Chapter

Physiological Responses to Outdoor Recreation: How it Can Help you Prepare your Outdoor Activity and How to Intervene

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Abstract

Outdoor activity can help to promote an active lifestyle; however, it is often associated with risks from its surrounding environment. Understanding physiological responses to several outdoor activities and how to use simple monitoring tips to reduce risks will provide real-life applications in the preparation of outdoor recreation. The purpose of this chapter focuses on common stressful conditions: thermoregulation, energy demand, musculoskeletal injuries risks, sleep and recovery. These are some constraints that can be encountered in any outdoor context. The physiological responses and recommendations based on up-to-date research will provide useful methods for risk assessment and how to manage them. Finally, the health benefits from outdoor activity in different populations will complete this chapter in order to help specialists structured and adapted their intervention planning.

Keywords: outdoor recreation, thermoregulation, metabolism, musculoskeletal injuries risks, recovery, physiology

1. Introduction

Outdoor activities have many health benefits, such as promoting physical activity and could play a role in stress management and mental health [1, 2]. However, the outdoor environment can be challenging for human physiology. Therefore, preparations are needed before the start of the activity in order to prevent any potential risks. The present chapter will outline the basics human physiological responses to different environmental challenges during outdoor activities and how to better prepare for them in the wild. Most of the research related to environmental physiology and guidelines in outdoor safety were conducted in work-related environments from different occupational health-related studies. This previous research could give us a better understanding of the physiological responses in the environment and may be used to prepare for outdoor activities. However, the physiological responses in a work-related environment could be different in the outdoors, and thus recommendations may have to be adapted for outdoor recreational activities. For this reason, the present chapter will include both work-related and outdoor-related physiological responses and guidelines.

2. Thermoregulation

Human body core temperature needs to stay in a short-range of approximately 37 ± 1° C [3]. During an outdoor event, the environment can impact the core temperature. Accordingly, wearing clothes, seeking shelter or exposure time will help keep the homeostasis of a core temperature between 27 and 42°C [4]. However, some outdoor sports involve risks related to cold exposure due to the distance from a shelter, and in turn, this could affect core temperature.

The environment influences human thermoregulation in different ways by four physics principles: radiation, conduction, evaporation and convection. The heat transfer from or to a human body with the environment is based on physics rules. Convection is a transfer of heat by fluid motion (gas or liquid) across the surface. Conduction is a heat transfer from a solid material to another through direct contact, for example, the hot sand on a beach to your feet. Radiation in the environment comes from the sun radiation, which is reflected from the ground or a rock. Nonetheless, the radiation can arise from the human skin that constantly radiates heat in all directions. This radiation can be observed with an infrared device and be used for safety in some work area where workers are exposed to high-temperature variations, such as a frozen food factory. Finally, evaporation is the primary way to dissipate heat from the human body. For example, sweat must evaporate (turn into a gas form) to dissipate the heat. In a situation where the sweat stays in liquid form, it represents a water loss without heat loss for the human body. The interactions between the environment and the human body are illustrated in **Figure 1**. Some equations are proposed to understand the thermoregulation resulting from these different factors interactions between the human and his environment: the heat balance equation:

$$\boldsymbol{M \pm R \pm C \pm K - E = 0} \tag{1}$$

M: metabolism (heat production in Kcal), R: radiation or radiant heat exchange (where the value is negative when the environment temperature is lower than the skin and can be measured with a globe thermometer or infrared), C: heat exchange by convection (where the value is negative when the air temperature is lower than

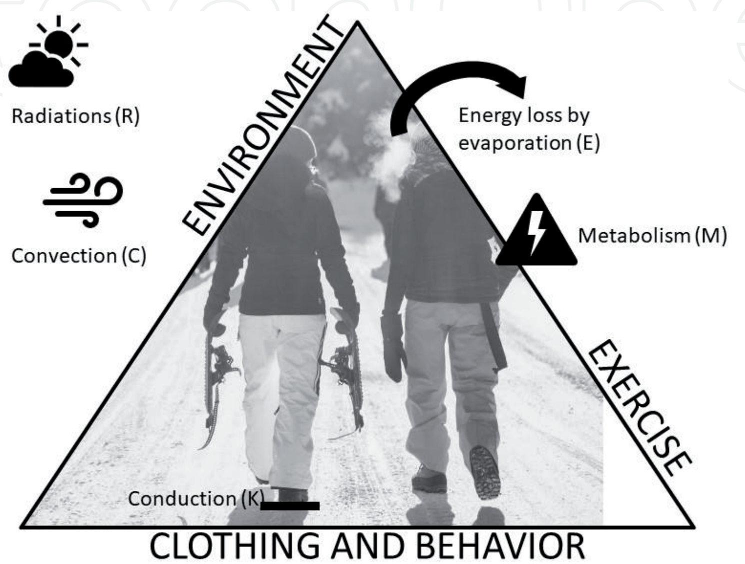

Figure 1.
Thermal balance between environmental factors as well as behavioral and physiological human responses.

skin temperature that can be measured by a thermometer and hot-wire anemometer), K: heat exchange by conduction (this value is usually negligible, except for activity like swimming or diving, K can be 20 times heat conductive (heat-removing in cold water) than air. Finally, E: heat loss by evaporation can be estimated by weight difference to estimate the sweat amount where some equations can help to convert in heat (energy) loss [5–8].

From this equation (Eq. (1)), other authors add some parameters: Gagge and Gonzalez [9] added work (+W) to the equation (Eq. (2)); work means any physical activity where a heat production will result from muscle activity. Winslow, Gaggeand, and Herrington [10] also proposed correction due to the storage of body heat (S). It was observed that most tissues are about 0.83. Even if all these equations are from old studies, they are the foundation of many guidelines for outdoor activities.

$$M \pm S \pm R \pm C \pm W - E = 0 \tag{2}$$

Some human behavior factors help humans to survive in an environment where the balance will be superior (core temperature increase) or inferior (core temperature decrease) at 0 in the equation's result. The 0 represent the thermal comfort, and to reach it, one of the planning of outdoor activity is clothing. It is also possible to calculate the thermal comfort from clothes in some environment with the Clo units [11]. One Clo unit represents the thermal isolation to maintain comfort and mean skin temperature at 33°C at rest in an environment with the air temperature of 21°C, relative humidity less than 50% and air velocity at 20 ft./min as defined by Gagge et al. [12]. This way to measure the impact of clothing still use today in occupational health and sports enthusiast [13, 14].

