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Review

Endurance athletes and climate change

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ABSTRACT

Climate change has contributed to increases in the Earth's temperature since the beginning of the industrial age and the warming has accelerated in the last four decades. While climate change has negative impacts on overall global health, more recent events have highlighted the effects on endurance athletes. Endurance athletes primarily train and compete outdoors and are affected by changes in the environment. Notably, climate change contributes to extreme weather, which can result in heat illness; pulmonary disease secondary to air pollution; and an increased risk of infections (i.e., tick-borne and mosquito-borne illness) due to habitat alterations. Elevated environmental temperatures can lead to exertional heat illness (heat exhaustion, heat injury, and heat stroke) and contribute to dehydration with electrolyte disturbances. Hot, dry environments also increase the number and severity of wildfires that affect weather patterns and raise the amount of particulate matter in the air, contributing to air pollution and pulmonary issues. Lyme disease is now the most common tick vector-borne disease and climate change is expanding the geography that harbors tick species carrying the infectious agent. For these reasons, endurance athletes are a unique population to explore the impacts of climate change on sport participation and illness. As governments, sports organizations, multinational corporations, and others address the impact of climate change, athletes, coaches, race organizations, and healthcare providers should begin to consider strategies that mitigate the health concerns of climate change related to training and competitions.

Introduction

Within the last 150 years, the Earth's surface temperature has increased by 1.19 °C (2.14°F), with the greatest increase occurring over the last four decades [1]. According to the National Oceanic and Atmospheric Administration (NOAA), the ten warmest years on record have occurred since 2005, with 2016 being the hottest year on record, followed closely by the year 2020 [1]. This rise in temperature has negative effects on the health of humans and most other species in the plant and animal kingdoms. Climate change is believed to have contributed to the deaths of 150,000 people in 2009, and that number is expected to more than double by the year 2030 [2]. Despite these humbling statistics, changes to acute and chronic illnesses affecting overall health of the global population are much greater. Droughts increase the likelihood of wildfires and can both directly and indirectly damage agriculture. Changing weather patterns can increase the frequency and the strength of hurricanes, increase flooding that spreads waterborne diseases, and expand the habitats of invasive plant and animal species that harm or push out native species [3,4].

While the health effects of climate change are increasing and ongoing, the influence on endurance athletes, especially those involved in distance running and cycling, are of particular interest. Athletes participating in endurance sports have increased exposure to environmental risks posed by climate change [5]. There are notable examples of record temperatures at recent high-profile events, including the United States Olympic Track and Field Trials in June 2021, where the heat index exceeded 42.2 °C (109°F), and the surface temperatures radiating off the synthetic track exceeded 65.6 °C (150°F) [6–8]. Poor air quality exacerbated by wildfires has also forced the cancelation of several endurance events [9, 10]. Furthermore, several prominent endurance athletes have documented cases of Lyme disease, which impaired their ability to perform at elite levels [11–13].

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Climate change can have numerous effects on endurance athlete participation in sport and can also contribute to sports-related illnesses. Some of the most significant risks to athletes include exertional heat illness due to rising temperatures, pulmonary illness due to wildfire-caused air pollution, and increased vector borne illnesses, particularly Lyme disease, as warmer regions expand the tick habitat northward [14–19].

Given the recognition of these influences on human health, the purpose of this narrative review is to characterize the current understanding of the effects of climate change on endurance athletes, particularly regarding exertional heat illness, pulmonary illness, and Lyme disease. The objectives of discussing three selected topics is to help to bring awareness and broaden the discussion on how climate change impacts health in this population.

