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Considerations for occupational heat exposure: A scoping review

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Abstract

The ability to regulate core body temperature is a critical factor in avoiding occupational heart stress in demanding environments. Heat-related illness in an occupational setting is complex and multifactorial and includes environment (intrinsic and extrinsic), the occupational clothing requirements and physiological factors. Much of this research began in the gold mines in South Africa after several miners died due to heat related illness. Similar research was conducted during World War Two and was crucial for the creation of acclimatization techniques and strategies for acquiring thermal tolerance. Techniques such as fatigue recovery and body cooling are still used today to prevent heat related illness in individuals with occupations that have frequent exposure to heat and high physical loads. These individuals are at greater risk of heat related illness as extended exposure to a hot or humid environment in combination with strenuous physical activity can overwhelm the body's homeostatic cooling mechanisms. In addition, individuals from special populations with chronic or acute health impacts such as diabetes mellitus, also have a greater risk for the aforementioned. Currently, there are several heat prevention strategies, including training and education, regulation and monitoring, in place to protect workers from heat related illness and casualty. These strategies, along with future considerations and the impact of climate change will be highlighted in this review.

Introduction

It is well known that certain occupations such as agriculture, athletics, mining, firefighting, construction etc. carry a much larger physical as well as environmentally stressful load than others [1–4]. As these individuals operate within physically demanding conditions, heat stress becomes a significant element in labour production and working conditions [5]. The magnitude of physiological strain imposed by the exercise, labour or physical exertion and the surrounding environmental stress is influenced several intrinsic and extrinsic factors (Fig 1)

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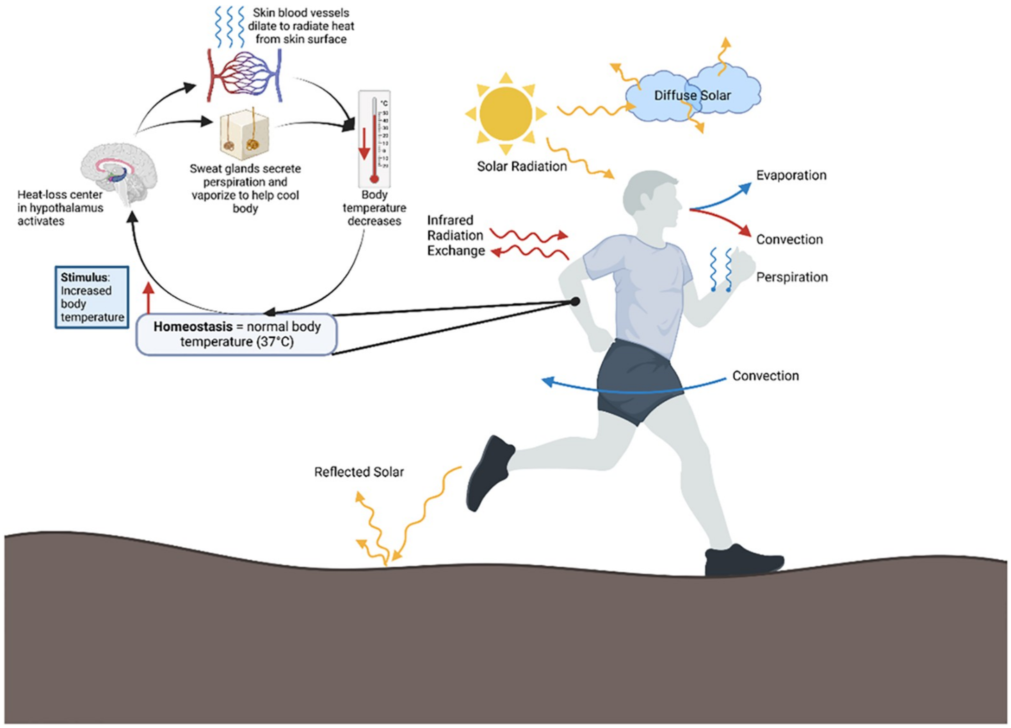

Fig 1. An overview of thermoregulation during exercise.

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including the environmental hazards, an individual heat exchange capacity with the environment, their metabolic rate, and their level of preparation [6].

"Heat stress" refers to external factors that may affect the body's ability to adequately deal with heat accumulation, whereas "heat strain" refers to the internal physiological response to heat accumulation [7]. The capacity to tolerate excess accumulated heat is governed by the autonomic processes of thermoregulation [8]. The body's core temperature is a tightly controlled thermoregulatory system (For a detailed review on thermoregulation, see [8–10]) and is maintained by a combination of feedback and feed-forward mechanisms [11]. Exposure to warmth triggers a complementary set of autonomic responses, including suppression of thermogenesis, facilitation of heat loss through water evaporation (e.g. sweating) and dilation of blood vessels (vasodilation), all of which are regulated by the hypothalamus [10]. Therefore, during physical exertion, the rate of heat accumulation increases rapidly, triggering the autonomic nervous system to increase heat flow away from the core until a heat gain equals heat loss and homeostasis is achieved. Behavioural responses plays a primary role in body temperature regulation such self-pacing to reduce stress or drinking water when dehydrated [12]. Slowing down work to prevent heat stress was reflected in shearers and this reduced their productivity in their work [12]. While thermophysiological responses to physical exertion are well understood, individual variations to heat stress can vary [9]. Exertional heat illness is a significant risk when heat production exceeds the ability to effectively dissipate excess heat. Acute complications include exercise-associated muscle cramps, heat syncope (losing consciousness) and heat exhaustion, seizures and life-threatening symptoms of heat stroke [13–16].

