

Surviving the Cold: How Circumpolar Peoples Have Adapted to the Extreme Conditions of the Arctic

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Contents

SUMMARY	3
Introduction	4
Circumpolar overview	4
Overview of the World Regions.....	4
Divisions of the Arctic.....	5
Characteristics of the Four Seasons	6
Sleep Habits	6
Flora and Fauna	7
Ice age perspectives	7
Ice Ages	7
Neanderthals.....	8
Cold-Climate Adaptations	10
Morphological	10
Physiological.....	11
Insulative.....	11
Hypothermic	11
Metabolic	12
Cultural	13
Discussion	14
REFERENCES	18

SUMMARY

The Arctic is a place characterized by extreme seasonality and frequent cold exposure due its distinct environment and its location with respect to the sun. Many consider it a terminal environment verging on the limits of what is physiologically possible; yet four million people still reside here owing in large part to their multitude of adaptations— morphological, physiological, and cultural. For example, researchers have pinpointed characteristics like higher basal metabolic rates, the use of brown adipose tissue (BAT), and decreases in respiratory rate as evidence of how the Inuit and other native populations have endured the extreme conditions and climates of the Arctic. While many studies have identified numerous adaptations, little have connected them to another intriguing phenomenon: human hibernation, which could have revolutionizing effects for not only those wishing to survive the Arctic but also for those wishing to embark on long, deep space voyages in the future. Many characteristics of hibernation are common in other mammals and can be found in human populations like the Inuit's, who live in environments that would indeed induce hibernation in its mammalian relatives such as the polar bear, which enters a state of dormancy and hypometabolism for about four months during the winter. By examining how Arctic populations have adapted to the cold in a variety of ways, implications for the possibility of human hibernation can be made and its potential assessed.

INTRODUCTION

Cold exposure varies across the world. In places like America, which are located mid-latitude, this exposure primarily manifests in the winter. On the extremes, there are places like the Tropics, located near the equator, which have very minimal cold climates; therefore, little need for any cold adaptations. In contrast, such cold exposure is inevitable in the Arctic and typically lasts all year long. Indeed, it is not uncommon to find temperatures as low as -40°C . Understanding the prevalence of such conditions reinforces the need for Arctic people to develop and acquire cold adaptations.

Enduring such a climate presents many challenges and it can cause a lot of stress and damage on the body. Mäkinen (2007) detailed such effects, noting that it begins with pain in the forearms and progresses to respiratory, cardiovascular, and musculoskeletal symptoms. Moreover, cooling severely impairs cognitive and physical performance by increasing thermal discomfort, triggering or aggravating symptoms of chronic diseases, and causing injuries like frostbite and hypothermia.

Indeed, cold exposure and the associated cooling can have disastrous consequences on the body even leading to mortality and lower life expectancies. Young & Mäkinen (2010) even write how every 10°C increase in mean January temperature in the Arctic increases life expectancy by six years and decreases infant mortality by 4 deaths/1,000 live births. Such studies reinforce the notion that warmer temperatures yield better health outcomes. With their reduced access to healthcare and other basic life services, circumpolar peoples must find creative ways to adapt not only culturally but physiologically and morphologically as well.

The purpose of this paper is to examine the cold adaptations that circumpolar peoples exhibit in order to assess the potential for human hibernation. Human hibernation is a novel phenomenon whereby humans enter a hypometabolic state, permitting them to preserve their bodies for long periods of time especially during extreme cold conditions. This research paper will show that many strides are being made to induce a torpor-like state in humans; consequently, making human hibernation a real possibility.

Additionally, the focus on circumpolar people will demonstrate that such a phenomenon is necessary and will greatly increase survival by expanding on their already advanced cold adaptations, which include: higher basal metabolic rates, the use of brown adipose tissue (BAT), decreases in respiratory rate, sophisticated clothing, and new technologies. With cold exposure not waning anytime soon, circumpolar peoples will have to continuously adapt, and human hibernation presents a promising horizon for such endeavors in the future.

CIRCUMPOLAR OVERVIEW

Overview of the World Regions

Many organizations divide the world into varying number of regions, oftentimes, to serve a specific purpose. For example, the United Nations acknowledges eight world regions—Sub-Saharan Africa, Oceania, Europe & North America, Australia & New

Zealand, Central & Southern Asia, Eastern Asia, Northern Africa & Western Asia, and Latin America & the Caribbean—to better coordinate policy and representation. The Arctic region, itself, is typically excluded from such delineations since many of its lands lie on the outskirts of continents and countries that, themselves, have already been classified elsewhere.