Methods

An initial literature review was performed between July 20, 2021 – September 30, 2021, using PubMed and Google Scholar with search terms in relation to "climate change" and "endurance athletes" that included: "heat illness," "heat exhaustion," "heat stroke," "heat illness," "heat stress," "pulmonary illness," "air pollution," "asthma," "allergies," "wildfires," "Lyme disease," "ticks," and "injuries." Google Boolean searches were also utilized to identify historical climate data. Two authors (blinded for review) conducted the search and reviewed results to determine papers specific to three topics of interest: heat illness, pulmonary disease, and Lyme disease. A total of 132 articles met the search criteria for this review. The articles used range in dates from 1977 – 2021. Recognizing a lack of specific studies evaluating climate change and endurance athletes, the authors elected to write a narrative review.

Specific issues faced by endurance athletes due to climate change

Heat illness

One of the most noticeable effects of climate change endurance athletes face is elevated ambient temperature and relative humidity during training and competition. Elevated heat and humidity increase the risk of exertional heat illness, which include heat exhaustion, exertional heat injury, and exertional heat stroke; exertional rhabdomyolysis; exercise associated muscle cramping; and exertional hyponatremia [20, 21]. Climate change is causing more frequent and longer heat waves. Among 50 metropolitan cities across the US, the duration of the heat wave season has increased by 47 days since the 1960s [22]. These prolonged periods of hot temperatures present a greater risk for developing exertional heat illness in endurance athletes.

As previously noted, during the United States Track and Field Olympic Trials in June of 2021, the women's 10,000-meter final and men's 5000-meter final had to be moved to earlier times of the day to reduce radiant heat load from the track for the runners [23]. Some of the highest rates of exertional heat illness are found in the endurance sports of cycling and running [24]. Between 2015 and 2019, 0.5% of Boston Marathon participants who required medical attention during or at the end of the race were diagnosed with exertional heat stroke. One-third of those athletes required hospitalization for their condition. While the race day temperatures for those five years ranged from 17 to 20 °C (62.6 – 68°F), the years of 2017 and 2019 had the warmest race days with a recorded average of 8.6 cases of exertional heat illness per 10,000 race starters [25]. There were 393 cases of exertional heat illness recorded for the Falmouth Road Race between 1984 and 2011. The highest recorded race day ambient temperature for that fifteen-year period occurred in 2003 with a temperature of 27.7 °C (81.8°F), when 61 cases of exertional heat illness were reported. Of those, 53 cases were diagnosed with exertional heat stroke [26]. The risks for heat stroke are greatest when there is also high humidity. Humidity and high ambient temperature interfere with heat transfer and the body's ability to cool itself. Training and competing in extremely hot temperatures without appropriate preparation, especially without adequate heat training, may increase the chances of exertional heat illness, particularly heat exhaustion and exertional heat stroke [27–29]. The critical thermal maximum body temperature in humans is typically between 41.6 and 42.0 °C (106.9 and 107.6°F) [30]. Exertional heat stroke usually occurs when the body temperature exceeds 41 °C but can occur at lower temperatures in some individuals. When core temperatures become too high, organ dysfunction, and even death may occur [30–32]. Physiological adaptations (acclimatization) to high ambient temperature and relative humidity require repeated exposure to hot conditions over several weeks [33]. Heat strain is more likely to occur at higher core temperatures. Sweat evaporation and heat dissipation from skin are the main mechanisms for maintaining temperature regulation during heat stress. However, a significant loss of fluid volume can reduce heat transfer from the core to the skin and reduce sweating, both of which contribute to increased core temperatures [29, 34]. Hyponatremia can also occur during long endurance events, usually from fluid overload, and is more prevalent when environmental temperatures are elevated [35, 36]. Exertional hyponatremia occurs when the blood sodium levels decrease below 135 mmol/L [37]. Symptoms of hyponatremia include headaches, dizziness, nausea, muscle cramps, fatigue and confusion. Severe hyponatremia can result in brain swelling with seizures or encephalopathy and can be fatal [36, 38, 39]. Exertional hyponatremia is usually due to excess ingestion of hypotonic fluids combined with increased arginine vasopressin release, which leads to water retention in the kidney and decreased excretion in the urine. Both mechanisms serve to conserve water during physical activity, which may ultimately decrease the blood sodium concentration. While some sodium is also excreted in sweat, for most athletes, the amount lost is negligible. However, a very small number of athletes do lose enough water and sodium through sweating that can contribute to decreased blood sodium concentrations [37, 38, 40-42].