2.1 Physiological responses to a cold environment

A cold environment can affect a stable thermal balance by inducing physiological changes. Briefly, when the blood and/or the skin temperature decreases, the information goes to the hypothalamus to induce: 1) vasoconstriction in skin blood vessels to reduce heat loss in the environment and, 2) the skeletal muscles are activated to produce heat, causing the shivering. These responses help to increase heat production and in turn increase body temperature to keep homeostasis. These physiological changes are influenced by individual characteristics such as body composition, ethnicity, sex, age, and fitness levels [6]. But other factors could also affect these responses such as medication, caffeine and alcohol [15–17]. For example, consuming acetaminophen may decrease core temperature and heat production [18]. However, it should be noted that the physiological responses to a cold environment are complex and that the fundamental mechanisms involved in this process are poorly understood.

2.1.1 Effect of cold environment exposure on exercise performance

In a cold environment, the human body responds differently from an acute than repeated exposure to cold. During an acute exposure to cold, the skin receptors are responsible for alerting the human body by some discomfort. Usually, the human body begins to experience some discomfort at a skin temperature under 29°C. However, with acclimatization by repeated exposure to cold, a tolerance is developed partially by a psychological adaptation, by a central nervous system adaptation and lower finger skin temperature loss [19, 20]. During outdoor activity, this acclimatization can help motivate people to enjoy winter outdoor sports, but it can further increase the risk of cold injuries [19, 21].

During winter outdoor activity, other considerations need to be taken regarding energy intake and exercise performance. Metabolism increases 2-5 times by the sympathetic system at rest, but at exercise, it will depend on the intensity and can reach 10-20 times higher. For the moment, the literature is not consistent with the oxygen consumption at the same intensity in a cold environment. Some authors will report a higher oxygen consumption, and others reported a similar consumption [22]. These different results can be explained by different temperature expositions, the exercise intensity and, the participants' fitness levels [22, 23]. A similar controversy can be observed with the heart rate at submaximal exercise that can be explained by the exercise intensity. Oska et al. [23] observed that the heart rate was lower at the cold environment for a moderate exercise intensity (50%VO2max), but was higher during very light exercise intensity (25%VO2max). Nonetheless, the authors agreed on the decrease of maximal oxygen consumption and the decrease of maximal cardiorespiratory capacity [4, 22]. Finally, other physiological responses can affect exercise performance during outdoor activity in a cold environment such as: a decrease in strength, a decrease of maximal power, coordination lost a decrease of dexterity, higher reaction time and decision-making that can increase the accident risks for some sport like climbing [6, 8, 20].

2.1.2 Individual characteristics

Some individual characteristics need to be taken into consideration with the planning of outdoor activities. As mentioned earlier, body composition, ethnicity, sex, health status and age can influence the physiological responses to cold. Body fat percentage and the ratio body surface on body mass can affect the thermoregulation efficiency. That is, subcutaneous fat is an excellent insulator due to reduced conductor proprieties by the lower quantity of blood vessels and water. This creates an excellent resistance to heat exchange towards the environment in which individuals with higher fat percentage will conserve more heat in a cold environment. Skinfold measurements may be used as a clinical tool to quantify subcutaneous fat thickness and could be used as an indicator of tolerance to cold. The ratio body surface to body mass also influences the rate of heat loss. In fact, a larger individual with a smaller surface area will increase their tolerance to cold. These two anthropometric characteristics explain why older people, adolescents and children are more at risk than an adult. Usually, these populations have lower subcutaneous fat and a disadvantaged ratio. Furthermore, older individuals often have medication intake that can play a role in thermoregulation, and this may increase the risks in a cold environment [4]. Ethnicity can also influence thermoregulation responses. For example, research has shown that Caucasians have a different oxygen consumption, skin temperature and rectal temperature responses to acute cold exposure than African American [24]. These differences seem to be explained by several adaptation patterns (by genotypes and/or phenotype) across other various ethnicity groups such as Eskimos, Alacaluf Indians and Australian Aborigines [25].

For the sex influence, the estrogen secretion influences the hypothalamus where even if women have generally a higher percentage of body fat, they have a lower tolerance to cold and lower skin temperature for the same effort and same environmental conditions than men [26, 27]. This implies postmenopausal women have a higher cold tolerance than premenopausal women. It was also observed by Kaikaew and al. [26], that women will start shivering at a higher environmental temperature than men. This sex different should be taken into consideration during preparation and during outdoor activity.

2.1.3 Prevention and intervention tips

Frostbite and hypothermia can have important consequences, which include superficial tissue loss to loss of consciousness. The Wilderness Medical Society has provided some simple guidelines in a cold environment [28]:

- Be aware of any underlying factors that increase risks in a cold environment, such as medical problems like Raynaud's syndrome or diabetes, substance intakes like medication, alcohol or drugs that can decrease peripheral perfusion, individual's characteristic like age and sex;

- Bring spare dry clothes, mostly for the peripheral members (e.g., socks, mitts);

- Bring chemical or electric hand and foot warmers;

- Locate shelters during the activity if needed;

- Maintain hydration and energy needs. Exercise is a great way to produce heat, but the energy and hydration needs will increase too;

- Be careful of moisture from perspiration or activities in the snow; wet clothes increase heat loss;

- Minimize blood flow restriction such as tight clothing or footwear, backpack, and hiking carriers for babies;

- Verify regularly for pain/cold discomfort and numbness or venous return if possible.

