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Exploring the benefits of cold exposure in health and athletic performance - review of articles

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Abstract:

Introduction and purpose: In recent years there has been an increase in scientific research regarding the body's exposure to low temperatures. The potential health benefits have captured the attention of both researchers and the general public. This article review provides an analysis of the existing literature concerning the impact of cold body exposure on health and athletic achievements.

Material and methods: A review of the literature available in the "PubMed" database and books was conducted. The search was performed by using the following keywords: "cold exposure", "cryotherapy", "cold shower", "cold-water immersion" and "winter swimming".

State of knowledge: Encountering low temperatures can be perceived as a physiological stressor. The body responds to this situation by activating adaptive mechanisms to maintain homeostasis, such as the activation of brown adipose tissue, improved glucose control and increased immune system activity.

An increasing amount of data supports the positive impact of cold exposure on athletic performance. Potential benefits are indicated such as enhancing physical endurance through increased heat production and stimulation of the circulatory system, as well as facilitating faster body recovery.
Results and Conclusions: The article review indicates a growing interest in the impact of cold exposure. While there are encouraging findings of positive effects, further research is necessary for better understanding and determining the optimal conditions for achieving maximum benefits. This information could have a significant impact on the development of training strategies and health prevention.

Keywords: cold exposure, cryotherapy, cold shower, cold-water immersion, winter swimming.

Introduction and purpose:

Cold exposure, defined as intentionally exposing the body to low temperatures, arouses the interest of researchers, athletes and healthy lifestyle enthusiasts. In recent years, there has been a significant increase in the amount of scientific literature that has provided new perspectives on the potential health benefits and the impact of cold exposure on athletic performance.

Studying the mechanisms of the cold response allows us to gain insight into complex physiological and biochemical processes. From vasoconstriction to shivering thermogenesis, the body activates a number of mechanisms to maintain a constant body temperature[1]. Exploring further into the topic, we will discuss the relationship between cold exposure and its potential impact on immune function and inflammatory responses[2]. Cryotherapy, a therapeutic approach involving controlled exposure of the body to low temperatures, has gained significant recognition as a method supporting physical and mental health[3]. Exposure to low temperatures can be used as one of the tools in the fight against obesity and maintaining proper body weight by changing metabolism and promoting the activity of brown adipose tissue[4]. In addition, sport is a particularly interesting area that deserves attention. Increased endurance, more effective heat dissipation during training and faster regeneration are just some of the potential aspects that have been analyzed in this context and used in practice[5].

This article, by examining the mechanisms, health benefits and impact on sports performance, intends to provide a holistic understanding of the impact of low temperatures on the human body.

Materials and methods:

A review of the literature available in the "PubMed" database and books was conducted. The search was performed using keywords such as "cold exposure," "cryotherapy," "cold shower," "cold water immersion," "winter swimming," and the collected information was thoroughly analyzed.

State of knowledge:

1. The body's reaction to low temperatures

Immersion in cold water affects the human body by stimulation of baroreceptors and thermoreceptors and activation of the sympathetic and endocrine nervous systems[6]. An important role here is played by brown adipose tissue (BAT), which, as a thermogenic tissue, uses free fatty acids to produce heat through the process of mitochondrial detachment, which makes it particularly energy-consuming in cold environments where thermogenesis is active. BAT activation is the result of sympathetic activation and adrenergic signals induced by norepinephrine. It is also correlated with the absorption of circulating fatty acids and glucose and results in increased metabolic rate and improved insulin sensitivity[4].

Cardiovascular system

Heart rate: Both Mantoni et al.[7] and Tipton et al.[8], discovered that whole-body cryotherapy causes an increase in heart rate. An immediate increase in the number of beats per minute was observed after just 30 seconds of immersion in cold water. On the other hand, a small study by Kauppinen[9] demonstrated that the heart rate reached its highest point just before immersion. There is also evidence that systematic immersion or bathing in cold water caused a smaller increase in heart rate compared to control group[8].

Blood pressure: Kauppinen et al. in their study showed a significant increase in both systolic and diastolic blood pressure during immersion in cold water[10]. It is worth mentioning that both systolic and diastolic blood pressure returned to initial values within 30 minutes after the end of immersion.[10].