Exertional rhabdomyolysis can also be associated with exertional heat illness, specifically with heat stroke. Hyperthermia, overexertion, prolonged exercise, and/or dehydration are risk factors for this condition [43–45]. Rhabdomyolysis is characterized by the breakdown and subsequent death of striated muscle cells and results in symptoms including muscle pain and weakness [46, 47]. When muscle fibers break down, they release proteins into the blood, including myoglobin, which can lead to acute renal failure. Athletes who have been taking analgesics or had a recent viral or bacterial illness appear to be at greater risk [46, 48-50]. With immediate recognition and treatment, most athletes with exertional rhabdomyolysis will not have lasting damage. However, severe cases of rhabdomyolysis can cause acute renal failure. Athletes who experience this serious complication will require IV fluids and sometimes dialysis. Occasionally, a kidney transplant may be required [51].

Ultimately, increasing environmental temperatures associated with climate change may increase the risks associated with endurance event participation and may even limit the ability of athletes to train for and compete in these events.

Air pollution and pulmonary illness

Climate change creates conditions that contribute to the onset and duration of wildfires, and wildfires exacerbate climate change through the destruction of biomass and the production of air pollutants [52, 53]. Large wildfires, such as those seen in the western US, can create their own weather patterns by creating pyrocumulonimbus clouds, which generate lightening that can spark more fires and change wind patterns [54]. These wildfires also produce smoke and particulate matter that can be carried thousands of miles by the jet stream [54–57]. The smoke contains gases and particulate matter that, when inhaled, can cause or aggravate cardiovascular and respiratory health conditions and can contribute to premature death in individuals with pre-existing heart or lung conditions [58–60]. According to the Environmental Protection Agency (EPA), air pollution particulate matter can contribute to airway inflammation, coughing, labored breathing, worsening asthma, and even heart attacks [61, 62]. Evidence suggests that air pollution can affect all sub-types of asthma and may pose an increased risk of airway irritation in children [58-60, 62]. A study of emergency department visits during a large three-week southern California fire in 2007 showed that asthma diagnoses increased by 2.6 patients per day and the number of individuals reporting difficulty breathing increased by 3.2 visits each day [63].

While fine particulate matter (<2.5 μm) is believed to have negative health impacts due to its ability to penetrate deep into the lungs to create inflammation and cell damage, larger coarse particles (2.5 −10 μm) may have a greater impact on the young who typically spend a great deal of time outdoors while their respiratory systems are still developing. Coarse particulate inhalation was previously associated with increased asthma diagnoses and emergency room visits for acute exacerbations [58, 59, 64, 65]. Lung damage or a pulmonary condition caused by particulate matter in children may affect future endurance sport performance.

While larger particulate matter may be more detrimental to developing lungs, a study of female marathon runners showed a 1.4% reduction in performance for every 10 mg/m^3 increase in inhaled fine particulate matter [66]. During exercise, minute ventilation increases to the point where simultaneous nose and mouth breathing are required to provide adequate oxygen intake. These pulmonary changes result in more air pollutants being deposited directly into the airways and lungs [67]. Marathon runners have been shown to greatly increase the amount of particulate matter they breathe in during a marathon race due to the significant escalation of ventilatory effort they experience while running [68]. Training or competing at high intensities also causes more breathing through the mouth, which bypasses many of the respiratory system's natural defenses against microbial or particulate matter [69, 70]. These inhaled substances increase respiratory stress and inflammation contributing to bronchoconstriction [71–73]. Data from multiple Diamond League 5000-meter races showed that elite female runners had significantly slower race times in the presence of increased levels of ozone, fine particulate matter, and coarse particulate matter, most likely caused by airway irritation, reduced arterial pressure, and chest tightness [71].