While this may be true, many definitions of the Arctic exist; consequently, allowing researchers to generate studies at that location. In simplest terms, the Arctic is the land and sea north of the Arctic Circle (Figure 1). More specifically, above 60°N latitude (Young & Mäkinen, 2010).

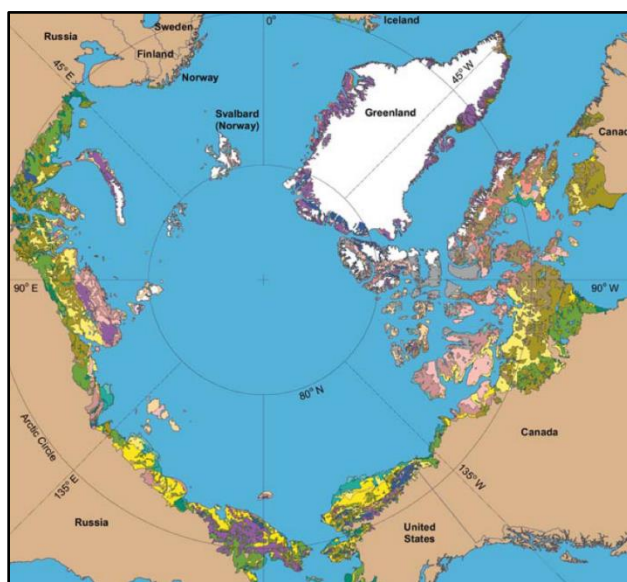


Fig. 1. A Map of the Arctic Region (Adapted from Walker et al., 2005)

Divisions of the Arctic

Since Arctic lands are scattered across numerous continents, it is not uncommon to find circumpolar areas distinguished upon such lines. Many classify the Arctic into two regions—the European Arctic and North American Arctic—with some even acknowledging a third Asian Arctic.

The European Arctic consists of Finland, Norway, Russia, Iceland and Sweden. Because of their close proximity to central Europe, many of these countries interact frequently with the European Union. For instance, between 2014-2020, the EU gave Finland and Sweden 1 billion euro for its Jobs and Growth Program (Stepień et al., 2021). This shows that people living in the European Arctic enjoy an intricate relationship with Central Europe, which is vital for their livelihood since the investments benefit 70% of the four million people that make up the Arctic (Allen et al., 2017)

While it seems like an Asian Arctic should exist given its geographical relationship with Europe, the opposite is true. Such a distinction has never been adopted

since Asian countries do not actually possess land in the Arctic; however, this has not stopped researchers from trying to establish this division. For instance, Bennett (2014) argued that such a classification should exist given Asian countries' heavy investment in the region. Countries like Japan are building necessary infrastructures that are heavily impacting polar-identity building. Indeed, despite the Asian Arctic's nonexistence in the literal sense, circumpolar people still enjoy the many benefits and opportunities offered by the presence of Asian countries in the Arctic.

Finally, many acknowledge the presence of a unique North American Arctic, which consists of: Alaska, Canada, and Greenland (Daniels et al., 2000). For the most part, these regions interact with the governments of their respective countries except for Greenland, who also interacts continuously with the EU.

Regardless of these classical divisions, all the countries mentioned above comprise the Arctic Council, an intergovernmental organization created to address the issues faced by Arctic governments and their peoples. Since the Arctic is rarely categorized as a world region, this forum is crucial to protect the agency of those living in the Arctic, and it helps the rest of the world put a face to a geographical region that would otherwise have no formal representation.

Characteristics of the Four Seasons

One of the most unique features of the Arctic is its extreme seasonality with long, dark winters and short, bright summers. For example, in Barrow, Alaska, there is light all day from mid-May to August and then a long, period of darkness from mid-November to January (National Geographic, 2011). As a result, people typically only consider two seasons in the Arctic: summer and winter.

On the contrary, places located mid-latitude, like most of the United States, experience all four seasons. Consequently, this means animals and humans alike, do not have to adapt to extreme cold or darkness because of their temperate climates. Interestingly, places near the equator only exhibit one season: summer. This means they experience warmth all year-round, which is in direct contrast to the Arctic, who experiences cold climates even in the summertime.

