Services, Centers for Disease Control and Prevention, National Institute for Occupational Safety and Health, DHHS (NIOSH) Publication 2016-106.

72. Nybo L. Fatigue mechanisms determining exercise performance: Hyperthermia and fatigue. J App Physiol 2008;104:871-878.

73. Oksa J. Cooling and neuromuscular performance in man (Ph.D.). University of Jyväskylä, Jyväskylä 1998.

74. Pandolf KB, Burse RL, Goldman RF. Role of physical fitness in heat acclimatisation, decay and reinduction. Ergonomics 1977;20:399-408.

75. Piedrahita H. Working in cold conditions indoors: Effects on musculoskeletal symptoms and upper limb movements (Ph.D.). Technical University, Luleå 2008.

76. Pienimäki T. Cold exposure and musculoskeletal disorders and disease. A review. Int J Circump Health 2002;61:173-182.

77. Pilcher JJ, Nadler E, Busch C. Effects of hot and cold temperature exposure on performance: A meta-analytic review. Ergonomics 2002;45:682-698.

78. Pill JF, Lundbye-Jensen J, Trangmar SJ, Nybo L. Performance in complex motor tasks deteriorates in hyperthermic humans. Temperature 2017;4:420-428.

79. Procope BJ. Effect of repeated increase of body temperature on human sperm cells. [In Vitro]. Int J Fertil 1965;10:333-339.

80. Rachootin P, Olsen J. The risk of infertility and delayed conception associated with exposures in the Danish workplace. J Occup Med 1983;25:394-402.

81. Radakovic SS, Maric J, Surbatovic M, Radjen S, Stefanova E, Stankovic N, Filipovic N. Effects of acclimation of cognitive performance in soldiers during exertional heat stress. Mil Med 2007;172:133-136.

82. Ramsay JD. Task performance in heat: A review. Ergonomics 1995;38:154-165.

83. Ramsay JD, Morrissey SJ. Isodecrement curves for task performance in hot environments. Appl Ergon 1978;9:66-72.

84. Ray M, King M, Carnahan H. A review of cold exposure and manual performance: Implications for safety, training and performance. Saf Sci 2019;115:1-11.

85. Robertshaw D. Man in extreme environments, problems of the newborn and the elderly. In: Cena K, Clark J, ed. Bioengineering, Thermal Physiology and Comfort. Elservier Scientific Publishing Company, Amsterdam, The Netherlands; Oxford, UK; New York, NY, USA: 1981.

86. Romeijn N, Verweij IM, Koeleman A, Mooij A, Steimke R, Virkkala J, van der Werf Y, Van Someren EJW. Cold hands, warm feet: Sleep deprivation disrupts thermoregulation and its association with vigilance. Sleep 2012;35:1673-1683.

87. Rosner MH, Kirven J. Exercise-associated hyponatremia. Clin J Am Soc Nephrol 2007;2:151-161.

88. Roti MW, Casa DJ, Pumerantz AC, Watson G, Judelson DA, Dias JC, Ruffin K, Armstrong LE. Thermoregulatory response to exercise in the heat: chronic caffeine intake has no affect. Aviat Space Environ Med 2006;77:124-129.

89. Selkirk GA, McLellan TM. Influence of aerobic fitness and body fatness on tolerance to uncompensable heat stress. J Appl Physiol 2001;91:2055-2063.

90. Simmons SE, Saxby BK, McGlone FP, Jones DA. The effect of passive heating and head cooling on perception, cardiovascular function and cognitive performance in the heat. Eur J Appl Physiol 2008;104:271-280.

91. Sormunen E, Rissanen S, Oksa J, Pienimäki T, Remes J, Rintamäki H. Muscular activity and thermal responses in men and women during repetitive work in cold environments. Ergonomics 2009;52:964-976.

92. Stookey JD. High prevalence of plasma hypertonicity among community-dwelling older adults: results from NHANES III. J Am Diet Assoc 2005;105:1231-1239.

93. Tait PW. Medicine use, heat and thermoregulation in Australian patients. Med J Aust 2011;195:327.

94. Taylor NAS. Human heat adaptation. Compr Physiol 2014;4:325-365.

95. Taylor NAS, Kondo N, Kenny WL. The physiology of acute heat exposure, with implications for human performance in the heat. In: Taylor NAS, Groeller H, eds. Physiological bases of human performance during work and exercise. 1st ed. Edinburgh: Elsevier 2008.

96. Tipton M, Pandolf K, Sawka M, Werner J, Taylor N. Physiological adaptations to hot and cold environments. In: Taylor NAS, Groeller H, eds. Physiological bases of human performance during work and exercise. 1st ed. Edinburgh: Elsevier 2008.

97. Toffanello ED, Inelmen EM, Minicuci N, et al.Ten-year trends in dietary intake, health status and mortality rates in free-living elderly people. J Nutr Health Aging 2010;14:259-264.

98. Tseng CM, Chen YT, Ou SM, Hsiao YH, Li SY, Wang SJ, et al. The effect of cold temperature on increased exacerbation of chronic obstructive pulmonary disease: a nationwide study. PLoS ONE 2013;8:e57066.

99. Undem BJ. Pharmacotherapy of asthma. In:Brunton LL, Lazo JS, Parker KL, eds. Goodman & Gilman's The pharmacologic basis of therapeutics. 11th ed. New York: McGraw-Hill 2006.

100. Westway K, Frank O, Husband A, McClure A, Shute R, Edwards S, Curtis J, Rowett D. Medicines can affect thermoregulation and accentuate the risk of dehydration and heat-related illness during hot weather. J Clin Pharm Ther 2015;40:363-367.

101. Wyndham CH. The physiology of exercise under heat stress. Annu Rev Physiol 1973;35:193-220.

102. Yeargin SW, Casa DJ, Armstrong LE, Watson G, Judelson DA, Psathas E, Sparrow SL. Heat acclimatization and hydration status of American football players during initial summer workouts. J Strength Cond Res 2006;20:463-470.

103. Yoda T, Crawshaw LI, Nakamura M, Saito K, Konishi A, Nagashima K, Uchida S, Kanosue K. Effects of alcohol on thermoregulation during mild heat exposure in humans. Alcohol 2005;36:195-200.

104. Yoda T, Crawshaw LI, Saito K, Nakamura M, Negashima K, Kanosue K. Effects of alcohol on autonomic responses and thermal sensation during cold exposure in humans. Alcohol 2008;42:207-212.

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