Asthma is a chronic condition characterized by reversible bronchial obstruction that causes wheezing, coughing, and chest tightness [62, 74]. Distance runners have a high prevalence of asthma [75]. Many endurance athletes experience symptoms similar to asthma during training and competition [75–77]. It has been hypothesized that these athletes have higher rates of asthma or asthma-like symptoms due to hyperventilation during activity, as well breathing in allergens or other particulate matter while training or competing outdoors [75]. Asthma attacks are triggered by a variety of irritants such as dust mites, pests, pollen, molds, and air pollution, including gases and particulate matter from wildfire smoke. Exposure to ozone and sulfur dioxide can also trigger asthma attacks in certain individuals, with ozone contributing to increased emergency department visits for asthmatic attacks in adults [78].

Wildfires are a significant source of both gases and ozone. Wildfire smoke is specifically linked to increased pediatric visits to the emergency department for asthma exacerbation [58, 79]. Both ozone and sulfur dioxide cause airway narrowing and reduced air flow during exercise increasing ventilatory rate and effort [79]. Furthermore, air pollutants can cause airway inflammation and cellular injury, which may trigger inappropriate immune system responses and allow pollutants to become allergenic, especially when these pollutants are inhaled with other common allergens. In individuals who already have atopy or common allergies, the mixture of gaseous and particulate matter, along with allergens, can result in worsening asthma [59, 64, 80].

Tick borne illness and Lyme disease

Lyme disease is a concern for endurance athletes who train and compete in grassy or wooded areas where ticks are common, including trail runners, hikers, and mountain bikers. In both the US and Canada, warmer, damp climates provide a more favorable environment for tick survival and an increase in the likelihood of host contact [81].

Lyme disease was first recognized in 1972 in several children from Connecticut suffering from cardiac issues and arthritis [82]. *Borrelia burgdorferi,* a spirochete bacterium, was isolated in 1982 as the cause of the disease [83, 84]. *Borrelia mayonii* has also been recognized as a rare cause of this illness [85]. Lyme disease is the most common vector-borne disease in the US and typically occurs in the summer and fall months in the Midwest, Mid-Atlantic, and Northeast regions of the US. It is also found in Canada and some areas of Europe and Asia [83, 84]. More recently, cases have been spreading into surrounding geographical areas where Lyme disease cases were previously uncommon [86]. One study based on population modeling and temperature mapping predicts the range for *Ixodes* ticks will be greater than the current distribution with potential to expand to a wider area as the habitat changes with warming temperatures [87].

Warmer temperatures increase the available tick environments and how quickly ticks spread into previously unoccupied areas. Rainfall and elevation factors also play a role in how, where, and when ticks expand their habitat [88]. Climate change is also increasing the white-footed mouse population and range, expanding the reservoir for both the *Borrelia burgdorferi* bacterium and the *Ixodes* tick. The population of white-tailed deer, another prominent host species for the *Ixodes* tick, is growing and expanding in the warmer and wetter conditions where food sources are now more readily available [89, 90].

The *Borrelia* bacterium is spread to humans via the bite of the *Ixodes* tick, commonly referred to as the black-legged tick (formerly deer tick) [90]. Infected individuals may be asymptomatic or experience a range of signs and symptoms including the characteristic erythema migrans or a "bull's-eye" rash around the area of the tick bite. Systemic symptoms include fever, headache, fatigue, muscle aches, joint pain, and malaise. Left untreated, the infection can cause inflammatory arthritis and affect the heart and the nervous system [91]. Notably, Lyme carditis can include atrioventricular node conduction derangement, pericarditis, endocarditis, or myocarditis, myocardial infarctions, or heart failure. Lyme disease can also lead to encephalopathy, meningitis, or peripheral neuropathy [92–95]. Lyme disease can be challenging to diagnose as laboratory testing may not reliably confirm a positive result for six weeks following the exposure [96, 97]. Lyme disease is treated with antibiotics including doxycycline, amoxicillin, or cefuroxime [94, 95, 98, 99]. These medications may cause side effects including photosensitivity (doxycycline) in a small percentage of individuals, which may impact athletes training or competing outdoors. These sensitivities may also necessitate sun protection or training outside of peak sun hours [100, 101].