Sleep Habits

As a result of this extreme seasonality and variation in photoperiods, circumpolar people experience a lot of sleep problems especially in the winter, when constant darkness is routine. During this period, the absence of light removes a crucial zeitgeber, an external cue that synchronizes an organism's biological rhythm to a 24-hour light/ dark period. Consequently, fatigue, negative sleep quality, and insomnia ensue (Friborg et al., 2014). Moreover, delayed circadian rhythms have been found to be associated with seasonal affective disorder (SAD) as well as risk factors for heart disease and cancer (Arendt, 2012).

Although sleep delay and internal desynchrony is paramount in the winter, it seems like circumpolar people sleep more during this season than in the summer. Lubas et

al. (2019) examined the relationship between sunlight exposure and sleep outcomes in workers at a base camp in Alaska, and through actinographs and surveys, they found that workers sleep 102 minutes less when exposed to longer daytime light. Moreover, Paul et al. (2015) corroborates such a finding, noting how evening light exposure delays melatonin production; consequently, leading to insufficient sleep and later bedtimes. Melatonin is a hormone that induces tiredness at night; thereby, promoting sleep onset.

Essentially, these studies suggests that circumpolar people sleep longer when evening light is absent or limited, and such a condition is met in the winter season. While the quality of sleep may decrease, the increasing duration implies that Arctic people can decrease their metabolic activity for longer periods of time in response to environmental changes. Such a decrease parallels the dormant state that mammals enter when they hibernate—especially those who hibernate during the winter. Although more studies need to be done, clearly, the foundation for human hibernation does exists and this is due, in large part, to the effects caused by extreme seasonality.

Flora and Fauna

There are approximately 21,000 species of animals and plants living in the Arctic, all of whom are cold-adapted to deal with the environmental conditions present (Taylor et al., 2020). Many species accumulate in the low artic, regions that have remained unglaciated during the last ice age. More specifically, they can be found in terrestrial, marine, and freshwater ecosystems like marshes, lakes, and ponds. Some notable species of fauna include polar bears, reindeers, whales, seals, and caribous. To add on, notable species of flora include mosses, lichens, shrubs, and hemicryptophytes.

Unsurprisingly, less than 10% of species present are endemic to the Arctic (Daniels et al., 2000). For the most part, many species are migratory, only coming to the Arctic during the summer, when the sun is above the horizon all day long. Migration allows many species to avoid the bottleneck caused by the low productivity and high thermal costs associated with the winter season (Studd et. al, 2021). Additionally, it helps expand genetic diversity across all the Arctic and, at the same time, allow for animals to avoid glacial disturbances that may arise (Chapin, 1995). Regardless of whether or not species intend to stay all year round, they must be cold adapted with a heavy coat of fur or short extremities. Biologically, hibernation, antifreeze compounds, and asexual reproduction may also be in their repertoire (Taylor et al., 2020).

ICE AGE PERSPECTIVES

Ice Ages

Ice Ages are periods when the temperature of Earth's surface reduces, resulting in the expansion and creation of polar ice sheets and glaciers. To this date, there have been five major ice ages in Earth's history that have been recognized: the Huronian, Cryogenian, Andean-Saharan, Karoo, and Quaternary. Today, Earth is present in the Quaternary period, which began 2.6 million years ago (mya). To be more precise, it is in the Holocene epoch or interglacial period. Interglacial periods are smaller time courses within a larger

ice age where solar radiation peaks, causing glaciers to retreat. Its antithesis, glacial cycles, are time courses where glaciers advance. In a typical epoch, both interglacial and glacial periods can exist but not at the same time.

Regarding the Quaternary period, there are actually two epochs, the Holocene and the Pleistocene (Ehlers et al., 2014). The Pleistocene began earlier approximately 2.6 million years ago, and it lasted until the beginning of the Holocene, which many researchers have traced back to 11,700 years ago using ice cores in Greenland (Walker et al., 2009). Interestingly, there was a glacial cycle, referred to as the Last Glacial Maximum (LGM), that occurred towards the end of the Pleistocene 100,000 years ago. This cycle was responsible for extensive glaciation in areas located in high latitudes like those countries belonging in the Arctic and areas mid-latitude like Europe (Ehlers et al., 2014). Generally, when glaciers and icebergs begin to melt especially during interglacial periods, ocean circulation patterns change, pulling in more carbon dioxide, and slowly pushing the Earth back into ice age conditions (Bishop, 2021).

While humans today may enjoy the warmth that comes with its interglacial period, previous human populations like the Neanderthals were not as lucky. They lived in the thick of the glacial cycles and were forced to endure the extreme conditions and cooling that came with it. By detailing these glacial-interglacial cycles, one can begin to understand the onerous conditions that characterized the environment of past humans.