Moreover, it is also known that individuals involved in such occupations are at greater risk of acute and long-term health complications [1, 3]. Previous research has demonstrated that occupational exposure to heat and high physical loads are associated with health conditions such as kidney dysfunction, cardiovascular issues, reproductive problems, chronic pain, osteoarthritis, and other musculoskeletal issues [17]. These health implications are associated with higher prevalence of morbidity and mortality in the aforementioned populations [17]. The purpose of this paper is to provide readers a brief review on the effects of occupational exposure to heat and high physical loads on acute and long-term health. In addition, this paper will summarise some evidence based potential preventative methods such as fatigue recovery methods, body cooling strategies and training and educational programs.

Methodology

Study design

A scoping review, as defined by Grant and Booth [18], was determined to be the most relevant methodology for this review. Our research question is focused on mapping the available evidence regarding heat exposure in labour environments. The goal of which is not to be exhaustive but will provide a succinct overview of the current state of the literature. The review was guided by Arksey and O'Malley's methodological framework for scoping reviews [19] and further informed by the work of Levac et al. [20]. Accordingly, as we are attempting to "map" and summarize available evidence that is heterogenous in terms of both methodology and discipline, a scoping review is the most appropriate approach [20, 21]. A six-stage methodological framework is recommended; however this review did not undertake Step 6: stakeholder consultations due to time restrictions. The following steps were implemented [19, 20, 22]:

Step 1: Identifying the research question

Step 2: Identifying relevant studies

Step 3: Study selection

Step 4: Charting and tabulating available data

Step 5: Collating, summarising, and reporting the results

Step 6: Stakeholder consultations

This review followed the recommendations detailed in the Preferred Reporting Items for Systematic Review and Meta-Analysis Protocols checklist for Scoping Reviews (PRISMA-ScR) [21] including recommendations from the Joanna Briggs Institute Reviewer's Manual [23]. Although scoping and systematic reviews share many common traits, falling beyond the scope of a scoping review are risk of bias assessment, meta-biases and assessment of evidence strength [21, 24] and will not be included in this review. It was decided that a scoping review was the most appropriate methodology as the overall goal is to provide an overview of the available evidence whereas a systematic review aims to provide a summary answer.

Step 1: Identifying the research question. The primary objective of thesis review was to provide an overview of the current literature with regards to heat exposure in various occupational settings. Secondary objectives were to determine what gaps in the literature as well as potential future directions.

Step 2: Identifying relevant studies. A literature search was performed between 15 September and 20 October 2022. using the PUBMED and Google Scholar databases using a combination of the following search terms; "health", "complications", "heat", "environment", "occupation" and "physical load". Broad themes were collaboratively developed based on a preliminary search of the literature and were used to guide the narrative discourse of the review. Only peer-reviewed studies with practical or clinical relevance were considered however, grey literature was also considered if it was relevant to the topic.

Step 3: Study selection. Following the search, all relevant studies were added to an excel sheet. Potentially relevant studies were reviewed in full, and themes were extracted. Studies were excluded if they were not relevant to overall thematic discourse. Studies that investigated heat exposure in various occupational settings were considered for inclusion (Table 1). Articles written in English and French were considered.

Step 4: Charting and tabulating available data. Themes were identified from the relevant studies by members of the study team. Each theme (major and minor) was discussed among the study and a consensus was obtained.

Step 5: Collating, summarising, and reporting the results. The results of the search strategy yielded 4,735 articles. After full text review, 107 articles were identified resulting in eight major themes and minor themes.

Results and discussion

Historical context

Much of what is currently known regarding heat casualties and occupational heat acclimation comes from early heat stress research related to miners in the gold mines of South Africa [25]. The Witwatersrand Basin Gold Mine, which opened in 1884, was one of the deepest mines in the world and has a depth of up to 3.2 kilometres. The environment of this mine was uniquely challenging due to thermal stress and occupational workload as the rock temperatures approach 60˚C; risk for heat stroke arises at temperatures as little as 28˚C. Due to extreme conditions, heat related deaths were common and thus research began investigating how to prevent heat related casualties while still maintaining gold production. Mechanized mining techniques were eventually installed, along with cooling plants, which temporarily decreased mine temperatures, humidity and subsequent heat related death. However, as the depth of the mine increased, heat stroke and temperature related death increased and continued to be a concern. The HEAT-SHIELD team has published a comprehensive review on occupational heat-related illnesses and fatalities [26]. Further research into the consequences of occupational exposure to heat and high physical loads was conducted during World War Two in an attempt to reduce the growing amount of heat related casualties in the Pacific Theatre of War. The environmental conditions of warfare training and military operations increased the risk and incidence of heat illness under adverse weather conditions [27]. During this time, humidity and heat waves were frequent and posed an even greater risk for heat related illnesses and casualties [28]. Research during and post-World War Two was largely focused on the thermal balance of the human body and suggested that heat accumulates, and body temperatures rise when the surrounding atmosphere is unable to absorb the heat produced internally by one's

Table 1. Study criteria.

