

Effects of cold climate on growth and development

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Abstract

Climate is one of the environmental conditions on which people live. Climate conditions impact every aspect of people's daily life and production activities, even the survival of humankind. In recent years, human activities have adversely changed the climate. The emergence of global warming and extreme weather has prompted people to pay attention to the impact of climate on life. The adverse climate issues include reduced quality of air and food, facilitated spread of diseases and increased mortality of the population. Being more orientated to climate changes in the past, research has been less alerted to the negative impacts that climate changes could bring to human health. This could be ascribed to that after living in a region for a long time, the human body has "adapted" to climate. And after adaptation, routine health outcomes such as disease incidence and hospitalization rate become less obvious, making the habitants blind from the undesirable impacts of climate on the health status. This review article summarizes the impacts of cold climate on human development, including maternal/fetal factors, lifestyle factors, etc., and delineates the relationship between cold climate and human health.

Keywords

cold areas; human development; climate and health

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Human growth and development are the result of the programmed temporospatial changes of biology influenced by multiple factors, including environment, sociology and other aspects^[1]. And some of the dominant traits, such as skin and hair color, can be visually recognized within a short period of development. Additionally, some chromosome anomalies and/or genetic defects that cause growth and development disorders will appear in childhood^[2]. With the continuous improvement of prenatal diagnosis technology and pregnancy protection, the incidence of growth and development disorders caused by genetic defects has been decreasing. In contrast, environmental factors play an increasingly important role in human growth and development. For example, intrauterine malnutrition can lead to fetal abortion, and the physical growth of children with nutritional deficiency after birth can be seriously retarded, and so can brain development^[3]. The functions of immune system and endocrine system are also lower in children with nutritional deficiency than in ones receiving adequate nutrition. With recent advances of research from clinicians, epidemiologists and developmental biologists, the developmental origin of health and disease (DoHaD) is emerging as a new research direction. This theory was first proposed by David Barker, who found that differences in living standards can lead to differences in disease incidence. Children growing up in

families with poor living standards have a lower birth weight and an increased risk of coronary heart disease in their adulthood^[4]. Based on DoHaD research, researchers proposed that exposure to external stimuli, changes and certain events (famine, war and other adverse living conditions) in the early and critical stages of development can let the human body achieve "stress adaptation", alter the development trajectory, and increase the risk of disease in the later stages of life^[5]. Climate and environmental factors are also important causes for pessimal stimulus, vicissitudes and other stressors mentioned above in the human body and can adversely impact on human development in the same way as DoHaD. Therefore, understanding the relationship between climate and human development and elucidating the ignored and hidden factors that are not conducive to human growth and development for intervention are crucial to the formulation of population health policies, disease prevention and chronic disease management.

China has a large territory and complex climate type, characteristics and distribution. People living in different climatic regions have different lifestyles, and their living habits have obvious regional characteristics. Because China is located in the northern hemisphere, the temperature in northern regions

is generally lower than in southern regions. In winter, the temperature difference between Heilongjiang Province and Hainan Province is even 60°C. China has a large population in cold areas, reaching 500 million people, and in many provinces, people live in severe cold areas and have to endure low temperatures with an average winter temperature of -20°C. The cold climate can cause many inconveniences to people's life and great harms to human health. Low temperature has been listed as one of the causes for increasing mortality. To cope with cold weather, the Chinese government has taken heating measures in northern cities. Interestingly, heating is a double-edged sword for human health. Studies have shown that heating in northern cities reduces the burden of cardiovascular diseases caused by cold^[6], but air pollution caused by heating is also a major health hazard for northern residents, which is estimated to shorten the life expectancy of 500 million northern residents by 5 years on average^[7-8]. This is a truly alarming phenomenon that should arouse our alert: measures employed to tackle one health problem may well create others that could be more severe.

1 Effects of dietary habits on growth and development in cold regions

Maternal physical and mental status and lifestyle are very important for fetal development. Children born in famine and energy shortage have a significantly increased risk of cardiovascular diseases and metabolic diseases when they grow up, and this effect can last for several generations. With the social development of China, the problems of hunger and nutritional deficiency have been significantly improved; on the contrary, excessive nutrition has become a new issue. For instance, obesity has become a new social problem, particularly in northern residents living in cold regions. As an economically underdeveloped region, the Northeastern China has one of the highest obesity rates, which is significantly related to the dietary structure. In order to resist the cold, people in the north have to work hard for a long time under low temperature and eat high calorie food. Specifically, the proportion of edible oil and salt is higher in northern diets, thereby higher levels of blood lipid and blood pressure in northern residents.