Neanderthals

One such past human population that demands specific interest is the Neanderthals, a human population that shares a most recent common ancestor with modern day humans. They arose 300,000 years ago and inhabited the majority of Western Eurasia. This means their existence coincided with the Pleistocene, more specifically, the LGM— a period in the Pleistocene where glaciers advanced and covered a large surface area of Earth. Such a phenomenon yielded numerous challenges. For example, as the cold increased, animals began to increase in size, which made hunting injuries more prevalent. Additionally, resources at higher latitudes became unreliable, environments deteriorated, and 30-40% of megafauna became extinct (Spikins et. al, 2018). All these factors and more contributed to conditions like famine, which ultimately led to increased mortality along with a decline in adult life expectancy. Clearly, the cold impacted Neanderthals in more ways than one, demanding that they find effective ways to adapt.

Morphologically, Neanderthals had a large volume-to-surface area ratio culminating in broader bodies and shorter limbs with the sole purpose of reducing heat loss and maximizing heat production (Ocobock et. al, 2020). For instance, they had tall and narrow noses to increase mucosal surface area, which enhanced their ability to warm air. Additionally, Neanderthals exhibited greater muscle mass and skeletal bone robusticity, which enhanced their thermoregulatory abilities, allowing them to reduce their “susceptibility to cold-related injuries” (p. 266).

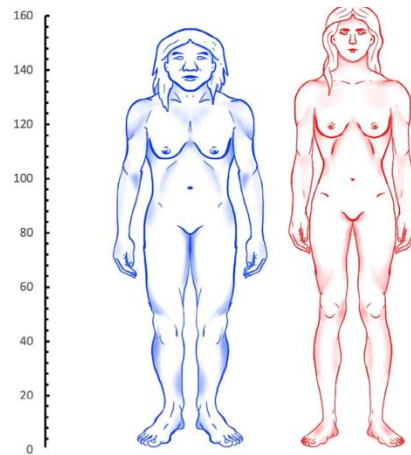


Fig. 2. A Comparison of a Neanderthal female (blue) and a Modern female (red) with a scale of height in centimeters on the left. (from *Ocobock et al., 2020*)

Physiologically, Neanderthals expressed high total energy expenditure (TEE), a phenomenon created by two other physiological variables. Those being basal metabolic rate (BMR), which is the minimum number of calories burned needed to stay alive, and physical activity levels (PAL) (Ocobock et. al, 2020). Neanderthals had high levels of both, which allowed them to maintain high body temperatures in the wake of their cold, harsh climates. BMR, in particular, clearly contributed to heat production as its value increased by 20% in the winter compared to the summer. On the other hand, PAL was more related to poor locomotor efficiency, a consequence of the unkind terrain, which increased metabolic cost. As a result of this, there was increased heat production, TEE, and the aforementioned morphological adaptation of broader bodies.

While it is true that all these variables contributed to the Neanderthals' physiological survival, recent literature suggests an additional mechanism— hibernation. The pioneers of such a theory are Bartsiokas and Arsuaga (2020), who were able to find diseases in the skeletal remains of 29 Neanderthals in Atapuerca, Spain that correlated with those present in hibernating species. Such diseases include: chronic vitamin D insufficiency, renal rickets, hyperparathyroidism, and the formation of rachitic osteoplaques and hibernational zones of arrested growth (HZAGS). Both authors emphasize HZAGS as the conclusive evidence of Neanderthal hibernation because such a condition is diagnostic of animal hibernation and suggest bouts of arousal from torpor.

Undoubtedly, Neanderthals adapted in a variety of ways. Though they excelled morphologically and physiologically in their given environment, they failed to adapt culturally, and this became a contributing factor in their extinction. Gilligan (2007) suggests that Neanderthals relied too heavily on biological adaptations instead of pre-adaptation through things like clothing. For example, they wore simple garments created out of Mousterian technology (i.e. scraper tools), which were only 1-2 clo. Clo is a unit that describes the thermal resistance of clothing with lower scores indicating weaker resistance. In contrast to Neanderthals, modern day humans wear complex garments that

need to be sewn, cut, and pierced. These are 4-5 clo in comparison. Additionally, Neanderthals were not obligate fire users possibly due to the costs of maintaining fires and how conspicuous it was (Ocobock et. al, 2020).