Inclusion
• Investigated heat-related factors in an occupational setting
• Studies done with humans only
• Articles in English and French
Exclusion
• Not thematically relevant to heat-related factors in occupational or labor environments
• Studies done in animals

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metabolism. Failure of this heat regulatory mechanism could result in total cessation of heat flow from the body and cause many adverse effects, such as heat stroke and death [27, 28]. Many heat acclimatization techniques and strategies for acquiring thermal tolerance, such as increased cold fluid hydration, biologically and chemically engineered clothing and even frequent induction of heat exposure, were deployed during World War Two in an event to reduce the amount of heat related illness and casualty [29, 30]. Much of this research helped create the occupational framework that is still see implemented today.

Physical labour in hot environments. The thermal environment is made up of a variety of parameters, such as ambient air temperature, air velocity, relative humidity, and radiation, that influence body temperature via conduction, convection, evaporation, and radiation [31]. In combination with strenuous physical activity, extended exposure to a hot and humid environment can overwhelm the body's homeostatic mechanisms to cool itself [31, 32]. Body temperature can increase and lead to heat-related illnesses (HRI), such as heat exhaustion and heat stroke. If the body's thermoregulatory responses are unable to adequately counteract these conditions through increases in heat loss and ventilation [32].

Factors that affect heat dissipation. Even when homeostatic responses are functioning effectively, there are many factors that can hinder adaptation to excessive exposure to hot environments, especially during physically laborious activities [32, 33]. An already stressed thermoregulatory system due to hot ambient conditions (e.g., agricultural work during summer, ultra-deep mining) can become overwhelmed by metabolic heat production from physical work (e.g., construction, wildland firefighting). Moreover, insufficient hydration or the insulation from protective clothing (e.g., urban firefighting, hazardous waste disposal), increasing the risk of HRI [32, 34].

Wearing personal protection equipment while engaging in vigorous activity is required for several occupational duties (e.g. electric utility work, open pit mining). However, this limits workers' ability to dissipate heat [32, 34]. For instance, wildland firefighters are one of the populations with the highest risk for HRI due to their prolonged duration of arduous activity in hot environments while wearing heavy fire-protective apparel [35]. Given the necessity of personal protective equipment, it may be beneficial to incorporate personal cooling devices or garments in them to provide the worker with a relatively cool microclimate while working in a hot environment [36].

The ability to dissipate excess heat effectively is significantly influenced by the type of clothing that individuals wear. Agricultural workers are another population among those at severe risk for heat-related mortality in the United States due to their exertion rate in lieu of economic considerations [37, 38]. For example, fernery workers, who are frequently paid piece-rates, would rather continue to work than take breaks to hydrate or rest [38]. A study conducted by Moyce et al. showed that piece-rate pay is linked to a four-fold higher incidence of HRI [3]. Thus, it is crucial to design interventions to safeguard occupational workers who are susceptible to HRI [3, 38].

Serious heat-related illness may result while engaging in strenuous activity in hot environments. Heat rash, heat cramps, heat exhaustion, and heat stroke are illnesses that can occur as a result of excessive heat stress when conducting physical labour in hot environments. Heat rash occurs when sweat becomes trapped in glands on the surface of the skin. This condition can manifest as inflamed bumps that range from small blisters to pronounced lumps depending on severity [39]. Heat rash most often occurs at locations where skin folds and where clothing rubs against the skin. Vigorous exercise in hot environments can also lead to heat cramps, which are painful, involuntary, and brief muscle spasms. The muscles most often affected by heat cramps include those of the upper and lower limbs, as well as the posterior body wall [39, 40]. Similarly, heat exhaustion is another explanation of

HRI. This is the body's response to an excessive loss of water and salt, often as a result of excessive sweating. Symptoms of heat exhaustion include dizziness, weak and rapid pulse, nausea, and loss of consciousness [32, 40]. Without effective treatment, heat exhaustion could lead to heat stroke, a life-threatening condition. Prolonged exposure and physical exertion in high temperatures can lead to heat stroke, which can occur if body temperature rises to 40˚C [41–44]. Emergency treatment is required as this condition can quickly damage various organs including the brain, heart, and kidneys. Overall, it's imperative to take additional precautions to prevent the onset of heat-related illnesses when working in physical environments.

Early research on acclimatization

In 1768, researchers observed that habituation to hot climates could mitigate the potential risks to human health [45]. Two hundred years later, Lind and Bass conducted a renowned study in hot-dry conditions (49˚C, 20% relative humidity (rh)) to demonstrate how repeated exercise in hot-dry or hot-humid environments induces changes in physiological function that resulted in increased heat tolerance [45, 46]. These physiological adaptations are categorized as acclimatization in naturally occurring conditions, or acclimation in artificially controlled environments. Many observations within the research of in the 1940s have led to our current understanding of the changes associated with heat acclimation. Robinson et al. described the effects of acclimation in hot-dry environments (40˚C 23% rh) on five laboratory workers who walked on a treadmill (1.56 m/s, 4.0 or 5.6% grade) for 1 to 1.5 hours per day over 10 to 23 days [47, 48]. They discovered that exercise-heat acclimation occurred relatively quickly (about a week) while repeated performance of the same task became easier over time [39]. The men's average skin and rectal temperatures reduced from 36.9 to 35.8 ˚C and from 39.7 to 38.7 ˚C respectively, during the same period [48]. Furthermore, Eichna et al. evaluated acclimation responses to humid heat (33˚C, 96% rh) and found the time course of acclimation to be similar to hot-dry conditions: about 75% of the physiological changes manifest in 4 to 6 days of exposure and are nearly all present between 7 and 10 days [47, 49]. Later studies reported observations of heat acclimation to result in temporary increases in resting cardiac output and peripheral circulation, decreased heart rate, increased temporary heat exchange, reduced core body temperatures, and potentiated sweating response [48–51].