Chia *et al.* found that the risk of premature delivery and the probability of low birth weight of the fetus were higher when unhealthy diet, mainly including processed meat, high sugar and high saturated fat foods, was consumed during pregnancy compared with healthy diet mainly including fruits, vegetables, whole grains, low-fat dairy products and high-quality protein foods^[9]. Therefore, the diet during pregnancy and lactation has a significant impact on the growth and development of the fetus. Numerous animal studies have found that high-fat diets during pregnancy and lactation can lead to obesity and metabolic

syndrome in offspring^[10], including insulin resistance^[11], elevated blood lipids^[12], and increased risk of liver disease later in life^[13]. Once the oxLDL level in fetal umbilical cord blood is increased, it will reduce the function of islet β cells and affect metabolic health in early life^[14]. In addition to the influence on the metabolic system of offspring, the damage to the brain development of offspring is also significant, which is manifested as slow cognitive development, depression and aggression. An animal study with maternal high-fat diet during pregnancy and lactation revealed that the number of neurons and the responsiveness of dopamine neurons in offspring were decreased^[15]. More interestingly, not only the maternal, but also paternal high-fat diet can affect fetus development. Obesity has been well documented to lead to decreased sperm production and quality, and new studies have found that high-fat diet alters male seminal plasma composition, thereby affecting the intrauterine immune environment, which is critical for embryo implantation, placental development, and full-term pregnancy^[16].

With the improvement of living conditions, childhood obesity has become a major public health challenge in China. Obesity in childhood and adolescence is not conducive to their growth and development, but adversely affects the skeleton, heart, lung, intelligence and even the reproductive system, causing a variety of sequelae such as heart and liver diseases. Not only that, childhood obesity may also lead to low self-esteem in adolescents, making it more difficult to integrate into society and developing psychosocial complications. A study on the regional differences of children's obesity in China shows that the obesity rate of children in the north is significantly higher than that in the south^[17], which may be related to the eating habits in the northern cold regions. And some parents worry that their children are undernourished which slows their growth and development, and they wrongly believe that a fatter child is healthier. However, a large-scale study by Zhang *et al.* found that there is no significant difference in stunting between thin and obese children^[18].

2 Effects of low temperature environment on growth and development in cold regions

Life in northern regions has marked seasonal differences. The living standard in cold regions of China is generally backward, the level of social and economic development is less advanced, and the seasonal differences in food supply are more obvious with the quantity, variety and freshness of fruits and vegetables varying with the seasons. Such seasonal differences also include outdoor temperature, sunshine duration, and UV intensity, which affect the frequency and duration of residents' outdoor activities, as well as vitamin D synthesis and content. Northern China is warm in summer and cold in winter, with a large annual temperature difference. In northeast and northwest China, wintertime is long;

living in cold regions for a long time has a significant impact on human growth and development. Hominin bone size and shape show significant geographic variations; for example, residents at higher latitudes tend to have wider and larger bodies and shorter limbs than those at lower latitudes. According to Bergmann's Law and Allen's Rule, these differences were adapted to the changes in the cold climate by reducing the body surface area to reduce heat loss. Previous studies have shown that people who live in cold regions have stronger bones than those in hot regions, but a new study found that people who live in cold regions have lower cortical thickness and bone density and their bone loss accelerates with age^[19]. Robbins found that the amount of bone trabeculae in mice fed at low temperature was lower, even though they ate more food^[20], indicating that the cold living environment are not suitable for bone growth. Vitamin D is an important nutrient to promote bone development and maintain bone health. It is an important component of bone metabolism and calcium and phosphorus homeostasis. However, due to the short sunshine time and insufficient ultraviolet radiation in cold areas, people wear more clothes to protect themselves from the cold when going out, minimizing the skin area exposed to the sunlight. In order to keep warm, houses are installed with window glass of more layers and greater thickness, which further insulate the ultraviolet radiation from reaching the human body. This eventually leads to bone dysplasia and osteoporosis, which increases the susceptibility to fractures^[21]. Deficiency in Vitamin D can caused many health problems as it has many other benefits to the human body, such as preventing myopia in adolescents^[22], cancer and autoimmune diseases, and reducing high blood pressure^[23].