2.2 Physiological responses to a heat environment

Physiological responses to high temperatures have the same goal as the cold environment: keep a body temperature balance inside the vital range. Similarly to cold temperature, when the core temperature increase the blood activate signals to the hypothalamus. These signals activate sweat glands in order to increase evaporation and vasodilation in the skin blood vessels to increase heat loss and regulate core temperature for homeostasis. Similarly to cold temperature, responses can be different from one individual to another regarding various characteristics such as ethnicity, sex or age. Furthermore, due to the changes in the blood flow by peripheral vasodilatation for sweating and the increase of cardiac output, medication uptake can affect the thermoregulation responses and increase hyperthermia risks. Another response to a warm environment is an increase in heart rate at rest and during exercise. People at risk using medication that affects cardiovascular parameters need to be supervised closely and carefully.

2.2.1 Hydration and guidelines in a hot environment

The thermoregulation needed in a hot environment increases metabolism and sweat, while hydration and energy/mineral uptake can be a challenge due to this higher need [13, 29, 30]. Some guidelines in occupational health propose to drink around 0.23-0.25 L of cold water every 15-20 min [31]. Other authors are more precise like the US Army table, in which water intake is adapted according to the following factors: temperature, activity intensity and duration. The guidelines vary from 3.8 cups/hour at over 90°F WBGT (wet-bulb globe temperature index) for 10 min of hard work (600 W) to 1.9 cup/hour for an unlimited time at easy work (250 W) at 78-81.9°F WBGT [32]. Nonetheless the guidelines you follow, drink content should also be taken into consideration due to risks of hyponatremia. Plasma sodium can rapidly drop below 130 mmol/L during high-intensity exercise in a hot environment. It is for this reason, the ACSM recommends to drink during exercise over 2% of body weight loss from water deficit and after exercise consuming meals, snacks and beverages with sodium to help the recovery [33]. To help you plan the need of hydration, occupational health Institution, like the IRSST (Institut de recherche Robert-Sauvé en Santé Sécurité au Travail) proposed calculators in their website to plan rest, activities, hydration and other recommendations to reduce risks in a hot environment. It should be noted that these recommendations are specific to workers, thus, they may not be appropriate for all outdoor activities.

2.2.2 Acclimation in a hot environment

Acclimation to heat at exercise can be done with different varieties of frequency, intensity, duration, and environmental temperature. Adaptation time varies between 4 and 14 days [34–36]. This acclimation needs to be maintained to keep performance capacities (submaximal performance, VO_2max and power). The acclimatization induced a higher and more sustained (decrease sodium and chloride concentrations) sweat rate when needed and improve thermal comfort [30, 34]. Also, the physiological acclimation from repeated exposure to heat induces an increase in sweating and skin blood flow responses, a plasma volume extension, a better fluid balance, better cardiovascular stability (a lowered heart rate but higher stoke volume to induce a better sustained cardiac output and blood pressure), and a lower metabolic rate [30, 34]. All these acclimations help sustain activities in heat environment with a better tolerance, a lesser need for minerals and better sweat evaporation. These acclimations can stay up to a month [37].

2.2.3 Individual factors that can influence thermoregulation in a hot environment

Like the cold environment (**Figure 2**), individual characteristics can play a role in the thermoregulation response. The sex will contribute to some variations. Women will have a body temperature that will fluctuate about 0.5-0.8°Celsius during her menstruation cycle, and the progesterone and estrogen levels with oral contraceptives can influence the thermoregulatory control of skin blood flow and body temperature during physical activity and rest [27]. Furthermore, women have lower sweating rates than men for the same heat loss demand (metabolic demand and environmental temperature) at high temperature (40°Celsius) [38]. Finally, age, genetic and % body fat can influence the thermoregulation in a heated environment for a similar reason as explain for cold exposure. It is for this reason; the individual's characteristics need to be taken into consideration during the outdoor activity preparation.

2.2.4 Prevention and intervention tips

Heat environment should be avoided if possible. If the context is impossible to control, it is essential to prepare consequently by having enough water and heat

Figure 2.
Summary of physiological responses to thermoregulation during acute and repeated exposures (cold and hot environment).

acclimatize to the participant in the outdoor activity. Do not forget that thermal stress relies on multiple factors such as sex, age, ethnicity, anthropometry, substance intake, and health history.

Hyperthermia and other heat-related illnesses can have important consequences, from heat, cramps to heatstroke. The Wilderness Medical Society provided some simple guidelines in heat environment [39]:

- Be aware of any underlying factors that increase risks in heat environment, such as medical problems high blood pressure, substance intakes like medication (beta-blockers, amphetamines…), alcohol or drugs, individual's characteristic like age and sex;

- Bring enough water or plan where to refill your bottle, hydrate before during and after the activity, the hydration status is an high-risk factor;

- Promote acclimatization: 8 days, 1-2 h per day heat exposure and regular physical activity before the outdoor event if it plans to be in a heated environment;

- Use WBGT (wet-bulb globe temperature index) temperature to assess the heat risks;

- Wearing the right clothing for the right temperature.

3. Altitude and physiological responses

The challenge to climb high mountains and enjoy the view from the summit is probably an outdoor activity goal for many hikers. Altitude environment could drastically challenge human physiology, where appetite, sleep, cardiorespiratory responses and metabolism are affected. Some physiological responses can be affected as low as 1000 m above sea level (a.s.l.) and begin to decrease performance around 2000 m a.s.l. [40]. During hiking ascent, the barometric pressure decreases and the partial pressure of oxygen (PO_2) in the arterial from the cardiorespiratory system too. This lower pressure affects the O_2 diffusion between alveoli and the arterial blood, and between the arterial blood with the tissues like the muscles. This lower oxygen diffusion in blood arteries and consequently, a decrease of oxygen saturation can be monitored with a pulse oximeter device. An immediate adjustment during the initial rise will be the activation by chemoreceptor in the aortic arch and carotid arteries, stimulated by hypoxia (low PO_2), inducing a ventilation increase to compensate [41, 42]. A few hours later, plasma volume decreases frequently due to water loss through ventilation and increase of urine production [43]. This change increases the hemoglobin concentration in the blood flow, increasing the oxygen exchanges to the muscles. After a few hours in altitude, the erythropoietin (EPO) will increase the release by the renal system. The EPO regulates the red blood cell production and increases the blood hemoglobin concentration further. Also, the cardiac output (the function of the heart rate X stroke volume) will increase during rest and exercise; due to the plasma decrease (decrease of cardiac stroke volume). The heart rate will disproportionately increase [43, 44]. This increasing cardiac output, consequently, increases the blood pressure, and people at risks should be monitored for safety. The amount of fluid loss can be a challenge to stay hydrated during ascent; a general rule is to consume at least 3 L of fluid by day in high altitude [7]. The physiological responses to altitude and susceptibility to altitude illness vary between individual, this explains why monitoring often during rising will help you to recognize normal responses to abnormal responses.