Recent studies have built on this pioneering research by analysing and identifying the underlying mechanisms of acclimatization. For example, increased production of sweat is identified as a crucial physiological alteration that happens during heat acclimatization; it causes a steady improvement in whole-body evaporative heat loss which increases the body's capacity to dissipate heat [52–54]. This can result in up to 26% less heat retained in the body during exercise [32]. Additionally, the sweating response aids in supporting the fluid balance of the body by decreasing sodium loss via sweating (about 50% less) [17, 32]. This leads to increases in total body water and blood volume which both lower the risk of dehydration and support cardiovascular stability during heat stress [49–55]. Thus, acclimatization to heat is a key tactic for reducing the incidence of heat-related illnesses [32]. In Wyndham et al.'s classic study which examined the effect of an 8-day heat acclimation in South African gold miners on heat tolerance, they discovered a marked reduction in heat-related illnesses and improved work output [56–58]. As a result, early studies on heat acclimatization have yielded much information that should be used to guide the development of protective guidelines for individuals working in hot environments where strenuous physical labour will take place.

Movement towards safer occupational environments

Of the many nations and agencies that have put recommendations and safeguards in place to help protect workers from hot environments, the HEAT-SHIELD consortium [59] is one of the most significant. Beginning in 2016, the European Union (EU) based Consortium consists of 12 research institutions, two policy-making organizations, four industrial entities and two civil society organization dedicated to reducing the negative impact of workplace heat stress [60].

HEAT-SHIELD's primary focus is on providing recommendations and adaptive strategies for the five major occupational sectors that are most at risk for heat stress; agriculture, manufacturing, construction, transportation and tourism. These industries together represent over 50% of the EU's labor pool [60]. Several publications have resulted from the collaborative efforts including physical activity and exercise [61], agriculture [62–68], manufacturing [64, 69–72], construction [64, 66, 70, 73–76] and environment and climate [61–63, 65, 67, 69, 77–80]. The combined efforts of these studies have aided in the development of practical tools that can be used by enterprises and employers including defence against heat plans [81, 82] and a weather platform [83].

Protective actions against exposure

In occupations that involve heat exposure, it is critical for employers to have prevention programs that protect against the development of HRI. These often have a variety of components including, but not limited to, heat stress measurements, engineering controls, medical monitoring and acclimatization protocols. The HEAT-SHIELD Consortium [84, 85] created a list of recommendations to help workers stay safe in the heat. Recommendations include having a plan, extra breaks, weather, cooling oasis, assessing heat strain risks, reorganizing the day, stay hydration, clothing and heat education [84].

Heat stress. Occupational heat stress refers to the combined work exposure of external environmental heat and metabolic heat that makes it difficult for the body to maintain a normal temperature [86, 87]. Increased susceptibility to heat stress from clothing and workload can lead to HRIs (Fig 2), so occupational exposure limits (OEL) are important for protection [87]. The National Institute for Occupational Safety and Health (NIOSH) has specified and revised OELs to which workers should be exposed to using wet bulb globe temperature (WBGT) as the preferred environmental heat metric [86, 87]. Other studies have also looked at using Heat Index as an alternative measure for setting OELs when WBGT is unavailable [86, 87]. Employers should be routinely measuring heat stress in their workplaces and implementing additional protective measures to prevent OELs from being exceeded and protect workers from severe heat stress and HRIs [86]. One paper suggests that heat stress management should start when WBGT exceeds 18˚C and physical work be stopped when WBGT exceeds 33˚C [87].

Engineering controls. Another protective measure against heat stress is encouraging employers to implement engineering controls as part of their HRI prevention programs [86–88]. This involves having devices or processes that reduce sources of heat within the work environment [87, 88]. Examples include air conditioning to reduce temperature, ventilation, and fans to dilute warm air, shade structures to block solar radiation, and using mechanical assistive devices to decrease the workload and physical demands of workers [89]. The HEAT--SHIELD created a warning system that is connected to 1800 meteorological stations in Europe where they provide heat stress risk levels and behavioural recommendations for short-term (5 days) and long-term (up to 46 days) [85]. This helps European workers and companies plan ahead of them and prevent heat stress.