Blood circulation in the cerebral arteries: Mantoni et al.[7] analyzed blood circulation in cerebral arteries during immersion in water at 0°C. Short-term immersion caused an average reduction in cerebral artery blood flow by 43%. During submersion, the study participants experienced symptoms such as fainting, drowsiness, and visual disturbances[10].

Respiratory system

Tipton et al.[8] showed an increase in mean minute ventilation during the first and second minutes of cold water immersion. Shorter immersions at lower temperatures led to a more intense increase in the above parameter[8]. In addition, Mantoni[7] as well as Tipton[8] in their work found a decrease in the partial pressure of carbon dioxide after immersion in cold water.

Endocrine system

In a study by Kauppinen et al.[11] short immersions in cold water caused an immediate and significant increase in both norepinephrine and cortisol levels. Longer (5-minute) immersions only caused a statistically significant increase in cortisol levels. In contrast, Huttunen et al[12] observed an increase in norepinephrine levels with little change in cortisol levels.

2. Cold Exposure Techniques

Cryotherapy (from the ancient Greek *krýos* - cold; *therapeía* - treatment) is a broad concept meaning the use of low temperatures for therapeutic purposes. It is one of the oldest and simplest methods used to alleviate acute soft tissue injuries, muscle pain and soreness, as well as accelerate regeneration.[13]

Local cryotherapy. Local cryotherapy is the local application of ice, ice packs or cold gasses. Due to this treatment, intramuscular temperature is reduced by 3-8°C, which reduces the level of metabolites in the tissues, preventing inflammation and swelling[14].

Cold showers. Cold showers are a simple and widely available method of cryotherapy. There are reports in the literature about their beneficial effects on the immune and cardiovascular systems[15]. A randomized controlled trial of 3,018 participants conducted by Buijze et al. showed that taking cold (10-12℃) and short (30-90 seconds) showers every day for 30 days was able to reduce the subjective symptoms of a cold or flu by 29%[16]. The number of clinical studies clearly confirming their positive impact on health is still insufficient.

Cold-water immersions (CWI). The exact mechanism of action of CWI on the body is not yet known[17]. It has been proven that immersion in cold water reduces thermal load and pain, and also prevents swelling, inflammation and muscle spasms[18]. So far, no unified protocol for performing CWI has been developed regarding the optimal duration, temperature, depth of immersion and the number and frequency of immersions. Studies demonstrating the positive effects of CWI were typically performed in water at a temperature of 10°C to 20°C, for 5–15 minutes for a single immersion or 1–5 minutes per immersion for multiple immersions[19]. CWI performed to hip or shoulder level revealed better results compared to limb-only immersion. Physiological responses to CWI vary from person to person, but detailed considerations on this subject are not available in the literature[20].

Whole Body Cryotherapy (WBC). WBC is a method that involves exposing the body to extremely low temperatures (<-100°C) for a short time (up to 3 minutes)[21]. It is believed that extreme temperatures may stimulate cutaneous receptors and the sympathetic nervous system, leading to a reduction in muscle metabolic rate, cutaneous microcirculation, receptor sensitivity, and nerve conduction velocity[22]. Moreover, a decrease in internal temperature during WBC (by up to 2°C) may affect the concentration of catecholamines and cytokines, accelerating the process of tissue regeneration[14].

3. Cold exposure and the immune system

Cold water baths have been widely recognized by society for thousands of years as a way to improve immunity[23]. Some studies suggest a less frequent occurrence of respiratory tract infections in walruses, while others suggest a link between the frequency and severity of upper respiratory tract infections and cold water exposure, hence the lack of conclusive evidence to support this thesis[23].

Cold exposure causes rapid activation of the sympathetic nervous system, increased production of catecholamines and corticosteroids that affect immune function by inducing leukocytosis, decreased release of pro-inflammatory cytokines or expression of adhesion molecules on the surface of immune cells, and decreased mitogen-stimulated lymphocyte proliferation, a measure of cellular response used to assess the ability of T cells to replicate in response to their stimulation[24].