Indeed, Neanderthals lacked a lot of specific cultural adaptations, but they did develop some that were beneficial. For example, things like close-knit groups and collaborative social structures allowed them to be more effective hunters as they could stalk and kill big game like mammoths, rhinoceros, and bison. Spikins et. al (2018) even proposes that such interdependence contributed to things like healthcare, which became an important aspect of daily life. Care in the form of fever management and medicinal plants were collaborative efforts to reduce mortality and preserve knowledge to the next generation. Likewise, such collaboration extended into parenting, defense, and social learning. Although this sort of cultural adaptation was important for their success, Neanderthals' lack of innovation when it came to clothing and their heavy reliance on their biology hurt them in the long run as they could not adapt in time to the changing conditions and constant temperature fluctuations in the late Pleistocene.

COLD-CLIMATE ADAPTATIONS

Modern humans originated 200,000 years ago out of Africa. After aridity encapsulated the region, they dispersed across the globe, concentrating in places like Europe and the Americas, located mid to low latitudes (Harcourt, 2016). Other places like the Arctic, located at high latitudes, were not so popular due to the stress and physical toll the cold exerted on the human body. Nonetheless, generations of people have called it home. While it may seem impossible that people could endure such a climate and condition, a look into their abundance of adaptations reveals why circumpolar people are so remarkable and fine-tuned to the Arctic.

Morphological

Contrary to popular belief, circumpolar people do not have unique morphological adaptations in comparison to other modern-day humans. This means that people everywhere today will tend to possess the same build and frame no matter where they are in the world.

According to Tattersall (2009), Homo Sapiens have a light frame with a slender thorax and a narrow pelvis. Moreover, their skulls are short in length and balloon-like, contributing to a small facial skeleton in comparison to the wider face seen in the Neanderthals. Granted that such adaptations would not help against the cold per say, Tattersall demonstrates that our cranial distinctions allowed for the reorganization of our brains, which helped us develop symbolic thinking. Symbolic thinking is the ability to envision new possibilities by decomposing the world into symbols, which can be represented in language, drawings, and technologies.

While archaic humans had biological potential for such thinking, they never refined it as evidence in their lack of art and personal ornamentation (Harvati, 2010). Consequently, this attests to the theory that Neanderthals were very stagnant and

uncreative. For example, they never learned to develop new technologies; instead, they were controlled by nature's rhythms and chose to migrate when the climate got too difficult. On the other hand, *Homo Sapiens* learned to craft new technologies directly against external stimuli. They chose to go at their own pace and not that of the environment.

For this reason, *Homo Sapiens* began to develop a sedentary lifestyle, cultivating plants and domesticating animals. This led to an explosion in technology as tools were needed to exploit environmental resources. Unlike the Neanderthals, who were hunter-gatherers, modern humans felt no responsibility to the environment and were intent on dominating it. By finding ways to adapt culturally and physiologically, modern humans did not have to morphologically change and adjust their appearance in accordance with their settings. In other words, this means circumpolar people will look morphologically like any other person in the world.

Physiological

In response to the cold, humans can either habituate or acclimate. Habituation is normally reserved for repeated cold exposure that does not involve whole-body cooling. Mäkinen (2007) notes that habituation entails reduced shivering, vasoconstriction, and stress responses. On the other hand, acclimation is a more sophisticated mechanism in response to whole-body cooling. It involves three possible responses: insulative, hypothermic, and metabolic. Unsurprisingly, circumpolar people tend to perform the latter because of their long bouts enduring the cold, while other modern humans only habituate given that their cold sensations are short-lived and mainly reserved for a season.

Insulative

Insulative responses involve increasing the amount of insulation in response to minor cold stress. This mechanism focuses on increasing vasoconstriction to decrease skin temperature whilst maintaining a stable internal temperature (Saltykova, 2018). In doing so, heat loss is minimized, and thermal insulation increases by 0.5-0.65 clo. The only drawback with this response is that it is only effective above a threshold of 26-27°C when vasoconstriction is maximized. Below that point, this response becomes ineffective. Since many circumpolar people live in drastically colder climates, this response is inadequate and only reserved for populations like the Aboriginals, off the coast of Northern Australia, who endure a 25°C temperature year-round with occasional strong winds.