Medical monitoring. Medical monitoring and surveillance are another essential component of protecting workers from HRIs [88, 89]. For all workers who will be exposed to heat

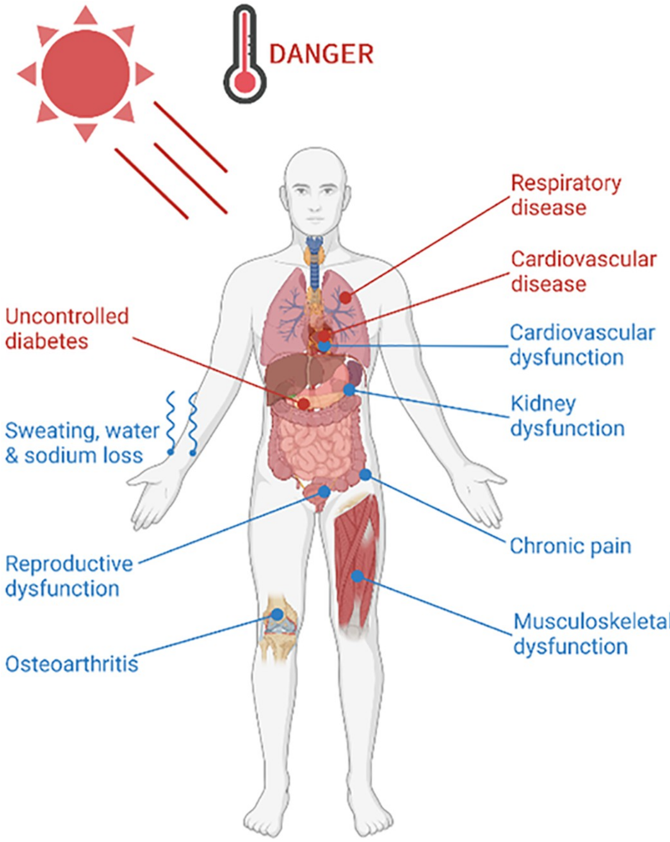

Fig 2. Effects of heat-related injuries on organ systems. Systems in red are conditions create greater susceptibliliy to HRI, while the text in blue are the effects of HRI on organ systems.

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stress, a medical monitoring program should be put in place [89]. This involves having pre-placement and periodic medical evaluations to perform comprehensive physical exams and obtain medical and occupational histories [86, 87]. Health assessments should focus on occupational heat exposures, prior history of HRIs, and personal HRI risk factors such as cardiovascular disease, certain medications, and alcohol and drug use [86, 87]. By screening workers for factors that predispose them to HRIs and evaluating them regularly for any changes in health, early efforts can be made to minimize disease and injury. Adverse health effects can also be recorded as part of surveillance data to identify any patterns in distribution and occurrence related to the work environment [88].

Acclimatization protocols. Acclimatization protocols are important to protect workers from hazardous heat exposures and HRIs [86–88]. Acclimatization refers to "a gradual physiological adaptation that improves an individual's ability to tolerate heat stress" [87]. For the first 7 to 14 days of heat stress exposure, the body physiologically adapts by increasing sweat production, improving blood circulation, and lowering heart rate. Without acclimatization, the risk of HRIs is highest during the first 2 to 4 weeks of exposure [86]. Therefore, these protocols should apply to all new hires and long-term workers who are unacclimatized or have deacclimatized [87, 88]. Studies support incrementally increasing heat exposure over a period of 7 to 14 days with frequent breaks and monitoring so workers can gradually and safely develop acclimatization [90]. The European Commission Horizon started a HEAT-SHIELD project in 2016 to help improve and protect European workers' health with the support of experts [84].

Training and educational programs

Current heat preventions have several strategies in place to protect workers including training, education, and regulations [91]. There are several guidelines for heat stress monitoring and prevention such as the International Organization for Standardizations [92], American Conference of Governmental Industrial Hygienists [93] and US National Institute for Occupational Safety and Health heat standards (NIOSH) [94]. In the past decade, U.S occupational Safety and Health Administration created a nationwide Heat Illness Prevention Campaign to increase awareness and educate workers about heat stress related work [94]. Several companies have formal training and education for their workers that ensures they are working in a safe environment. Examples include active teaching, first aid procedure, traditional learning (printed handouts, manuals), fire safety training, ergonomic training and intervention, biofeedback, risk perception and perceived risk manageability, hands on training and e-learning training [95–97].

An important part of effective heat stress training programs is education on HRI, such as heat stroke and heat exhaustion [49, 88]. To minimize the risk of HRIs in occupations with heat exposure, it is important for workers to be properly educated on common HRIs, their warning signs and symptoms, and how to respond in acute situations [90, 88]. By being able to identify heat-related signs and symptoms early, such as dizziness and nausea, employees can promptly seek help and inform their workplace [10, 32]. Emergency response plans are an effective method of training workers on how to do so. For example, some programs recommend calling emergency services right away and then performing other first aid interventions like moving the individual to a cooler place and wetting their skin with cool water to lower their temperature [32, 88, 90].

In addition, workers should be provided with adequate amounts of hydration fluids and take regular breaks to prevent HRIs from heat stress [94]. One method is the work/rest cycle where mandatory rest breaks in cool areas are taken for a minimum of 15 minutes per hour of working in high heat conditions [94]. Another option is self-pacing which trains employees to reduce their work pace in extreme heat to avoid unsafe heat strain without fear of negative repercussions [94].

Training programs should address the proper use of personal protective equipment (PPE) [88–90]. To facilitate heat transfer from the body to the environment, clothing should ideally be loose fitting [89, 93, 94]. PPE can also be used to reduce absorption of solar heat such as lightly coloured and/or reflective clothing, ice vests, wetted overgarments and circulating air suits. In occupations that require the use of heavy PPE (i.e. military personnel, firefighters, construction workers) that further impedes heat loss, certain administrative controls and techniques should be implemented to alleviate their unavoidable effects [98, 99]. Strategies include modifying the uniform at the hottest time of day and implementing work-to-rest ratios [9, 98, 99]. For example, members of the military may alter their uniform when certain heat extremes are reached by un-blousing their uniform pants from boots and rolling up their sleeves; or construction workers may opt for light coloured, loose fitting, or natural fiber clothing. Natural fiber clothing such as cotton has the ability to absorb moisture and can draw sweat off the body. This allows the body to cool quicker which is extremely helpful in warm environments where water evaporation can be difficult. Wearing white or light-colored clothing can help increase the reflection of the sun, reduce the heat temperature of the worker and prevent heat strain [100].