The outdoor environment in winter is harsh, and people are more likely to be injured when engaged in production activities or sports, leaving sequelae. A German study found that when exposed to cold environment, the nerve conduction velocity decreased and the distal motor latency prolonged, which may eventually lead to outdoor sport injuries and an increased risk of falls in the elderly^[24]. However, compared with the possible harm due to outdoor exercise in cold weather, the unwillingness to go out for exercise is more harmful to human development. The harm of exercise in cold weather can be offset by warming up before exercise, choosing correct clothes and exercise modes^[25-26]. Insufficient exercise leads to higher rates of obesity^[27], reduced vital capacity, and increases vision loss^[28], which are detrimental to children's growth and health later in life and may gradually become risk factors for common diseases in cold regions, such as obesity and cardiovascular disease, insufficient vital capacity and chronic obstructive pulmonary disease. An American study found that children exercised indoors was much less effective than when they exercised outdoors^[29]. Once children suffer from developmental disorders, they tend to be sedentary most of the

time. The probability for these children to do outdoor physical activities is 4.8 times higher than that indoor ones, which is conducive to the maintenance of their motor functions^[30].

Every organism has its optimal requirement for living environment temperature and is able to tolerate the fluctuations of ambient temperature within a certain range. The cold environment is an inevitable source of stress for habitants in cold areas, and can induce cold stress reaction^[31] leading to changes in energy metabolism and neuroendocrine function. Studies have found that stress hormones such as adrenaline (E), noradrenaline (NE) and thyroid hormone (TH) in blood fluctuate under cold stress. A series of neuroendocrine changes can render cognitive, reasoning, learning and memory impairments. For example, exposure to acute cold stress can impair the cognitive performance on sample tasks that reflect short-term or working memory function^[32]. Reed, *et al.* found that cognitive ability was related to climate and the decline of thyroid hormone levels. In this study, people who spent the winter in Antarctica showed a decline in cognitive ability 11 months later, but this effect was reversed after taking thyroid hormone supplements^[33]. A study in Britain found that living in a cold house with insufficient heating for a long time could lead to depression. For those who had no mental distress at the beginning of the survey, living in less warm house would nearly double the probability of experiencing severe mental distress; people who were on the verge of severe mental pain were more than three times more likely to experience severe mental pain. Cold housing has a significant potential for mental health harm, particularly for people at risk of pre-existing mental illness. The effect of shorter sunshine duration on mental health should not be ignored^[34]. Sunlight may cause changes in serum neurotransmitters and affect mental state^[35]. Studies have found that the occurrence of depression is related to seasonal changes. The symptoms of patients with a history of recurrent depression appear in autumn and winter and relieve in spring and summer. Light intensity is considered an important factor affecting the progression of depression, and bright light treatment is very effective for this mental disorder^[36]. Impairment of children's cognitive and reasoning learning functions and poor mental state of guardians are detrimental to the development of the mental system, which are the main causes of mental retardation. Maternal psychological stress, mental status, and depression affect fetal brain development and have long-term effects on offspring behavior and mental health. Cold weather limits children's outdoor activities, social time, and social style with less opportunities to contact with peers. Studies show that social interaction is important for promoting the formation of healthy personality, improving mental state in children, and enabling early detection, intervention and treatment of developmental diseases, which can significantly improve the prognosis of autism spectrum disorders (ASD)^[37].

The cognitive level of healthy children may not be well developed due to the interference of acquired factors, and the influence by the biological factors for the developmental disorders is a huge hidden danger to children. The results of a study on sleep quality in cold regions also deserve attention. Hyperlipidemia is more common in cold region habitants and thereby lipid-lowering drugs are more extensively used in cold regions. Generally, the quality of sleep in cold regions is higher due to the indoor warmth, but taking lipid-lowering drugs may cause insomnia. Studies on sleep quality and human health revealed that insomnia increases the risk of diabetes, hypertension and other diseases. Remind us that the side effects of treatment methods for common diseases in different regions can also cause health differences among people.