Between 1850 m and 5895 m, some people (22-77% of travelers) can experience acute mountain sickness (AMS) [43]. This sickness includes headaches with one or more of the following symptoms: vomiting, lethargy, nausea, loss of appetite, insomnia but with a normal mental status [40, 43]. Usually, around 80% of individuals experiencing AMS will resolve their symptoms when stopping ascension and resting at the current altitude for 2-7 days [45]. Be aware, more severe altitude illness can occur and can be fatal if not treated in time, like the High-Altitude Cerebral Edema or the High-Altitude Pulmonary edema, where monitoring your group is vital for their safety.

3.1 Physiological response acclimatization and risk during a long expedition in altitude

Human physiology responses acclimate to altitude exposure from a few days to weeks. Some changes help humans to perform at high altitude. These physiological changes should, theoretically, improve O_2 transport to the active muscles during exercise, and it is why athlete use altitude training acclimatization to improve their performance [42, 46]. However, some individuals can be affected differently during the acclimatization period when exercising. The maximal aerobic capacity decreases in altitude and by consequence, the exercise intensity will need to decrease too at the beginning of the acclimatization process. Basal metabolic rate will increase, but appetite decreases, which can lead to a daily energy deficit that can affect exercise tolerance and, during long expeditions, muscle mass loss [7, 40, 47]. Furthermore, many individuals experience sleep disturbances and/or sleep apnea; the hypoxia can induce central sleep apnea and affect people at risk of cardiovascular disease [41, 48]. Moreover, sleep is important to recover and perform hiking during the long ascent and can affect the time and performance during long expedition in altitude. Finally, after 4-6 weeks at high elevation, climbers can experience a decrease in total mass area, a capillary density decrease, mitochondrial dysfunction and a decrease in glycolytic activity, which can impact their capacities [40, 44]. However, some other acclimatization will help exercise tolerance after a few days to some weeks, depending on individuals [42, 49]. Cardiac output and peripheric blood flow will return to normal, reducing cardiac work and improving the diffusion time for oxygen extraction by tissues [49]. Also, continuous residence in altitude improves exercise tolerance compared to initial exposition [42].

3.2 Prevention and intervention tips

Hiking in altitude environment can be a beautiful outdoor recreational activity with great landscape pictures opportunities. However, preparing this kind of activity will need to consider long periods of rest and acclimatization and regularly to monitor your group.

Altitude is a challenging environment and can have consequences, from mild headaches to fatal altitude illness. The scientific literature provides some simple guidelines to prevent altitude illness [42, 43, 50]:

- Prepare a slow and gradual ascent, a general recommendation is a daily ascent around 500 m altitude gain including a night's sleep, with an extra acclimatization day every 1000 m;

- Using Acetazolamide or Dexamethasone can prevent AMS, but can have side effects and have limits to considerate;

- The descent is the best treatment for acute altitude illness, prepare plans if some people need to return at normobaric environment quickly;

- Use different tools to assess and monitor your group: Lake Louise AMS score [51] and pulse oximeter devices;

- If you can provide repeated exposure to hypoxia (normobaric or hypobaric) before your excursion or spending a week at moderate altitude (2200 m-3000 m) before exposure to high altitude, this can improve exercise tolerance and decrease risks of AMS;

- Plan enough water and food, knowing that altitude will increase your needs.

4. Workload, sleep and recovery process

4.1 Physiological risk to load

Outdoor activity can be a repetitive action like walking for hikers or rowing for canoes. Repetitive movement for a long period of time increases the risk of musculoskeletal injuries [52]. Musculoskeletal injuries are multifactorial; some authors have proposed underling hypotheses [53]. During repetitive motion some motor units in the muscles are recruited continuously, they are called the Cinderella fibers, increasing risks of injuries by a sustained contraction for a long period of time [52–54]. Other mechanisms like neural pathomechanisms, reperfusion injures, impaired heat shock responses and mitochondrial damages was also proposed to explain musculoskeletal injuries in repetitive workload (Forbes 2002). Rest and changing the activity (movement) can help to reduce the risks, ergonomic papers propose to plan sufficient rest to avoid injuries [55]. It is for this reason; rest time and recovery need to be planned for this kind of activity. Even if it can be difficult to use occupational health guidelines for rest, outdoor activities should plan regularly rest time and changing movement if possible in order to avoid musculoskeletal injuries.

4.2 Hiking workload

Hiking energy cost will depend on many factors such as the load, the slope, the environmental conditions, the surfaces, the clothing and footwear and the individual capacities. Walking velocity has an impact on energy expenditure and fatigue; individuals have their own threshold where running would be more cost-effective than walking and will naturally shift from walking to running when it is more cost-efficient. This speed is usually around 7 km/h [56]. The slope impact on this energy cost was introduced as a concept of mechanical efficiency by Margaria [57]. This means you will need to assess your group to find the more effective speed or separate your group in subgroups consequently.

Furthermore, the physical workload can be planned to prevent fatigue. Usually, occupational studies recommend (eight hours a day, all week) that physical demands should be in a range of 33-50% of VO2max. However, backpack weight, altitude, temperature, and distances to travel during hiking expeditions can easily overtake this guideline. It is for this reason, allow enough rest period, assess the group mood and perception. The backpack choice (padded hip belt, size, fitting on the shoulder…) and load weight and his distribution are factors that can influence your participant's risks relative to their capacity [58]. Among the risks, dorsal back pain, knee pain, rucksack paralysis, stress fractures, low back injuries, metatarsalgia and foot blisters were reported in the literature [58, 59]. The hip belt suggests a more natural movement and stability at the hip, but factors like walking velocity, body weight and posture, hip-belt size, distribution and weight of the load in a backpack in the function of the participant center of mass position can affect the hip belt [59]. Furthermore, shifting load from shoulder to hip decrease discomfort and decrease load impact on the spine by decreasing risks of low back pain or injury [60]. Another reason to be careful with the shoulder forces is the macrovascular and microvascular hemodynamic that can be compromised and lead to neurological dysfunction and probably a loss of hands fine motor control [61] and consequently possibly increase frostbite risk in cold environment.