Agricultural and construction workers often work outdoors in high heat environments, making heat training and education exceptionally pertinent [101]. Between 2000 and 2010 in the United States, there were over 350 occupational heat related deaths. A multi-level HRI prevention program called Heat Education and Awareness Tools (HEAT) uses a social-ecological model approach that has been successful among agricultural labourers [102]. HEAT training uses an engaged and relational approach to learning, taking into consideration the perspectives and satisfaction levels of employees, as well as accounting for risk factors at multiple levels (individual, interpersonal, supervisor, and community) [101]. The HEAT training regime is one of many strategies implemented to inform and protect against occupational HRI.

Next, understanding the effectiveness of training can help mitigate resource allocations and improve future training and education strategies. Studies looked at the perception of workers after they completed their training and education. Most responses were positive suggesting that their attitudes were positive towards the training and creating a safety-mind behaviour [96]. Middle-aged workers (24–54 years old) had a more positive attitude towards heat related training than other age groups [91]. E-learning based training showed the most efficacy in changing attitudes and behaviour [96]. There is strong evidence for workers who suggest training and education sessions having enhanced health and knowledge about heat related stress [95, 96]. Individuals who participated in training sessions had more impact due to their involvement and active learning. Given that only 50 to 63.8% of workers complete training sessions as part of HRI prevention programs, there needs to be more heat-related trainings, guidelines and regulations for workers [91].

Fatigue recovery methods and body cooling strategies

Fatigue recovery. Fatigue can result from occupations that are strenuous and may be a result of increased workload or activity. Symptoms include emotional exhaustion, insomnia and physical pain [103]. 58% of fire-fighters ranked their head being the hottest part of body during their work [36, 104]. Construction workers, miners and agriculture workers are also exposed to high temperature and humidity and are at risk of developing heat stress [104]. There are several recovery methods that can be implemented by the workplace or personally by the individual.

Developing breaks between tasks and providing educational strategies about recovery can be a preventive measure against workers' fatigue and improve their health [103, 105]. In addition, fatigue could also result in certain occupational injuries. Risk for injuries relating to slips, trips, falls, exposure to harmful objects, burns, minor cuts, etc. has been shown to increase in hot weather conditions [106]. Personal methods include changing start and end times, taking vacations, and having longer break times in between shifts [103]. Fatigue is also experienced by many athletes, and they have fatigue recovery methods that help their wellbeing. Similar to workers, a flexible time schedule helps athletes recover better [105]. Other methods are active recovery, cold water immersion, massage, and passive recovery that workers can implement as work related fatigue recovery methods. Active recovery intervention is when individuals do aerobic-related activities such as biking or running to help relax muscles [105]. Passive recovery is when individuals are sitting comfortably in an armchair or stopping any activities that will strain their muscles for a short amount of time [107]. The effectiveness of these methods depends on the fatigue symptoms and the workload the individual is facing.

Body cooling. Using body cooling strategies can help alleviate the risk of physiological strains and reduced performance capacity caused by heat [108]. Using cooling interventions prior to labour in the heat, or pre-cooling, is shown to be less effective than using strategies throughout the labour period, also known as per-cooling. Optimising performance is achieved by using cooling strategies that address thermal perception (discomfort), fluid disturbances (dehydration), and thermal strain (body temperatures) [109]. The most effective cooling techniques involve the largest parts of the body, such as cooling the torso or limbs. For example, using a cooling vest is extremely effective in alleviating strain because of the large vascularization in the area. Other techniques such as iced beverages, neck cooling, ice towels, and increasing airflow can also be implemented as effective body cooling strategies [109]. Methods such as cold beverages address thermal comfort, contribute to hydration status, and result in lowered core body temperature.

Considerations for current working environments

Working in extreme heat may lead to various serious health repercussions that may contribute to increasing the burden on the healthcare system. The government is therefore responsible for implementing measures for at risk workers to ensure a safe working environment. In Canada, heat stress prevention regulations are outlined in the Canadian Occupational Health and Safety Regulations under Part II of the Canada Labor Code (Canada Labour Code (R.S.C., 1985, c. L-2). These guidelines are especially useful for federally regulated workplaces and for industrial hygiene specialists who are seeking to develop any thermal stress prevention program [110]. The requirements include but are not limited to; protective clothing and equipment, engineering controls such as shields, insulations and fans, employee training in recognizing signs of heat stress and administrative controls such as fluid replacement, work rest cycles, acclimatization and scheduling [110]. The regulations also emphasize the adherence to the Threshold Limit Values (TLVs) for heat stress exposure, which represent the maximum exposure limit for occupational hazards [110]. The TLVs aim to maintain body temperature within 1 degree of 37 ˚C. In the United States, the Centers for Disease Control and Prevention-National Institute for Occupational Safety and Health has published several similar recommendations for working environments with high risk of heat stress [93, 94]. These preventative methods include engineering controls that increase air velocity, absorb heat or reduce steam leak, the use of tools that minimize manual strain and metabolic demands, training supervisors and employees in recognizing heat stress, the promotion of self-monitoring, the availability of potable water, the encouragement of rest breaks, the use of a heat alert program and the implementation of a heat acclimatization plan [111].

