УДК [612.563+612.53](98) DOI: 10.17238/issn2542-1298.2020.8.1.89

INFLUENCE OF SHIVERING, HYPOTHERMIA AND CIRCADIAN RHYTHMS ON THE FEATURES OF RESEARCH USING INFRARED THERMOGRAPHY IN THE ARCTIC (Review) = ВЛИЯНИЕ ДРОЖИ, ГИПОТЕРМИИ И ЦИРКАДНОГО РИТМА НА ОСОБЕННОСТИ ПРОВЕДЕНИЯ ИССЛЕДОВАНИЙ С ПОМОЩЬЮ МЕТОДА ИНФРАКРАСНОЙ ТЕРМОГРАФИИ В УСЛОВИЯХ АРКТИКИ (обзор)

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Изучены факторы окружающей среды, которые характерны для арктических регионов и влияют на результаты термографических исследований, тем самым ограничивая спектр их применения. Небольшие отклонения температуры вызывают изменения излучения с поверхности тела и таким образом влияют на анализ и интерпретацию термограмм. Кроме того, при применении инфракрасной термографии для измерения температур биообъектов необходимо понимать технические и методологические особенности метода. Проводя исследования с участием местного населения, важно учитывать изменения температуры кожи под воздействием факторов окружающей среды. Географически к арктическим регионам относятся Канада, Гренландия, Исландия, Норвегия, Швеция, Финляндия, Аляска и северные области России, в которых преобладает холодный климат. Холодный климат, неблагоприятные погодные условия и долгие зимние ночи – одни из многих факторов, затрудняющих проведение исследований в Арктике. Проводя исследования в области физиологии, важно рассматривать температуру окружающей среды как фактор, влияющий на количественную оценку индивидуальных особенностей участников, а полученные в результате знания адаптировать для использования в качестве дополнения программ обучения студентов. Основное внимание авторы уделяют дрожи, гипотермии и циркадному ритму как последствиям воздействия факторов окружающей среды, которые могут влиять на особенности применения инфракрасной термографии для исследований в области физиологии в Арктике.

Ключевые слова: *температура тела, инфракрасная термография, дрожь, гипотермия, циркадные ритмы, Арктика.*

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Для цитирования: Насутион А.И., Панков М.Н., Кирьянов А.Б., Старцева Л.Ф. Influence of Shivering, Hypothermia and Circadian Rhythms on the Features of Research Using Infrared Thermography in the Arctic (Review) = = Влияние дрожи, гипотермии и циркадного ритма на особенности проведения исследований с помощью метода инфракрасной термографии в условиях Арктики (обзор) // Журн. мед.-биол. исследований. 2020. Т. 8, № 1. С. 89–98. DOI: 10.17238/issn2542-1298.2020.8.1.89

The use of thermal imaging in biomedical practice is of great relevance. At the moment, body temperature is one of the most accurate parameters that reflect a person's condition. Thermal radiation from the skin can tell us about changes occurring in the body and, sometimes, about their causes, since most often the deviation of temperature distribution from the norm is a sign of a developing pathology [1].

One of the modern methods of measuring temperature is infrared thermography. None of the existing techniques has such wide diagnostic capabilities in various diseases as thermography [2]. This method allows us to determine the localization of possible changes or inflammation, as well as their activity and prevalence. The informational content and reliability of thermal images for some diseases is approaching 100 % [3]. Moreover, infrared thermography causes no discomfort in patients [4–8]. This method is absolutely safe and easy to apply [9–11]. Its degree of safety is remarkably high, even with frequent use. Importantly, this method can be applied in pregnant women and young children [8, 12, 13].

One of the disadvantages, however, is that infrared thermography requires taking into consideration several factors that can affect either the analysis or the interpretation of thermal images [14, 15]. The main influencing factor is the environment: its temperature is very important for accurate human studies using infrared thermography [16, 17]. Most sources suggest a range of 18–25 °C, as the subject may shiver at lower temperatures or sweat at higher temperatures [17–19].

Cold temperatures, adverse weather conditions and prevailing darkness in the winter are just a few of the many factors impeding research in the Arctic [20]. Geographically, the Arctic regions include Canada, Greenland, Iceland, Norway, Sweden, Finland, Alaska and the northern areas of Russia where cold climate prevails [21]. The United States Centers for Disease Control and Prevention (CDC) found that 63 % of weather-related deaths between 2006 and 2010 in the United States were attributed to exposure to excessive natural cold, hypothermia, or both [18]. Meanwhile, changes in temperature in the Arctic adversely affect the health of not only indigenous residents: unsuitable clothing as well as a lack of knowledge on how to deal with cold and harsh weather conditions may be the main risk factors for temporary residents.