4.3 Physiological responses during sleep and recovery

Fatigue means different things for different individuals. In sports medicine, fatigue is often quantified by a decrement in muscular performance to produce force with/or perception of tiredness or pain [62–64]. Many factors can contribute to fatigue such as the intensity, the duration and the nature of the activity, the sex and individual capacities, but also the equipment used [62–64]. Rest induces physiological changes after exercise to improve physical capacities, however; improper recovery may cause residual fatigue, where systematic, can cause overload and increase injury risks, overtraining syndrome or decrease physical performance [65]. Fatigue is often separate as peripheric fatigue, from the muscle capacity (i.e., energy production, contractile mechanism) and central fatigue, from the central nervous system [65]. To reduce risk, plan your activity intensity progressively and according to the individuals or group capacity. If possible, plans an outdoor training before a longer expedition to build higher capacity and decrease the rest needed to recover.

Quality of sleep can be impacted by outdoor environments like altitude and temperature. Furthermore, altitude can cause central sleep apnea, insomnia, pulmonary or brain edema during sleep [66]. Sleep deprivation can impact your outdoor activities by a decrease of capacities, fatigue perception and even bad mood [66, 67]. However, the natural environment can also increase sleep quality for some individuals due to the light pollution and the physical activity (melatonin regulation). Light pollution and lack of exposition to natural light can impact sleep circadian rhythm [68]. The natural environment exposure can influence sleep quality positively by regulating melatonin secretion, reducing artificial light exposure, promoting exercise and reduce some city noises [69].

4.4 Prevention and intervention tips

Load and repetitive movements can increase musculoskeletal injuries risks. The scientific literature provides some simple guidelines to prevent some risks [54, 63]:

- Decrease the load as much as possible and increase physiological capacity before a long hiking journey;
- Plan many rest breaks during your activity;
- Change activity or movement if possible after repetitive tasks like walking or canoeing.

5. Nautical activities and physiological responses

5.1 Water safety

Marine activities can be an outdoor activity with some specific risks to avoid. Epidemiology articles have examined some typical injuries for different nautical sports. Twenty six percent of injuries from wakeboarding involved the head, back and ribs [70], and surfing and water skiing reported many cases of craniomaxillofacial laceration [71]. These injuries are only some example of dangers beyond drowning.

Water safety and aquatic recreation precaution are not always well understood. Moran and Ferner [72] reported that New Zealand residents and tourist surfers had a poor understanding of rip current (powerful and narrow channels, seaward flowing current along gulf, coast, beach and lakes), which is that can frequently occurring hazard. Rip current are also responsible of rescues and drowning with many swimmers, where public education and awareness strategies need to be implement in your activity preparation [73]. Lack of awareness of alcohol consumption and downing risk was also reported as a major safety problem in aquatic activities [74, 75]. From fatal and non-fatal drowning, an average of 49.5% and 34.9% respectively involved alcohol consumption [74]. This lack of understanding and knowledge dangers can also arise from marine envenomation, where tourists are often not aware of venomous creatures like starfish, sea urchins and stingrays [76]. These can also include infectious water area, where pathogens can contaminate the swimmer, surfer, or another nautical activity practitioner. One of these infectious diseases contracted in water is the Legionellosis disease, a severe bacterial infection with similar symptoms of pneumonia; this pathogen can be found in freshwater, natural water or artificial water and some cases were reported in Greece among hotels [76]. Finally, decompression illness (DCI) is probably the most common risk for an unexperimented diver. During DCI, microbubbles are formed by the nitrogen during an inadequate decompression in tissues and intravascular, damaging blood vessel (including pulmonary circulation), distorting tissues and initiate inflammatory response [76, 77]. Most of these risks are the result of lack of knowledge and/or awareness and could be prevented by a proper preparation: wearing the appropriate safety equipment, all practitioner should have proper training and education of the activity and the environment and having adequate communication tools for emergency situation.

5.2 Seasickness

Seasickness is a form of motion sickness, a common physiological response to unnatural motion stimuli where the vestibular system (semi-circular canals and otoliths) information from linear (mostly vertical) or angular acceleration of the head mismatching the eyes signals [78, 79]. This conflict can cause nausea, vomiting, cold sweating, pallor, dizziness, drowsiness and headache [80]. Seasickness can affect up to 25% of passengers on a large ship and will increase with a smaller boat and bad weather conditions [81]. Individual difference susceptibility can be difficult to predict who will have seasickness. However, a questionnaire *the Motion sickness susceptibility questionnaire* (MSSQ) and the short MSSQ can help to identify some people that could be susceptible to seasickness [82]. Furthermore, children aged 6-12 years old, women and lack of sleep can contribute to higher susceptibility to seasickness [81–83].

Exposure to motion environment (water) can gradually help prevent motion sickness. Accordingly, a few (1-3) days on a boat is usually enough to acclimatize depending on the individual [80, 81, 84]. The following recommendations [84] should help if you have an individual in your group with seasickness:

- Ask the passenger(s) with seasickness to look forward at a fixed point on the horizon and not close their eyes;

- If possible, gradually increase the number of motion stimuli, start the travel in calm waters;

- The passengers with seasickness should avoid close work (cooking, read inside, looking at computer…), avoid space without the horizon view, avoid alcoholic drink, and an empty stomach (eat before traveling);

- If the passage can actively synchronize the body with the motion;
- The passenger with seasickness should change their mind, like listen to music;
- Use a motion sickness susceptibility questionnaire to plan your activity in consequence; for example, people susceptible to seasickness could take medication, like scopolamine, before traveling combine to behavioral strategies (above).