While the prevalence of Lyme disease and other tick-borne illnesses in endurance athletes have not been well documented, professional and Olympic level athletes have reported significant losses in fitness, ability to compete, or early career termination due to the long-term health issues associated with infection with Lyme disease [11, 13]. Given that endurance sports are primarily performed outdoors, the risk of exposure to Lyme disease and other tick-borne illness (e.g., West Nile virus) may be of greater concern to endurance athletes.

Discussion

The potential health risks endurance athletes will face due to climate change are real with wide-ranging effects on how they train, compete, and avoid illness or injury. Our narrative review explores the effects of climate change on exertional heat illness, pulmonary illness, and Lyme disease in endurance athletes with the goal to broaden awareness. Highlighting these impacts may prompt additional research regarding these topics.

Furthermore, athletes and race organizations should consider how climate change will influence endurance events and event participation. There are strategies that can be employed by endurance athletes and race organizations to minimize the health risks associated with climate change, as well as assist in the mitigation of climate change.

Physiological adaptations to prevent heat illness

To avoid heat related illness, athletes will require heat acclimatization strategies to lessen the effects of heat as a limiting factor in training and competition. Appropriate heat training is necessary to both maintain and increase exercise intensity while avoiding exertional heat illness [102, 103]. Some event organizers have already encouraged athletes to prepare for extreme heat and humidity through heat training. Prior to the initial cancelation of the Tokyo 2020 Olympic Games originally scheduled for the summer of 2020, the weather was predicted to be markedly hot and humid. Athletes were informed of the potential conditions and urged to acclimatize properly before the competitions [104]. Extremely fit runners are able to perform at higher core temperatures without decreases in performance at an eight-kilometer distance race, even when measured rectal temperatures reached up to 40.9 °C (105.6°F) [105]. Adaptation contributes to performance gains; runners who completed longer times to exhaustion had larger core-to-skin temperature gradients and were able to dissipate more heat from their skin through a combination of sweating and conductive and convection heat loss to the immediate environment.

Heat acclimatization protocols are helpful for endurance athletes and contribute to performance gains. Runners who have larger core-to-skin temperature gradients and are able to dissipate more heat from their skin fatigue less rapidly than those with lesser core-to-skin temperature gradients [105]. Heat acclimation can improve thermoregulation through repeated exposure and allows for a more rapid cooling response (sweating and surface vasodilation) [102, 106]. Heat acclimatization strategies may include training in temperatures that match or exceed those of the competition site and can be augmented by use of a sauna, heat chamber, or other protocols [107, 108].

Electrolyte losses can also be reduced with appropriate heat training including the production of more dilute sweat [102]. Successful heat adaptation can allow athletes to maintain a lower core body temperature for a longer duration of time. The cardiovascular system adapts to work more efficiently in hotter temperatures and the heat transfer system increases blood flow to the skin and generates more efficient sweating to allow more heat dissipation from the athlete's body [102, 109]. Heat adaptation also increases the total plasma volume by about one liter to offset the increase in fluid lost through earlier and heavier sweating, which helps maintain blood flow during activity. Most electrolyte losses that occur through sweating can be replaced with a normal diet. Generally, electrolyte ingestion during most activities is not necessary unless an athlete loses excessive amounts of sodium in their sweat [102, 109-112]. Combining heat adaptation strategies with proper fluid intake may aid in the prevention of heat illness, as well as other related issues, including heat stroke, rhabdomyolysis, and kidney damage caused by dehydration or rhabdomyolysis [109, 113-115].