Foreign students make a significant contribution to increasing the temporary population of the Arctic. In general, it is residents of tropical countries that come to study at Russian universities. In 2016, the number of foreigners entering universities of the Russian Federation amounted to 244 597 people [22]. Over the following year, the number of students from tropical countries in Russian universities increased by 17 %, the number of students from India increased by 20 %, and those from China by 10 %. The Russian Ministry of Education reports that in 2015–2016 Russian universities enrolled about 3.1 thousand people from Vietnam and about 11 thousand from African countries [23].

Currently, studies explaining the influence of environmental factors on infrared thermography are rather scarce. When conducting research in the field of physiology, it is important to consider ambient temperature as a factor affecting the quantitative assessment of the individual characteristics of participants and adapt the resulting knowledge to complement student training programmes. The purpose of this article is to review factors that can influence both the analysis and interpretation of the results of applying infrared thermography in the Arctic. It also explains how important ambient temperature and related factors are to fill research gaps and minimize the limitations of infrared thermography in identifying pathologies in both permanent and temporary residents of the Arctic.

Environment. One of the factors influencing the analysis and interpretation of thermograms is the environment. Infrared thermography is based on measuring the heat radiated by the body in the infrared spectrum and the subsequent conversion of these vibrations into an electrical signal [24]. Infrared thermography does not imply a direct measurement of temperature, since the thermal imager determines only the energy of thermal radiation. The camera captures the radiation of the target object, as well as the radiation of its surroundings. Both of these radiation components are attenuated as they pass through the atmosphere. Therefore, the main problem is matching the detector's response curve to what is called an atmospheric window, namely, the range of wavelengths of infrared radiation that pass through the atmosphere with slight attenuation [25].

Infrared thermography is based on fundamental physical laws [26]. For a physical body, the energy emitted in the infrared region per unit surface area per unit time (emissive power) is determined by the total radiation power and depends on the body's temperature in kelvins. This can be seen from Equation 1 below [27]:

$$E = \varepsilon \, \sigma \, T^4, \quad (1)$$

where σ (the Stefan–Boltzmann constant) is $5.67 \cdot 10^{-8}$ W·m^{-2}·K^{-4}, and ε is emissivity. For a perfect blackbody, ε = 1. The emissivity of the human body equals 0.98.

The camera captures both the heat radiated by the body and that reflected by it (*Eq.* 2). To determine the surface temperature of the body, it is necessary to determine the value of the reflected temperature (*T*) (*Eq.* 3):

$$E_{received} = \varepsilon \, \sigma \, T^4 + (1-\varepsilon) \, \sigma \, T^4_{reflected}; \quad (2)$$

$$t = \{[\, E_{received} - (1-\varepsilon) \, \sigma \, T_{reflected}] \,/\, \varepsilon \, \sigma\}^{1/4}, \quad (3)$$

where *T* is the surface temperature and σ equals $5.67 \cdot 10^{-8}$ W·m^{-2}·K^{-4}.

As can be seen from the equations above, small temperature fluctuations change the body's thermal radiation power, which affects both the analysis and the interpretation of thermograms. However, qualitative and quantitative changes in temperature distribution indicate the radiation's abnormality [27]. Therefore, for the application of infrared thermography in the Arctic conditions, both technical and methodological aspects of the method should be clear.

The impact of cold climatic conditions on the local population is closely related to such physiological phenomena as shivering, hypothermia and circadian rhythms.

Shivering. Shivering causes particular discomfort to non-indigenous residents of the Arctic, which can affect the results of infrared thermography. This factor is extremely important as many scientists note that the subjects of research can shiver at low ambient temperatures [17, 28–30]. Shivering is a protective mechanism allowing heat transfer to take place through frequent involuntary muscle contractions, compensating for the lowered body temperature in a healthy living organism. At the molecular level, the mechanism of reflex protection against cold is activated when the low temperature is perceived by the preoptic nucleus of the hypothalamus [31]. The neurological mechanism of shivering is mediated by spinal alpha motor neurons and their axons [32]. Heat production through shivering is a major component of thermogenesis during body cooling. This thermoregulatory mechanism in humans is, as a rule, well adapted to heat dissipation in hot climates, but, at the same time, is poorly adapted to its preservation in the cold [33].

Shivering is related to cold-induced thermogenesis (CIT) [34]. When people are exposed to cold, they exhibit two basic types of physiological reactions in order to maintain their internal temperature. Firstly, they can rely on the body's thermal insulation properties, regulating blood flow to control heat loss; secondly, they can increase their energy consumption 3–5-fold compared with the state of rest [35] in order to counterbalance the cold-induced heat loss [34]. Furthermore, this condition can be triggered by hypothermia [36–38].

Hypothermia. Fluctuations in ambient temperature can lead to hypothermia, which can result in inaccurate diagnosis using thermography. Since shivering can provoke a 5-fold increase in energy consumption, it is the main mechanism for counteracting hypothermia and ensuring human survival in conditions of extreme cold [36–38]. As is well known, the human body is designed to maintain homeostasis under changing environmental conditions. Humans produce or release heat through thermoregulation mechanisms to protect themselves from extreme heat or cold.