In the study by Milda Eimonde et al.[25] the effect of a 10-minute immersion in 14℃ water on the immune system of healthy men aged 20-30 years, not regularly engaged in sports, was examined. Immersion caused the previously observed stimulation of the sympathetic nervous system, in addition to a decrease in tumor necrosis factor α, an increase in interleukin 6 within 6 to 12 hours of water immersion, while no effect on interleukin 1β was observed. In morphology, there was a transient increase in the percentage of neutrophils with a concomitant decrease in the percentage of lymphocytes, which returned to baseline values within 4 hours of water immersion. The clinical relevance of these changes is not clear and requires further study.

Low temperature weakens local nasal defenses against infection by constricting the mucosal vessels and consequently reducing the flow of leukocytes, resulting in impaired elimination of viruses from the nose, which can promote respiratory infections[26,27].

The effects of cold on immune function are not obvious or clear-cut. The clinical consequences of the biochemical and morphological changes described in the studies are uncertain. Prospective experimental studies that would unambiguously evaluate both the short- and long-term consequences of cold exposure, depending on its duration and intensity, appear to be necessary.

4. Cold exposure and body weight control

New strategies for losing and maintaining a healthy weight are becoming increasingly important in the context of the obesity epidemic. To start losing weight, you need to create an energy deficit. BAT activation increases energy expenditure and is mainly mediated by the sympathetic nervous system and thyroid hormones[28]. Cold exposure increases both BAT activity[29] and glucose uptake[30]. Studies in rodents have shown that upon exposure to cold, white adipose tissue (WAT) cells can engage in BAT-typical activity, a process called "browning"[31,32].

Human studies have not yet yielded consistent results in inducing direct conversion of WAT to BAT, however, sustained increases in sympathetic activation have been associated with the development of BAT-specific morphological and physiological features within WAT[33]. A study involving people who were cold swimming 2-3 times a week showed increased thermogenesis compared to the control group, but it was not possible to determine whether the additional amount of heat was generated by BAT or skeletal muscle tremors. According to researchers' speculations, both sources had a significant impact on the result[4].

J. R. Speakman and S. Heidari-Bakavoli showed a statistically significant correlation between the occurrence of obesity and type II diabetes and average higher annual ambient temperatures. The increase in the average annual temperature from 5 °C to 25 °C translated into a statistically significant increase in the incidence of both of these diseases. However, after correcting for the effects of race and poverty, the effect of environmental temperature on obesity lost statistical significance. In turn, in the case of type 2 diabetes, after adjusting for race, poverty and even obesity, the impact of higher environmental temperature still translates into an increase in the incidence of type 2 diabetes by as much as 12.4%[34]. The above differences suggest that the increase in the prevalence of diabetes is not only a result of the increase in the incidence of obesity, which is its risk factor. One possible explanation for this phenomenon is the protective effect of cold on the development of insulin resistance, which may become a future focus of type 2 diabetes therapy based on exposure to low temperatures.

5. Cold exposure and sport performance

It is common among athletes to use various post-training procedures and treatments to expedite the process of regeneration, potentially influencing their sports performance. In recent years, Cold Water Immersion (CWI) has gained significant popularity as one of these methods[18] , and its impact on sports performance has undergone extensive analysis.

A metaanalysis examining the impact of CWI on sports performance improvement has demonstrated benefits, particularly following high intensity physical exertion. CWI results in reduced delayed-onset muscle soreness, this can be associated with a reduction of circulating creatine kinase. The subjective perception of improved recovery after CWI is not limited to high-intensity exercises, but also extends to eccentric exercises (in which muscle work involves the lengthening of muscle attachments under continuous tension). Furthermore, the positive effect of CWI implemented after these types of training is more likely to pertain to an improvement of muscle power (the ability to generate maximum force in the shortest time) rather than static muscle strength[35].

When comparing various post-training regenerative procedures, immersion in cold water has been proven to be more effective compared to immersion in warm water, active recovery, and the so-called contrast water therapy (alternating between hot and cold water) in terms of reducing muscle soreness and increasing muscle power[36].