3 Effects of air pollution on growth and development in cold regions

In winter, the central heating system in the cold regions of northern China mainly adopts coal-fired heating by burning fossil dyes such as coal in urban area or the burning of straw in rural area, which create serious air pollution and threaten human health. Ever since the government promulgated the policy and regulations for strengthening the control of industrial pollution and reinforcing the public awareness of environmental protection, residents have begun to wear masks while traveling in pollution and haze weather, and as such the harm of outdoor air pollution has also been decreasing. Yet, the harm of indoor pollution is another serious health concern and requires timely implementation of appropriate measures. The cold climate forces people to live indoors most of the time. In order to keep the room warm, the doors and windows are usually kept closed and even tightly sealed, and consequently, the indoor ventilation becomes poor with the cooking fume, the smoke from the heating stove, and indoor dust being accumulated leading to an increase of PM2.5^[38]. Deaths due to PM2.5 increased from 3.5 million in 1990 to 4.2 million in 2015, with most of these deaths attributable to children who die from indoor pollution caused by the use of unventilated stoves and firewood^[39]. It is important to note that the damage caused by air pollution occurs even before birth, with the poor quality of air to which pregnant women expose being associated with increased adverse birth outcomes such as low birth weight and preterm birth^[40-41]. Poor indoor and outdoor air environment causes serious damage to children's lung development. Particles in the air act as inflammatory mediators after inhaling into the lungs to activate inflammatory response and increase airway reactivity, leading to bronchitis, asthma, lung infection and other children's susceptible diseases and increasing the prevalence of COPD and lung cancer in the later stage. Air pollution not only affects the respiratory system, but also significantly increases the risk of cardiovascular disease later in life. Studies have shown that people of all ages exposed to high PM2.5 have increased

systolic blood pressure and the incidence of hypertension^[42-44]. Moreover, air pollutants affect the leptin and adiponectin levels in umbilical cord blood, resulting in abnormal metabolism of fetal blood lipids and sugar, interfere with endocrine, and increase the risk of obesity, insulin resistance and juvenile diabetes^[45]. Recent research has found that air pollution also has a negative effect on brain development. Air pollutants can enter the central nervous system through the nasal mucosa or through the blood-brain barrier after entering the blood and increase the inflammatory reaction in the brain and the permeability of the blood-brain barrier to promote the migration of inflammatory substances and damage the development of the nervous system, leading to developmental disorders and behavioral abnormalities. In animal experiments, chronic inflammation and neuronal degeneration caused by air pollution have also been observed^[46]. Children who have frequent ventilation or use air purification devices in their homes have healthier growth trajectories and better cognitive development^[47].

4 Influence of outdoor environment on growth and development in cold area

Due to the distinct four-seasons climate in the north, urban green plants also show seasonal differences. The withering of outdoor trees in winter reduces the green space around people's living environment, and the higher the latitude, the longer the reduction lasts. Recent studies have found that green environments around the houses are associated with children's early intellectual development and consciousness activity development, which possibly because environments with more green spaces reduce air pollution and noise level and increase children's physical activity and social opportunities^[48]. A study that followed the mothers from pregnancy until the children grew up two years old found that in the early life while the children were less active outside, they had better neural development in the environment with more green space^[49]. Another study exploring green space and maternal health found that higher levels of greenery around residential areas reduced the risk of gestational diabetes in mothers with lower fasting insulin levels^[50] and improved the health status of pregnant women and newborns in later life.

5 Improve the population's attention to climate conditions

In recent years, the health status of Chinese people has improved, and the life expectancy per capital has increased. Chronic diseases have become the number one killer of Chinese population and a heavy burden to families and society. After reviewing previous studies, we found that climate has a huge impact on human development and health through the whole course of human life. The lifestyle and living environment affected by cold climate change children's normal growth and development

trajectory and create some risk factors for cardiovascular, cerebrovascular, respiratory and metabolic diseases in early life. However, there is a lack of awareness of this risk among the population. Clinicians and epidemiologists should give more health education to the population. Like many other risk factors that affect population health, the effect of climate on people's health can also be prevented. A British study found that the mortality rate caused by low temperature, contrary to what one might suppose, is lower in cold regions at higher latitudes, suggesting that people's awareness and prevention of cold could minimize the harm of this adverse factor to health. In conclusion, for people living in cold areas, it is important to change their unhealthy lifestyle for the sake of normal growth and development. For example, by opening windows for ventilation and installing household air purification devices, the harm of indoor air pollution can be reduced. Changing the diet structure can reduce the incidence of chronic diseases in the future. There is no doubt that general practitioners provide continuous diagnosis and treatment services for patients in the community, and they are the closest medical personnel to the residents. Through their good community management, general practitioners help residents identify

potential pathogenic factors in their lives to improve their future health, extend their work from treatment to prevention, achieve early prevention and early intervention, and strive to achieve the ideal state of treating before getting sick, can better ensure the health of population^[51].

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Author contributions

Wang Y C proposed the conception for the manuscript. Xing C wrote the manuscript. Wang Y C, Wang Y D gave critical discussions and revisions on manuscript.

Conflicts of interests

Wang Y C is an Editorial Board Member of the journal. The article was subject to the journal's standard procedures, with peer review handled independently of this member and his research groups.

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