Hypothermic

Hypothermic responses involve decreasing the internal body temperature in response to intermediate cold stress or stress higher than that required for an insulative response. This mechanism is associated with food intake since starvation can limit sympathetic nerve activation and subsequent reactions on cooling (Saltykova, 2018). In other words, a lack of sufficient nutrients can have significant cooling effects that can later trigger a metabolic response, which will help create more heat. This response is

characteristic of people like the Kahlari and Quecha who live in the Andes Mountain and endure nocturnal temperatures of 0°C.

Metabolic

Metabolic responses involve increasing the level of heat production in response to a powerful cold stress. It does not affect internal body temperature or the degree of thermal insulation present. There are three main mechanisms by which this response occurs: muscle uncoupling of oxidative phosphorylation, contractile activity, and inefficient cellular pumps.

Oxidative phosphorylation is a biological process to produce energy from oxygen breathed in from the environment. Brown adipose tissue (BAT) is the main substance responsible for uncoupling respiration. By increasing the synthesis of the thermogenin, an H⁺ transporter, BAT can indirectly accelerate respiration while decreasing the substrates sent to ATP synthase (Saltykova, 2018). Consequently, the decrease in ATP production means energy can be dissipated as heat instead. It is important to note that this mechanism contributes to thermogenesis only when there is minor cooling with no reduction in internal temperature. This means that BAT's ability to produce heat is largely restricted.

In contrast, muscle contractile activity is much less constricted and is considered the main source of regulated heat production in humans. It involves thermoregulatory muscle tone or rapid and irregular contractions of muscle fibers that can increase heat production by 15-50% through the increase of oxygen consumption (Saltykova, 2018). If cooling persists, this tone becomes the common phenomenon known as shivering, which increases heat production by 200-250%. However, such increases also lead to a loss of 50% of the heat produced because of an increase in peripheral blood flow. To counteract this heat loss, people can decrease their respiratory rate and pulmonary ventilation while also increasing their duration of exhalation and alveolar surface.

With muscles affecting respiration and BAT affecting the number of substrates needed to create ATP, there needs to be molecules that help with the uncoupling process by affecting the proton gradient. These molecules are free fatty acids. As fatty acids accumulate in the body, proton conductivity increases. This means that the proton potential can be disseminated as heat much to the satisfaction of brown fat, which wants to do the same thing.

Moreover, it is important to note that the concentration of free fatty acids is induced by noradrenaline, which activates lipoprotein lipases (Saltykova, 2018). As cold adaptation continues, the ability of noradrenaline to activate respiration through free fatty acids will increase, causing shivering to decline as it becomes less necessary. Noradrenaline is also crucial for decreasing the efficiency of pumps. By increasing the production of thyroid hormones, it helps increase the leakage of positive cations (Na⁺, K⁺, Ca²⁺) and the activity of ion pumps (Ca²⁺-ATPase and Na⁺/K⁺-ATPase). In turn, this increases the proportion of energy that can be dissipated as heat.

In summary, brown fat increases heat production indirectly with the help of thermogenin and free fatty acids; muscle contractions increase heat production by affecting respiration; and noradrenaline increases heat production by creating free fatty acids and decreasing the efficiency of pump. Indeed, the plentiful mechanisms and the wide range of cold exposure events underlying the metabolic response makes it the ideal physiological adaptation for circumpolar peoples.

Ironically, this response leads to a result, which parallels one of the Neanderthals' cold adaptations: an increase in basal metabolic rate. Certainly, this attests to some conservation on the circumpolar peoples' part. Leonard et. al (2002) describes how such an increased capacity for BMR elevation is what definitively separates Arctic populations from non-Arctic populations and is what allows for the former to have more success than the latter in colder environments. The authors go on to detail how circumpolar peoples have an increased sensitivity to thyroxine (T4) levels, which peak in the winter and are the main effectors involved in increasing BMR. Surely, these distinctions should come as no surprise considering how much more prominent and demanding the cold is in the Arctic—rendering anything less of a metabolic response inadequate for survival.

Cultural

While the survival of circumpolar peoples can be attributed to their physiology, their cultural adaptations are equally as important. Compared to past human populations like the Neanderthals, modern-day humans are much more advanced in their ability to adapt behaviorally to any environment, and this is seen especially with those living in the Arctic.

As mentioned previously, modern day humans were able to create complex and fitted garments, which were more difficult to make but provided more thermal insulation (Gilligan, 2007). Unsurprisingly, circumpolar populations like the Inuit still heavily rely on fitted clothing today made from animals like reindeers. In comparison to Neanderthals, the Inuit also have greater fire control through their development of structured hearths, better artificial shelters, and greater residential sedentism. All these factors attest to the lack of need for morphological adaptations.