Endurance event organizers can also play a role in helping athletes prevent exertional heat illness, as well as in the early recognition and treatment of this condition if it occurs. Events should be staffed with medical personnel who can recognize and treat exertional heat illness and exertional hyponatremia. Race directors should also ensure that the proper protocols to cool runners experiencing exertional heat illness are in place and resources are on-hand [120]. Endurance event coordinators can also educate participants on proper hydration protocols to help athletes prevent hyponatremia. Longer events can also use weigh stations to ensure participants are not gaining more than 2−3% of their pre-race weight or losing weight. Medical teams must also be trained to recognize the symptoms of hyponatremia for a rapid initiation of treatment [116, 117].

Addressing risk for pulmonary disease

Athletes should review the current air quality reports in their area prior to training and move indoors when air quality is poor. Local air quality reports and recommendations on time spent outside can be accessed through television, radio, newspaper, and internet sources [118, 119]. Athletes who must or wish to continue to train outdoors should consider using a high-quality fitted N95, KN95 or mask during activity and moving workouts to areas with better air quality and fewer smoke pollutants [120−122].

Race organizations can help to protect athletes by monitoring air quality around the time of events and rescheduling or cancelling events when air quality is poor. Fire and smoke maps should be monitored prior to the competition and racecourse changes should be considered to avoid unsafe conditions [123−125]. Protective masks can also be distributed to race participants to provide some protection from smoke and particulate matter inhalation. Additionally, races should have medical staff on hand who are able to recognize, monitor, and treat athlete respiratory issues [126].

Mitigating risk for tick borne illness

Tick-borne illnesses can be reduced by wearing long pants, long-sleeved shirts, and tall socks when outdoors. However, this strategy will interfere with heat transfer. Treating clothing and gear with permethrin and using tick repellents that contain lemon eucalyptus oil, DEET, picaridin, 2-undecanone, or para-methane-diol may help. Athletes should check their bodies, clothing, and gear for ticks after being outdoors [127, 128]. A tick must be embedded in the skin for 48−72 h to transmit Lyme disease and frequent tick checks to find ticks before they latch may be the most efficacious strategy for disease reduction. If an embedded tick bite is identified, athletes should consult with a physician to consider prophylactic antibiotics [129].

To help protect athletes, event organizations can monitor yearly cases of Lyme disease in the areas of their events, educate participating athletes on preventing tick bites, and provide athletes with insect repellent. Event directors can also have medical staff on hand who can recognize a tick bite, assist in appropriate tick removal, and provide proper antibiotics to athletes who are suspected of being bitten by a tick.

Summary

Climate change is an ever-increasing risk to endurance athletes. Endurance athletes are apt to experience the effects of climate change, especially during training and competition. While endurance events may contribute to climate change, strategies to minimize the carbon footprint and empower athletes and sports organizations to become part of the solution must be considered. Multinational organizations, such as the United Nations' Sports for Climate Action and climate change advocates like the Kilian Jornet Foundation, can serve as starting points for athletes and race organizations to better understand climate change and how to make a difference [130−132]. Even small steps, like athletes carrying their own reusable bottles or cups during competitions, using refillable pouches for on-the-go nutrition, recycling their old shoes, or adjusting their travel to lesser CO_2-producing modes can make a difference. Race organizations can also structure their event policies and education programs to be more environment friendly.

Additional research is needed to address the specific health concerns related to the impacts of climate change on endurance athletes. These knowledge gaps should be addressed in parallel with efforts to address consequences of climate change. Educating athletes and race organizations about the impacts of climate change on sport participation will increase awareness, and hopefully limit illness for those training or competing. Highlighting these concerns may empower athletes, competition organizers, and fans to take part in the discussion to address climate change.

Declaration of Competing Interests

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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