6. Conclusion and future research

Outdoor activities need some preparation to decrease risks for the participants. Knowledge of physiological responses may help better understand the principal preparation tasks and risks that can occur during outdoor activities. However, some physiological mechanisms remain unknown, and some are controversial, thus, more research is needed to fully understand human physiology in an outdoor environment and propose better prevention tools and guidelines. Furthermore, there is evidence to suggest that natural environment activities are associated with health benefits, but the mechanisms still not fully understood [85].

One of these health benefits is that outdoor activities can increase physical activity time [85–87], that can help decrease cardiovascular disease, metabolic complications and some cancer risks and improve physical capacity [88]. In a society where physical inactivity and sedentarily time is a major health problem, like sitting at a desk for long hours, outdoor recreative activities can be beneficial even for a short bout like walking in a park during breaks [88–90]. Furthermore, several studies have observed the positive effects of nature on health, stress and recovery [85–87]. This exposure to nature, even from a picture, could promote recovery and restore stress levels [91]. To conclude, all these benefits can help society and promote outdoor activities and green spaces. Also, further research is needed to better understand the underlying pathways of these benefits. Moreover, specific guidelines for the outdoor reality are needed in order to provide tools for outdoor professionals.

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Conflict of interest

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References

[1] Aliyas Z. Physical, mental, and physiological health benefits of green and blue outdoor spaces among elderly people. Int J Environ Health Res 2019; 1-12.

[2] Eigenschenk B, Thomann A, McClure M, et al. Benefits of outdoor sports for society. A systematic literature review and reflections on evidence. *Int J Environ Res Public Health*; 16. Epub ahead of print 2019. DOI: 10.3390/ijerph16060937.

[3] Cheung SS, Lee JKW, Oksa J. Thermal stress, human performance, and physical employment standards. *Appl Physiol Nutr Metab* 2016; 41: 148-164.

[4] Stocks JM, Taylor NA, Tipton MJ, et al. Human physiological responses to cold exposure. *Aviat Space Environ Med* 2004; 75: 444-457.

[5] Cheuvront SN, Kenefick RW. CORP: Improving the status quo for measuring whole body sweat losses. *J Appl Physiol* 2017; 123: 632-636.

[6] Castellani JW, Young AJ. Human physiological responses to cold exposure: Acute responses and acclimatization to prolonged exposure. *Auton Neurosci Basic Clin* 2016; 196: 63-74.

[7] Kenney WL, Wilmore JH, Costill DL. *Physiology of sport and exercise*. Human kinetics, 2020.

[8] Mäkinen T. Human cold exposure, adaptation and performance in a northern climate. *Int J Circumpolar Health* 2006; 65: 369-370.

[9] Gagge AP, Gonzalez RR. *Mechanisms of heat exchange: Biophysics and physiology. Handbook of Physiology: Environmental Physiology.* Bethesda: American Physiological Society, 1996.

[10] Winslow CE, Gagge A, Herrington LP. The influence of air movement upon heat losses from the clothed human body. *Am J Physiol Content* 1939; 127: 505-518.

[11] Davis JK, Bishop PA. Impact of clothing on exercise in the heat. *Sport Med* 2013; 43: 695-706.

[12] Gagge AP, Burton AC, Bazett HC. A practical system of units for the description of the heat exchange of man with his environment. *Science (80-)* 1941; 94: 428-430.

[13] Notley SR, Flouris AD, Kenny GP. Occupational heat stress management: Does one size fit all? *Am J Ind Med* 2019; 62: 1017-1023.

[14] Fantozzi F, Lamberti G. Determination of thermal comfort in indoor sport facilities located in moderate environments: An overview. *Atmosphere (Basel)*; 10. Epub ahead of print 2019. DOI: 10.3390/atmos10120769.

[15] Thompson-Torgerson, C. S. Holowatz LA, Kenney WL. Altered mechanisms of thermoregulatory vasoconstriction in aged human skin. *Exerc Sport Sci Rev* 2008; 36: 122-127.

[16] Kellogg DL. In vivo mechanisms of cutaneous vasodilation and vasoconstriction in humans during thermoregulatory challenges. *J Appl Physiol* 2006; 100: 1709-1718.

[17] Freund BJ, O'brien C, Young AJ. Alcohol ingestion and temperature regulation during cold exposure. *J Wilderness Med* 1994; 5: 88-98.

[18] Foster J, Mauger A, Thomasson K, et al. Effect of acetaminophen ingestion on thermoregulation of normothermic, non-febrile humans. *Front Pharmacol* 2016; 7: 1-8.

[19] Lehmuskallio E, Hassi J, Kettunen P. The skin in the cold. *Int J Circumpolar Health* 2002; 61: 277-286.

[20] Saedpanah K, Aliabadi M, Motamedzade M, et al. The effects of short-term and long-term exposure to extreme cold environment on the body's physiological responses: An experimental study. *Hum Factors Ergon Manuf* 2019; 29: 163-171.

[21] Makinen TM. Different types of cold adaptation in humans. *Front Biosci (Schol Ed)* 2010; 2: 1047-1067.

[22] Oksa J, Kaikkonen H, Sorvisto P, et al. Changes in maximal cardiorespiratory capacity and submaximal strain while exercising in cold. *J Therm Biol* 2004; 29: 815-818.

[23] Gagnon DD, Rintamäki H, Gagnon SS, et al. Cold exposure enhances fat utilization but not non-esterified fatty acids, glycerol or catecholamines availability during submaximal walking and running. *Front Physiol* 2013; 4 MAY: 1-10.

[24] Farnell GS, Pierce KE, Collinsworth TA, et al. The influence of ethnicity on thermoregulation after acute cold exposure. *Wilderness Environ Med* 2008; 19: 238-244.

[25] Taylor NAS. Ethnic differences in thermoregulation: Genotypic versus phenotypic heat adaptation. *J Therm Biol* 2006; 31: 90-104.

[26] Kaikaew K, van den Beukel JC, Neggers SJCMM, et al. Sex difference in cold perception and shivering onset upon gradual cold exposure. *J Therm Biol* 2018; 77: 137-144.

[27] Charkoudian N, Stachenfeld N. Sex hormone effects on autonomic mechanisms of thermoregulation in humans. *Auton Neurosci Basic Clin* 2016; 196: 75-80.