Despite these differences, the Inuit and Neanderthals also share similarities primarily their value for collaboration. As a result of the cold and fluctuating food supply, circumpolar people tend to create social safety nets. For example, they create systems to share food to reduce the risk of unsuccessful hunts (Ocobock et. al, 2020). Alliance and community are heavily valued to reduce the potential for events like famine or even more abstract phenomenon like hysteria and boredom caused by the long winters.

Moreover, circumpolar people also eat a lot of protein and fat like their Neanderthal relatives. They typically follow a more traditional diet consisting of mostly fresh fish, reindeer, and wild plants (Andronov et. al, 2021). According to Leonard et. al (2005), protein accounts for 26% of the energy in northern indigenous groups, with fat being 34-36% or 79-90 grams per day. On the contrary, people like Americans consume a

lot more fat along the lines of 95 to 68 grams per day but since their animals are feedlot and fattened most of this fat is saturated. This diet plays a large role in reducing the number of diseases and conditions that affect circumpolar peoples.

People who consume a western diet typically have a lot more chronic degenerative diseases than those who consume a more traditional hunter-gatherer diet. Carrera-Bastos et. al (2011) describes how a Western diet consists of high cereal, which can lead to vitamin D deficiency and a subsequent increase in the incidence of cancer. Additionally, the use of vegetable oil and refined sugars can cause micronutrient deficiency, increasing the risk of cardiovascular disease. On the other hand, high-protein diets, characteristic of circumpolar people, improves insulin sensitivity and hypertension. While it is true that Arctic populations follow a sedentary lifestyle and not a hunter-gatherer one, their unsaturated and high-protein diet still resembles those of the archaic populations before them. Consequently, this proves beneficial as it reduces the risk of accumulating degenerative diseases.

Interestingly, circumpolar populations like the Inuit have one of the highest BMIs in the world mainly due to their high intra-abdominal fat. Young et. al (2007) notes that 15.8% of Inuit men are obese with 36.6% being overweight and for Inuit women, 25.5% are obese with 32.5% being overweight. Although these numbers sound alarmingly, at each level of BMI, the Inuits have a lower level of risk factors than non-Inuit populations. For example, they have lower blood pressure and lower levels of glucose, insulin, and triglycerides (Galloway et. al, 2012). This attests to the many benefits of their high-protein diet.

Additionally, the Inuits' high levels of fat also serves as an adaptation to the cold since fat has insulative properties and will store the fuel needed for heat production. Analogous to circumpolar peoples, bears typically eat a lot of fat as well especially in the winter before entering hibernation. Fat helps them retain water for the digestion of proteins in a season where ice makes water inaccessible (Studd et. al, 2021). It is quite possible that the Inuits are doing the same. Their increasing trend of obesity may simply be a result of cold adaptations but may also reflect their preparations for the coming winter seasons.

DISCUSSION

Indeed, circumpolar people are well-adapted to survive the harsh and cold climate of the Arctic. However, what happens when these adaptations are not enough? How can one maintain their metabolic responses or even cultural adaptations when food becomes scarce, and people lack substrates to even initiate a sufficient cold response? In other words, what happens when the cost of maintaining heat production exceeds the available energy in the environment? This is the question that scientists have yet to answer, but recent literature suggests that a new possibility may exist for survival: human hibernation.

Hibernation is a form of seasonal torpor that occurs in the winter. Torpor is a biological process; whereby, the body temperature is reduced below 15-20°C. Such a process is characteristic of many endotherms like echidna, dasyurids, lemurs, hedgehogs, bats, and bears (Zancanaro et. al, 2004).

There are typically three stages associated with torpor: entry, torpor itself, and arousal. Before entering torpor, heart rate is inhibited, vasoconstriction increases, respiratory rate decreases, and body temperature begins to fall (Zancanaro et. al, 2004). During torpor, physiological mechanisms are minimized and heart rate as well as oxygen consumption decrease well below their euthermic or heat-producing levels. ATP production is decreased as well because of substances like BAT, and body temperature is relatively stable but, below a critical level, arousal or death may ensue. After torpor, arousal can occur resulting in substrates being mobilized and the cardiovascular system being stimulated in a very explosive process that takes minutes to hours. At the end of the process, animals can hopefully wake up in an environment that has enough food for them to maintain their heat production mechanisms.

While torpor may exist in some mammals, is it actually possible for humans or is all of this conjecture? Currently, humans can control their body temperature, but is it possible to move up the energy metabolism ladder and control hypometabolism to induce hibernation?