During cold weather, the body loses heat faster than it is generated, which consumes the stored energy and can lead to hypothermia, defined as the core temperature of the body below 95 °F (35 °C) [39].

Hypothermia leads to vasoconstriction and an increase in blood viscosity, an increase in the load on the cardiovascular system similar to overheating [38]. In other words, this additional strain on the heart is combined with many other problems, including increased sensitivity of the heart muscle, which can lead to dysrhythmia [40]. Hypothermia is often a symptom of other diseases; for example, some systemic infections disrupt thermoregulation and allow hypothermia to develop even in the warm season [41].

Other than that, infrared thermography also plays an important role in assessing inflammatory processes [42]. Inflammation leads to hyperthermia, while degeneration, decreased muscle activity and poor perfusion can cause hypothermia [43]. It was found that in the area of inflammation, despite the decrease in the intensity of most chemical processes, the intensity of the separated processes of cellular respiration and phosphorylation can increase. As a result, the temperature of the inflamed area will be higher than that of the surrounding tissue [44]. Therefore, we can say that changes in the normal temperature distribution are a sign of a pathological process [45]. This fact should be taken into account when interpreting thermograms [27].

Circadian rhythm. When researching in the Arctic, it is important to consider the circadian rhythms of body temperature fluctuations. Light of sufficient intensity is the main factor supporting the 24-hour period of human circadian rhythms [46]. Therefore, life in long day and night conditions can cause problems with sleep, mood, and productivity in people living in the Arctic [47]. It has been shown that skin temperature changes throughout the day. In the Arctic, people lack natural sunlight in the winter and have an excess of it in the summer. In the evening, the temperature of the body's core and proximal skin areas increases compared with distal areas; the opposite effect can, apparently, be observed in the morning [48]. Intensive insolation, excess sunlight in the summer and the predominance of darkness in the winter are some of the many problems that arise when conducting research in the Arctic. For most subjects, recordings should be made at the same time of the day and during the same season to make successive group comparisons possible.

Some studies claim that people living in the subarctic climate may experience more seasonal fluctuations in sleep patterns than those living closer to the equator [49, 50]. During the winter, newcomers are often limited in mobility and experience desynchronization of sleep and circadian rhythms, which impairs their cognitive function. Changes in circadian rhythms are also associated with fluctuations in melatonin secretion depending on the length of the day [46]. Since there is no data that could explain the level of melatonin in various people, both indigenous and non-indigenous, it can be assumed that it depends on the ability to adapt to extreme cold, length of the day and, sometimes, to prolonged physical inactivity. This indicates that changes in the circadian rhythms of both permanent and temporary residents of the Arctic may affect the interpretation of the obtained thermograms.

Conclusion. In studies using infrared thermography in the Arctic, it is necessary to take into account such physiological phenomena as shivering, hypothermia and the circadian rhythm of human body temperature, which are associated with the influence of climatic and geographical factors of the Arctic region.

Conflict of interest. Authors declare no conflict of interest.

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DOI: 10.17238/issn2542-1298.2020.8.1.89

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INFLUENCE OF SHIVERING, HYPOTHERMIA AND CIRCADIAN RHYTHMS ON THE FEATURES OF RESEARCH USING INFRARED THERMOGRAPHY IN THE ARCTIC (Review)

This article examines environmental factors typical of the Arctic regions that affect the results of thermographic studies, thereby limiting their range of application. Minor temperature deviations cause changes in radiation from the surface of the body and, thus, affect the analysis and interpretation of thermograms. What is more, to apply infrared thermography to measure the temperature of biological objects, it is necessary to understand the method's technical and methodological features. At the same time, for research involving the local population, it is important to take into account changes in skin temperature under the influence of environmental factors. Geographically, the Arctic regions include Canada, Greenland, Iceland, Norway, Sweden, Finland, Alaska and northern areas of Russia where cold climate prevails. Cold climate, adverse weather conditions and long winter nights are among the many factors impeding investigations in the Arctic. For physiological research, it is important to consider ambient temperature as a factor affecting the quantitative assessment of the individual characteristics of the participants and adapt the resulting knowledge to complement student training programmes. This review focuses on shivering, hypothermia, and circadian rhythms as the effects of environmental factors that may influence the use of infrared thermography for research on physiology in the Arctic.

Keywords: *body temperature, infrared thermography, shivering, hypothermia, circadian rhythms, Arctic.*

Поступила 25.03.2019
Принята 20.10.2019
Received 25 March 2019
Accepted 20 October 2019

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For citation: Nasution A.I., Pankov M.N., Kir'yanov A.B., Startseva L.F. Influence of Shivering, Hypothermia and Circadian Rhythms on the Features of Research Using Infrared Thermography in the Arctic (Review). *Journal of Medical and Biological Research*, 2020, vol. 8, no. 1, pp. 89–98. DOI: 10.17238/issn2542-1298.2020.8.1.89