On the other hand, there is data suggesting that post-training CWI may negatively impact muscle hypertrophy after strength training by reducing protein synthesis in skeletal muscles and increasing catabolic activity. Therefore for athletes where hypertrophy and muscle mass are desired outcomes, it would be advisable to avoid using this regenerative method[37]. Furthermore, some researchers suggest that it may reduce the effectiveness of strength training[38].

Other cryotherapy methods mentioned in section 2 of this article also find applications in sports. Some scientific reports suggest that after exercises that generate higher body heat levels, subjecting the entire body to the CWI or Whole Body Criotherapy (WBC) can lead to a systemic effect, creating a greater temperature gradient for tissue cooling. However, if the exercise generates minimal heat accumulation, the local application of cold using ice can lead to isolated tissue temperature changes. In such cases the local response may be effective enough to facilitate recovery[3].

An important and more accessible method used by athletes is taking cold showers. The cooling rate and effect of cold showers are lower than when using CWI; however, if CWI is not an accessible option, they can be effectively used to reduce the strain of the heart (by lowering the heart rate) after training conducted in a hot environment[39,40].

6. Cold exposure and mental health

The effects of cold exposure on mood are becoming increasingly apparent in light of recent literature reports.

The cross-sectional study conducted by Iliar Demori et al. involved 228 subjects aged 19-88 years, including 107 walruses and 121 controls. Self-assessment of mental and physical health in the subjects was measured using questionnaires. The walrus subjects reported lower levels of stress and better well-being, and their overall health rating was also higher than in the control group[41].

Yankouskaya et al. conducted a study in which 33 participants were immersed in water at 20°C up to neck height for 5 minutes. Both before and after CWI, they were subjected to functional magnetic resonance imaging (fMRI) and completed the PANAS (Positive and Negative Affect Assessment Scale) questionnaire. The subjects reported increased alertness, attentiveness, feelings of inspiration and pride (increased positive affect) and decreased feelings of nervousness and depression (decreased negative affect). The fMRI studies showed that increases in positive affect were accompanied by increased brain tissue activity in areas related to emotion, self-regulation and attention control. The relationship between decreased negative affect with the activity of brain areas was not demonstrated[42].

7. The use of cryotherapy in clinical practice

The use of cryotherapy in injuries of the musculoskeletal system

It is believed that cryotherapy reduces the intensity of metabolic changes and thus reduces the severity of inflammation that occurs after damage to joint structures. The hypothetical mechanism is based on a local reduction in temperature and blood flow at the site of injury or muscle damage[3].

However, many researchers believe that there is no clinical benefit from using any form of cryotherapy after injury - it weakens the natural healing response by reducing the inflammatory process. Some researchers even believe that cryotherapy should be completely removed from the standard treatment of soft tissue injuries[3]. This is confirmed by the newest and most comprehensive acronym introduced in 2019: PEACE & LOVE, in which ice was finally removed from treatment guidelines[43].

A legitimate use of cryotherapy is to protect against the development of serious edema after a significant injury. It limits the scope of swelling, and excessive, long-lasting swelling hinders the tissue recovery process[43].

The use of cryotherapy in cancer

Cryotherapy is also used in the treatment of cancer due to its anesthetic and vasoconstricting effect. It can be used in the treatment of cancers of the central nervous system, reproductive system, skeletal system and gastrointestinal tract[44,45]. Initially, cryotherapy had many postoperative complications, but their number was significantly reduced by introducing many changes. Recent research confirms that cryosurgery may be an effective treatment option for benign and malignant bone tumors, especially in cases where minimal bone loss is important[44].

The use of cryotherapy in heat stroke

Heat stroke is a condition in which the body temperature exceeds 40°C and the central nervous system becomes dysfunctional. Treatment includes many types of intense cooling activities[46,47].

Water immersion

The cooling technique is based on the use of the much higher thermal conductivity properties of water[46]. This method depends on the temperature gradient, but intense cooling of the skin may lead to chills and peripheral vasoconstriction, which in turn may reduce the effectiveness of the cooling process. Therefore, it is recommended to include a skin massage to prevent side effects[47].