[28] McIntosh SE, Freer L, Grissom CK, et al. Wilderness Medical Society Clinical Practice Guidelines for the Prevention and Treatment of Frostbite: 2019 Update. *Wilderness Environ Med* 2019; 30: S19–S32.

[29] Hosokawa Y, Casa DJ, Trtanj JM, et al. Activity modification in heat: critical assessment of guidelines across athletic, occupational, and military settings in the USA. *Int J Biometeorol* 2019; 63: 405-427.

[30] Sawka MN, Leon LR, Montain SJ, et al. Integrated physiological mechanisms of exercise performance, adaptation, and maladaptation to heat stress. *Compr Physiol* 2011; 1: 1883-1928.

[31] Uejio CK, Morano LH, Jung J, et al. Occupational heat exposure among municipal workers. *Int Arch Occup Environ Health* 2018; 91: 705-715.

[32] Kenefick RW, Sawka MN. Hydration at the Work Site. *J Am Coll Nutr* 2007; 26: 597S-603S.

[33] Sawka MN, Burke LM, Eichner ER, et al. Exercise and fluid replacement. *Med Sci Sports Exerc* 2007; 39: 377-390.

[34] Périard JD, Racinais S, Sawka MN. Adaptations and mechanisms of human heat acclimation: Applications for competitive athletes and sports. *Scand J Med Sci Sport* 2015; 25: 20-38.

[35] Nybo L, Sundstrup E, Jakobsen MD, et al. High-intensity training versus traditional exercise interventions for promoting health. *Med Sci Sports Exerc* 2010; 42: 1951-1958.

[36] Lorenzo S, Halliwill JR, Sawka MN, et al. Heat acclimation improves exercise performance. *J Appl Physiol* 2010; 109: 1140-1147.

[37] Lipman GS, Gaudio FG, Eifling KP, et al. Wilderness Medical Society

Clinical Practice Guidelines for the Prevention and Treatment of Heat Illness: 2019 Update. *Wilderness Environ Med* 2019; 30: S33–S46.

[38] Gagnon D, Kenny GP. Sex differences in thermoeffector responses during exercise at fixed requirements for heat loss. *J Appl Physiol* 2012; 113: 746-757.

[39] Lipman GS, Eifling KP, Ellis MA, et al. Wilderness medical society practice guidelines for the prevention and treatment of heat-related illness: 2014 update. *Wilderness Environ Med* 2014; 25: S55–S65.

[40] Bärtsch P, Saltin B. General introduction to altitude adaptation and mountain sickness. *Scand J Med Sci Sports* 2008; 18 Suppl 1: 1-10.

[41] Taylor A. High-altitude illnesses: Physiology, risk factors, prevention, and treatment. *Rambam Maimonides Med J* 2011; 2: 1-18.

[42] Muza SR, Beidleman BA, Fulco CS. Altitude preexposure recommendations for inducing acclimatization. *High Alt Med Biol* 2010; 11: 87-92.

[43] Luks AM. Physiology in Medicine: A physiologic approach to prevention and treatment of acute high-altitude illnesses. *J Appl Physiol* 2015; 118: 509-519.

[44] Mazzeo R. Physiological Responses to Exercise at Altitude. *Sport Med* 2008; 38: 1-8.

[45] Gallagher SA, Hackett PH. High-altitude illness. *Emerg Med Clin North Am* 2004; 22: 329-355.

[46] Chapman RF, Stray-Gundersen J, Levine BD. Individual variation in response to altitude training. *J Appl Physiol* 1998; 85: 1448-1456.

[47] San T, Polat S, Cingi C, et al. Effects of high altitude on sleep and respiratory system and theirs adaptations. *Sci World J*; 2013. Epub ahead of print 2013. DOI: 10.1155/2013/241569.

[48] Nussbaumer-Ochsner Y, Ursprung J, Siebenmann C, et al. Effect of short-term acclimatization to high altitude on sleep and nocturnal breathing. *Sleep* 2012; 35: 419-423.

[49] Sawka MN, Convertino VA, Eichner ER, et al. Blood volume: Importance and adaptations to exercise training, environmental stresses, and trauma/sickness. *Med Sci Sports Exerc* 2000; 32: 332-348.

[50] Luks AM, McIntosh SE, Grissom CK, et al. Wilderness medical society practice guidelines for the prevention and treatment of acute altitude illness: 2014 update. *Wilderness Environ Med* 2014; 25: S4–S14.

[51] Roach RC, Hackett PH, Oelz O, et al. The 2018 lake louise acute mountain sickness score. *High Alt Med Biol* 2018; 19: 4-6.

[52] Sjøgaard G, Søgaard K. Muscle injury in repetitive motion disorders. *Clin Orthop Relat Res* 1998; 21-31.

[53] Hulshof CTJ, Colosio C, Daams JG, et al. WHO/ILO work-related burden of disease and injury: Protocol for systematic reviews of exposure to occupational ergonomic risk factors and of the effect of exposure to occupational ergonomic risk factors on osteoarthritis of hip or knee and selected other . *Environ Int* 2019; 125: 554-566.

[54] Forde MS, Punnett L, Wegman DH. Pathomechanisms of work-related musculoskeletal disorders: Conceptual issues. *Ergonomics* 2002; 45: 619-630.

[55] Gallagher S, Heberger JR. Examining the interaction of force and

repetition on musculoskeletal disorder risk: A systematic literature review. *Hum Factors* 2013; 55: 108-124.

[56] Alexander RMN. Energetics and optimization of human walking and running: The 2000 Raymond Pearl Memorial Lecture. *Am J Hum Biol* 2002; 14: 641-648.

[57] Minetti AE, Moia C, Roi GS, et al. Energy cost of walking and running at extreme uphill and downhill slopes. *J Appl Physiol* 2002; 93: 1039-1046.

[58] Knapik J, Harman E, Reynolds K. Load carriage using packs: A review of physiological, biomechanical and medical aspects. *Appl Ergon* 1996; 27: 207-216.

[59] Oberhofer K, Wettenschwiler PD, Singh N, et al. The influence of backpack weight and hip belt tension on movement and loading in the pelvis and lower limbs during walking. *Appl Bionics Biomech*; 2018. Epub ahead of print 2018. DOI: 10.1155/2018/4671956.