With the progression of climate change, many governments have issued recommendations to limit heat stress due to the increased frequency of heat waves. In 2010, the number of Japanese workers that died of heat stroke markedly increased during an exceptionally hot summer [112]. Most of the fatalities represented outdoor workers exposed to these rising temperatures, including construction workers, gardeners, civil engineers, and demolition and road workers. The Labour Standards Bureau, Ministry of Health, Labour and Welfare of Japan, put forth recommendations to prevent heat stress which included frequent breaks, breathable and porous clothing, sunscreen, sodium-containing palatable water, and education in emergency care [113]. Japan is not alone, international governments are facing the burden of climate change as work-related heat stress cases rise, driving them to implement current preventative measures to assure the safety of at-risk workers.

Individual effects and considerations for special populations

There are various factors influencing how well an individual adapts to a hot environment. These can be divided into inter-individual or intra-individual factors. Inter-individual factors include age, disability, cultural habits, ethnicity, gender, body weight, medical conditions, and drug use impact one's ability to react to heat [26]. A study on obesity and thermoregulation found that obese individuals cool less rapidly and are more susceptible to HRIs [9]. The study also found that when fat tissue was excised, it showed lower conductivity than excised lean tissue. Medical conditions such as cardiovascular disease, respiratory disease, and uncontrolled diabetes also alter the body's ability to effectively cool down. A study that explored patients with heart failure found that cardiovascular dysfunction accompanying the condition impairs thermoregulatory processes and increases susceptibility to heat stress [114]. A reduction in blood flow to the skin contributes to this outcome in patients with cardiovascular disease. Complications involved in uncontrolled diabetes include damage to blood vessels and nerves, which can severely decrease the cooling function of sweat glands [115]. Moreover, drug use can produce effects that involve an increase in body temperature and factors impacting one's ability to cool in a hot environment. Certain drugs can produce this outcome by altering thermoregulatory mechanisms, inducing fever, and resulting in idiosyncratic and hypersensitivity reactions [116]. Intra-individual factors include acclimatization, clothing, shift schedule, environmental conditions, heat mitigations, metabolic demands, diet, physical activity, sleep, water consumption, working hours and work expectations that can influence heat stress during work. In-dept detail are explained in the publication by Ioannou et al [100]. Overall, body cooling strategies can be affected by several factors that can impact people's reactions to heat.

Extreme heat could worsen chronic conditions, including cardiovascular, respiratory, cerebrovascular and diabetes-related conditions, especially when these individuals are participating in intense physical activity or labour [113]. Performing physical labour in extremely high temperatures can alter hormonal and metabolic responses by changing substrate utilization. In part, this is due to the significantly reduced heat dissipation gradient resulting in changes to thermoregulatory mechanisms designed to promote body heat loss [117]. In more severe cases, higher temperature exposure can impact various systems simultaneously and lead to heat related consequences including heat stroke, exhaustion, cramps, syncope, decrease in cognition, rash, and rhabdomyolysis with severity reaching fatality in some cases. The gravity of the symptoms developed can be modulated by underlying health conditions [118]. Particularly, the thermodysregulation effect is exacerbated in people with chronic conditions. These individuals are unlikely to be able to detect and react to changes in temperature [75] and may be more susceptible to the negative consequences caused by heat, such as changes in electrolyte levels, headaches, nausea and fatigue [119].

Impaired heat dissipation capacity (such as reduced sweating and vasodilation in the skin) is a significant concern for people with diabetes and can have important consequences on cardiovascular health and glycemic control [115]. The systemic heat-triggered vasodilation can impact diabetes' management as it can speed up insulin absorption and lead to hypoglycaemia. If in a state of hyperglycemia, people with diabetes have an increased risk of dehydration associated with a higher risk of cerebral and coronary thrombosis. Additionally, heat can make insulin's effect less predictable and more erratic which adds an additional layer of complexity to managing diabetes during extreme heat or while partaking in physical labour [120].

Heat and resulting dehydration have also been found to be linked to kidney dysfunction promoting acute kidney function decline as a form of "heat stress" nephropathy, and could possibly lead to the development of chronic kidney disease [121]. The impact of heat on renal function has been further supported by reports from various agricultural communities in Central America, Mexico, India, and Sri Lanka. This phenomenon has been reported specifically amongst sugarcane, cotton, corn, and shrimp farm workers as well as construction site and mine workers, who all have extreme heat as a common exposure [122]. The impacted workers have reported nausea and vomiting, headache, muscle asthenia, back pain, and fever in addition to presenting with high creatinine levels, tubular atrophy, and inflammatory markers [121, 122].

Given the significant health impacts of extreme heat exposure, especially in the context of physical labour, strategies to reduce the impact and occurrence of these outcomes is important.

Specifically, amongst people with pre-existing conditions, such as diabetes, ensuring adequate acclamation, hydration status, glucose control, and accounting for age, presence of other comorbidities, and one's fitness level should be mandated in developing occupational work standards in these conditions.