Although there are different opinions, the literature suggests that a hypometabolic state can be induced in humans. According to Lee (2008), the discovery of 5'-AMP may offer a solution as it allows for nonhibernating animals to enter severe hypothermia (28°C or lower). In experiments where this metabolic inhibitor was put into mice, their procolipase expression increased, resulting in a severe hypothermic state where their metabolic activity dropped drastically; their internal temperature fell to 25°C; and their heart and respiratory rates dropped as well. Procolipase is a biomolecule that turns dietary fat into fatty acids. It is typically high in mice kept at constant darkness, where hibernation is said to occur. In fact, mice who are exposed to 12:12 hour light-dark cycles have little procolipase expression. Although the addition of 5'-AMP has only been done in mice, the experiments shows that it is definitely possible to induce severe hypothermia, hence torpor, in non-hibernating mammals.

Along the same lines, Choukér et. al (2021) discussed how stimulating Q-neurons could also provide a means for inducing a hypometabolic state. Q neurons originate in the dorsomedial hypothalamus (DMH) and project to the Raphe Pallidus (RPa), a key relay station that tells effectors in the body when to perform thermoregulatory functions. In experiments performed on mice, scientists discovered that agonists like clozapine-N-oxide (CNO) could stimulate receptors on Q-neurons, resulting in the suppression of thermogenesis and other metabolic depressions related to variables like respiratory rate. These variables resulted in mice entering a hibernation-like state despite their classification as a non-torpor species. While this agonist has not been tested on humans, their early success in mice suggests that hypometabolism is possible in non-hibernating

species, and scientists have begun identifying possible targets that could induce such a phenomenon.

There are many other hypothesized mechanisms for inducing hypometabolism. Zancanaro et. al (2004) suggests that one can try to reduce the overall body temperature by targeting thermosensitive neurons or developing drugs like Merpidine that can inhibit shivering and the additional heat production that comes with it. To add on, supercooling in the form of cryoprotective carbohydrates in the blood stream could improve survival during hypothermia. Interestingly, hypoxia, a deficiency in oxygen, can result in decreased metabolic rate and depressed thermogenesis in newborn mammals including humans. For clear ethical reasons, this mechanism has not been tested further but scientists suggest hypoxia can only affect hibernation in amphibia and reptiles.

Finally, there is an area of literature that believes humans possess genes specific to hibernation. The expression of proteins like HIT, hibernating induction trigger, are attractive molecules that could potentially induce a cascade leading to a hypometabolic state (Zancanaro et. al, 2004). Moreover, genes like *Lep* have been found to create leptin, a protein that signals lipostat. Lipostat is a crucial molecule for hibernation since it can sense body lipid content and change energy expenditure to ensure fat gain before hibernation and fat loss during. Other clear avenues involve gene therapy and stem cells, but more research is needed to identify specific compounds.

From this discussion, there is clear evidence to support the possibility of inducing a hypometabolic state, and circumpolar people have already begin to exhibit many of these compounds and processes. For example, BAT is used as a metabolic response to reduce ATP, and respiratory rate is reduced to ensure sufficient heat production. Both the molecule and process respectively are inherent in mammals that go through hibernation. To add on, history has shown us that there is a good chance Neanderthals hibernated as well. Bartsiokas and Arsuaga (2020) argued that the diseases indicated on the Neanderthals skeletal remains as well as the presence of HZAGS are indicative of arousals from torpor. Their findings provide overwhelming evidence that Neanderthals did in fact hibernate.

All in all, human hibernation is a real and possible phenomenon that may not be too far away in the distant future. Scientists have discovered molecules like 5'-AMP and drugs like CNO that have shown evidence of inducing a hypometabolic state in nonhibernating mammals. Moreover, history has shown us that human hibernation may have occurred in the Neanderthals. Although more research may need to be conducted to determine if a hypometabolic state can be induced in humans, many hypotheses show promise through in vivo experiments with animals. If human hibernation is as possible as the literature suggests, it will be revolutionary: circumpolar people may be able to find another route of survival in the Arctic; astronauts could reduce their payload and minimize their confinement-related stress to allow for deep space exploration; and patients suffering from trauma, or any other life-threatening condition could prevent further tissue degeneration during recovery. Scientists have only begun to scratch the surface with

human hibernation but once they figure it out, the possibilities will be endless, and the benefits will be game-changing.

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