[60] Wettenschwiler PD, Lorenzetti S, Stämpfli R, et al. Mechanical predictors of discomfort during load carriage. *PLoS One*; 10. Epub ahead of print 2015. DOI: 10.1371/journal.pone.0142004.

[61] Kim SH, Neuschwander TB, Macias BR, et al. Upper extremity hemodynamics and sensation with backpack loads. *Appl Ergon* 2014; 45: 608-612.

[62] Millet G, Perrey S, Foissac M. The role of engineering in fatigue reduction. *Eng Sport 6* 2006; 3: 381-386.

[63] Wan JJ, Qin Z, Wang PY, et al. Muscle fatigue: General understanding and treatment. *Exp Mol Med* 2017; 49: e384-11.

[64] Yoon T, Delap BS, Griffith EE, et al. Mechanisms of fatigue differ after low- and high-force fatiguing contractions in men and women. *Muscle and Nerve* 2007; 36: 515-524.

[65] Zając A, Chalimoniuk M, Gołaš A, et al. Central and peripheral fatigue during resistance exercise - A critical review. *J Hum Kinet* 2015; 49: 159-169.

[66] Buguet A. Sleep under extreme environments: Effects of heat and cold exposure, altitude, hyperbaric pressure and microgravity in space. *J Neurol Sci* 2007; 262: 145-152.

[67] Andrade A, Bevilacqua GG, Coimbra DR, et al. Sleep quality, mood and performance: A study of elite Brazilian volleyball athletes. *J Sport Sci Med* 2016; 15: 601-605.

[68] Dumont M, Beaulieu C. Light exposure in the natural environment: Relevance to mood and sleep disorders. *Sleep Med* 2007; 8: 557-565.

[69] Grigsby-Toussaint DS, Turi KN, Krupa M, et al. Sleep insufficiency and the natural environment: Results from the US Behavioral Risk Factor Surveillance System survey. *Prev Med (Baltim)* 2015; 78: 78-84.

[70] Carson Jr WG. Wakeboarding injuries. *Am J Sports Med* 2004; 32: 164-173.

[71] Othman S, Bosco S, Cohn JE, et al. Dangers beyond drowning: craniomaxillofacial trauma in adult water activities. *Oral Maxillofac Surg* 2020; 4-9.

[72] Moran K, Ferner D. Water Safety and Aquatic Recreation among International Tourists in New Zealand. *Int J Aquat Res Educ*; 10. Epub ahead of print 2016. DOI: 10.25035/ijare.10.01.05.

[73] Otzenberger H, Simon C, Gronfier C, et al. Temporal relationship between dynamic heart rate variability and electroencephalographic activity

during sleep in man. *Neurosci Lett* 1997; 229: 173-176.

[74] Hamilton K, Keech JJ, Peden AE, et al. Alcohol use, aquatic injury, and unintentional drowning: A systematic literature review. *Drug Alcohol Rev* 2018; 37: 752-773.

[75] Abercromby M, Leavy J, Tohotoa J, et al. "Go hard or go home": exploring young people's knowledge, attitudes and behaviours of alcohol use and water safety in Western Australia using the Health Belief Model. *Int J Heal Promot Educ* 2020; 1-18.

[76] Pakasi LS. Health risks associated with recreational water activities. *IOP Conf Ser Mater Sci Eng*; 434. Epub ahead of print 2018. DOI: 10.1088/1757-899X/434/1/012329.

[77] Levett DZH, Millar IL. Bubble trouble: A review of diving physiology and disease. *Postgrad Med J* 2008; 84: 571-578.

[78] Molisz A, Ryk M, Rataj M, et al. Cardiovascular testing of seasickness in healthy volunteers on life rafts. *Int J Occup Med Environ Health* 2020; 33: 467-477.

[79] Bertolini G, Straumann D. Moving in a moving world: A review on vestibular motion sickness. *Front Neurol* 2016; 7: 1-11.

[80] Lackner JR. Motion sickness: More than nausea and vomiting. *Exp Brain Res* 2014; 232: 2493-2510.

[81] Leung AK, Hon KL. Motion sickness: an overview. *Drugs Context* 2019; 8: 2-12.

[82] Golding JF. Motion sickness susceptibility. *Auton Neurosci Basic Clin* 2006; 129: 67-76.

[83] Trendel D, Haus-Cheymol R, Erauso T, et al. Optokinetic stimulation rehabilitation in preventing seasickness. *Ann Fr d'Oto-Rhino-Laryngologie Pathol Cervico-Faciale* 2010; 127: 162-167.

[84] Brainard A, Gresham C. Prevention and treatment of motion sickness. *Am Fam Physician* 2014; 90: 41-46.

[85] Kruize H, van Kamp I, van den Berg M, et al. Exploring mechanisms underlying the relationship between the natural outdoor environment and health and well-being – Results from the PHENOTYPE project. *Environ Int* 2020; 134: 105173.

[86] McCurdy LE, Winterbottom KE, Mehta SS, et al. Using nature and outdoor activity to improve children's health. *Curr Probl Pediatr Adolesc Health Care* 2010; 40: 102-117.

[87] DE B, LM B-A, TM K, et al. A systematic review of evidence for the added benefits to health of exposure to natural environments. *BMC Public Health* 2010; 10: 456.

[88] Garber CE, Blissmer B, Deschenes MR, et al. Quantity and quality of exercise for developing and maintaining cardiorespiratory, musculoskeletal, and neuromotor fitness in apparently healthy adults: guidance for prescribing exercise. *Med Sci Sport Exerc* 2011; 43: 1334-1359.

[89] Malik SH, Blake H, Suggs LS. A systematic review of workplace health promotion interventions for increasing physical activity. *Br J Health Psychol* 2014; 19: 149-180.

[90] Humphreys BR, Ruseski JE. Participation in physical activity and government spending on parks and recreation. *Contemp Econ Policy* 2007; 25: 538-552.

[91] Ulrich RS. Health Benefits of Gardens in Hospitals. *Plants People Int Exhib Floriade* 2002; 1-10.