Cooling by evaporation

It is more efficient than cooling by conduction. This technique is based on continuously spraying water on the skin and using a device that generates air flow. In their literature review, Hadad et al.[47] showed that the cooling rate using evaporative cooling was significantly higher compared to cold water immersion.

Ice-Pack application

There have been reports of positive results with the use of cold ice packs on large arterial areas in patients suffering from heat stroke. Kielblock et al. in their study showed that topical application of ice packs resulted in a much slower cooling rate than either complete ice pack coverage or evaporative cooling[48].

Invasive cooling techniques

Invasive methods of cooling include gastric and peritoneal lavage with cold water. The rationale of invasive therapies is to bypass the shell and directly cool the internal body organs. The effectiveness of this method is questionable, has no advantages over evaporative cooling and has many limitations[47].

8. Negative aspects of cold exposure and its safety

When discussing the benefits and advantages of cold therapy, it is necessary to address the potential negative health effects. Individual tolerance or response to cold depends on many characteristics, including general health, age, gender or body composition[49]. Risks concerning the therapeutic use of cold arise from excessive and/or prolonged exposure to low temperature or a pathological reaction of the body to the cold[23].

Prolonged exposure to low temperatures can lead to frostbite or even permanent damage to nerve endings[50]. Furthermore, the most common factors contributing to hypothermia include staying for a long time in conditions that promote heat loss, such as immersion in cold water, low temperature or air or strong winds[51]. Extended immersion in water with a temperature below 35°C can result in hypothermia since the body is continually losing heat to environment[52].

Exposure to cold initiates a reaction associated with heat shock. It includes irregular rapid inspirations, tachycardia, hyperventilation, peripheral vasoconstriction and increased blood pressure. This response peaks within the first 30 seconds after contact and adjusts within the first 2 minutes[53]. What follows is primarily the activation of the sympathetic nervous system. Further instances of breath-holding, which can happen when one immerses their face in cold water, trigger the parasympathetic nervous system, leading to a reduction in heart rate, possibly even causing bradycardia, or making it more likely for supraventricular extrasystole to occur[54]. Not only sympathetic but also parasympathetic stimulation of the heart can lead to arrhythmias. In addition, there is the possibility of simultaneous activation of both systems and the development of the so-called "autonomic conflict." In people with risk factors - such as long QT syndrome, coronary artery disease, atherosclerosis or myocardial hypertrophy - this can lead to fatal arrhythmias and even cardiac arrest[55].

The key to safety primarily involves careful and progressive adaptation of the body to cold temperatures. Therefore, gradually ease into cold water rather than jumping or diving in. The most intense thermal shock occurs in water between 10°C and 15°C[53]. Additionally, prolonged holding of breath should be avoided.

Conclusions:

This review of the scientific literature shows growing interest in the effects of cold exposure. Cryotherapy is already successfully used in clinical practice. Understanding the exact mechanisms by which cold exposure affects the body can potentially be used to combat obesity and type 2 diabetes, and may also unlock opportunities to new methods of improving physical performance, reducing inflammation and strengthening the immune system. However, it is worth emphasizing that the currently available evidence, although encouraging, has not reached a point where definitive conclusions can be drawn.

Author's contribution:

Conceptualization, KK, K.B; methodology, K.K, K.B., Ł.G, A.W., software, ., P.K. M.G., J.D., A.G., J.R., B.M. check, KK, K.B; formal analysis: KK, K.B; investigation, K.K, K.B., Ł.G, A. W., P.K. M.G., J.D., A.G., J.R., B.M. resources, K.K, K.B., Ł.G, A. W., P.K. M.G., J.D., A.G., J.R., B.M. data curation, writing - rough preparation, K.K, K.B., Ł.G, A. W., P.K. M.G., J.D., A.G., J.R., B.M. writing - review and editing, visualization: K.K, K.B., Ł.G, A. W., P.K. M.G., J.D., A.G., J.R., B.M. supervision, project administration: K.K., K.B. All authors have read and agreed with the published version of the manuscript.

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