Impact of climate change

At a macro level, Burke et al.'s [123] global estimates indicate that economic labour productivity peaks at an annual average temperature of 13˚C and rapidly decreases at higher temperatures [83, 84]. Coincidentally, physical labour is severely impacted by climate change (i.e., an increase in global temperature), which endangers global economic output [124, 125].

The effects of climate change are most pronounced in agricultural and industrial sectors, especially regarding labour supply (i.e., working hours) and labour productivity [123–126]. With increasing temperatures, workers are unable to spend all working hours towards performing physical labour due to the risk of acquiring heat-related illnesses [124, 125]. As such, physical labour limits will be reached faster, limiting the amount of physical labour that can be performed. For example, in rural areas of South Africa, as workers under heat stress take longer breaks to rest and rehydrate, it has been estimated that the total effect on productivity per adult would decrease 20% by 2100 [123–125]. Without suitable thermoregulatory infrastructure, activity and economic growth would decline, especially in low- and middle-income nations [125]. As a result, health inequalities may be observed among regions of varying climate. Although it is possible for physiological acclimatization to occur, it takes 1–2 weeks to take place, which gives enough time for sudden events, like heat waves, to still subject workers to adverse effects [126].

Conversely, at the micro level, climate change can lead to negative health consequences by threatening human engagement in physical activity. Several studies have reported a strong threshold relationship between temperature and physical activity. For example, Obradovich and Fowler [127] observed the probability of monthly physical activity in a US sample of 1.9 million adults (2002–2012) to rise as temperature increased, up to a threshold of 28–29˚C. Monthly physical activity then decreased after reaching 36˚C, and drastically declined after 40˚C. Heaney et al. observed a similar relationship where total hours ridden on bikes and average distance biked on bikeshares increased with temperature up to a peak average of 28.1˚C and 25.8˚C, respectively [128]. As temperatures increased past such averages, both ridership levels declined in a near-linear association [129].

The implications of these findings are that in regions below threshold temperatures, climate change can have a net positive effect in promoting physical activity. Those who experience this increased physical activity may then benefit from lower risks of cardiovascular disease, hypertension, obesity, and depression [130–132]. However, in regions above threshold temperature, the opposite effect has been observed due to decreased physical activity [127, 128, 130, 131]. The number of people who are likely to be exposed to heat stress exceeding the survivability threshold increases with global temperature change [133]. It can then be extrapolated that, as climate change continues to increase global temperature at a fast pace, countries will increasingly cross temperature thresholds which may lead to poorer health outcomes of their populations.

Future considerations

This review highlighted factors related to acute and long-term health issues of occupational exposure to heat and high physical loads. As a result of the temperature increases caused by climate change, the growing world population and is projected that the percentage of total

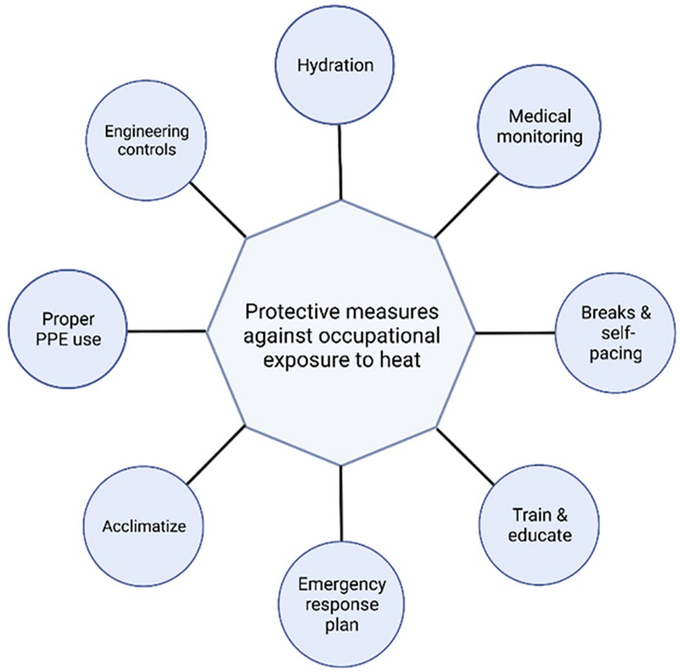

Fig 3. Summary of protective measures to prevent heat-related illness.

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working hours lost to heat will rise to 2.2% in 2030 –a productivity loss equivalent to 80 million full-time jobs. This number increases greatly when accounting for the impact of humid heat in addition to conventional heat exposure. Public health authorities face significant challenges to provide accurate, up-to-date and research-informed guidelines for employers and enterprises. Labor exploitation and precarious working environments for economic gains also places workers at increased risk [134].

Whilst several strategies exist to ameliorate and prevent the long-term consequences (Fig 3) of chronic heat exposure in an occupational setting; hyperthermia and dehydration remain significant risks to health. Future research should focus on effective monitoring with new technologies providing effective feedback real-time to prevent complications of chronic heat exposure. Moreover, genetic factors, such as inflammatory markers and insulin resistance may provide further insight into individual factors that may predispose individuals to more deleterious health outcomes. Understanding individual responses to extreme environments may assist in preventing occupational heat-related illness and injury. Thus, the potential benefit of genetic research may shed further light on protecting workers who are already at risk. Whilst climate change may be difficult to stop at the individual level, this review outlines measures that can be taken to protect workers and labors.

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