

# THE POTENTIAL MOLECULAR ROLE OF AGGRESSION AND BEHAVIORAL CHANGES AS A RESULT OF CLIMATE CHANGE

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## ABSTRACT

Climate change is a man-driven disruptor of our lifestyle, health, and well-being. Humans, like other species, adapt to long-term stressors like global warming through genetic and epigenetic adaptations. However, these adaptations are not always favorable, the outcome depends on many factors, including the magnitude and rate under which this change is imposed on the body. The implication of climate change on many human diseases such as melanoma, violence, child abuse, and others has been thoroughly investigated. Nevertheless, it is difficult to investigate the direct molecular alterations in humans in response to climate change. This difficulty is mainly due to ethical restrictions and the need for generational studies. Additionally, the indirect impact of climate change on humans cannot be ignored. The intense heat has forced many to an indoor lifestyle. This shift has led to a more sedentary lifestyle and more screen time, both of which were associated with an increase in depression, anxiety, and anti-social behavior. Finally, climate change is actively affecting our food security which represents another indirect cause for aggressive behaviors. This review aims to shed some light on the influence of climate change on mental health, behavior and the underlying mechanisms behind it.

**KEYWORDS:** Climate change, global warming, behavioral changes, violence, genetics, epigenetics

## INTRODUCTION

The occurrence of major environmental events has been happening regularly in the last decade. Our planet has lost millions of acres of forests to fires (Hirschberger, 2016; Cilli et al., 2022), many ice sheets and glaciers are rapidly melting (Coulson et al., 2022; Dietz & Koninx, 2022) and many species are endangered or even extinct (Román-Palacios & Wiens, 2020; Song et al., 2021; Grinder & Wiens, 2022; Penn & Deutsch, 2022). Therefore, many countries and conscious individuals are fighting to raise global awareness of this devastating problem.

According to the United Nations, Climate change is defined as “a change of climate which is attributed directly or indirectly to human activity that alters the composition of the global atmosphere and which is in addition to natural climate variability observed over comparable time periods” (UN, 1992). Also, according to the United Nations’ Intergovernmental Panel on Climate Change “Global warming is defined as an increase in combined surface air and sea surface

temperatures averaged over the globe and over a 30-year period”(IPCC, 2018).

It is well known that climate change and global warming are attributed to extensive pollution (Koch et al., 2021). Moreover, the opposite effect is true as well; global warming may lead to stronger and more hazardous effects of many ecotoxic chemicals and pesticide residues that will further worsen our climate (Noyes et al., 2009; Lovett, 2010; Oladipo et al., 2019; Kaka et al., 2021). Agencies have been trying to prioritize this problem for a long time and recently we could see an acceleration in the rate of increase in global temperatures. The past decade is the highest on record. Therefore, it is imperative to take more effective steps toward solving this problem and seek concrete solutions to minimize this acceleration.

## MATERIAL AND METHODS

This review aims to shed some light on the influence of climate change on mental health, behavior and the underlying potential molecular mechanisms behind it. The review will gather

information from all English-written articles published in the last 20 years. This review was approved by the Medical Research Ethics Committee for Health Sectors at Modern University for Technology and Information (**Approval number OB001\07\09\03\01**).

### **Climate Change and Overall Human Health**

For decades, the scientific community has been investigating the negative health effects of climate change and global warming on humans. Several studies have reported the direct/negative impact of climate change on our health and well-being. Auger et al., investigated the correlation between warm weather and sudden infant deaths (SIDs) in 30 years from 1981 to 2010 in Montreal, Canada. The case-crossover analysis included a total of 196 certified SIDs cases. The study showcased a strong correlation between high ambient temperatures and SIDs, especially at the age  $\geq 3$  months. In other words, the study is predicting that with the consistent rise in temperature, the impact on the risk of SIDs in humans should not be taken lightly (**Auger et al., 2015**). The same group investigated the association of hot temperature to stillbirths in the Quebec region during the same time frame and the study confirmed this association as well (**Auger, Fraser, et al., 2017**). Similarly, this correlation between increased ambient temperature and SIDs was confirmed in Korea (**Son et al., 2017**).

Moreover, a meta-analysis study associated hot climate with decreased workers' productivity, performance, and deterioration in occupational safety of outdoor workers in Sub-Saharan African countries (**Moda et al., 2019**). In Japan, public health authorities have been adjusting a heat wave adaptation plan to prevent heat strokes since over a decade ago (**Martinez et al., 2011**).

Furthermore, Climate change and global warming have been implicated in many other health problems as; many eye-related illnesses (**Echevarría-Lucas et al., 2021**) including retinal detachment, (**Auger, Rhéaume, et al., 2017**) cataract (**Cullen, 2011; Norval et al., 2011**), and skin-related illnesses such as melanoma (**Van Der Leun et al., 2008; Cullen, 2011; Norval et al., 2011**), and allergies (**Shea et al., 2008; Norval et al., 2011**) to say the least.

### **Human Behavior: Nature versus Nurture**

From an evolutionary perspective,

aggression is considered a tool for the survival of a species, this tool guarantees the successful gathering of resources and sexual selection. Therefore, historically the magnitude of aggression should increase depending on the increased value of the fought-over possession (**Lindenfors & Tullberg, 2011**). However, this theoretical distinction is not applicable in modern times, where there is no need to resort to aggression (**Veroude et al., 2016**).

1. Direct effects of climate change on our behavior

However, climate change has been shown to harmfully affect our mental health and exacerbate stress (**Padhy et al., 2015**). Another scientific investigation has shown an obvious increase in aggressive behavior in Psychiatric in-patients from 6 different hospitals in correlation to climate change in Baden-Württemberg, Germany (**Eisele et al., 2021**). Additionally, a study directly correlated the occurrence of violent crimes with higher temperatures in a rather cold country namely Finland (**Tiihonen et al., 2017**). Similarly, an increase in civil conflicts was observed during drought season. The data were collected from Asia and Africa, in the period from 1989 to 2014 (**Von Uexkull et al., 2016**). Even in sports, a study showed that the higher the ambient temperatures, the more aggressive the behavior becomes on the baseball pitch (**Larrick et al., 2011**).

Besides, a surge in gender-based violence has been also correlated with the continuous increase in global temperatures (**Desai & Mandal, 2021; Nations, 2022; van Daalen et al., 2022**). Also, violence against children and child abuse have been linked to climate change and global warming (**United Nations & Human Rights, 2019; Pereznieto et al., 2020**).

Furthermore, other mental health problems have been reported to be associated with climate change including depression, (**Frodl et al., 2010; Padhy et al., 2015**) and anxiety & stress. (**Rataj et al., 2016; Grant et al., 2019; Parry et al., 2019; Zisis et al., 2021; Schwartz et al., 2022**) Even the side effects of drug abuse have been observed to be worsened during extreme temperatures (**Marzuk et al., 1998**) and hospital admissions of drug-related mental diseases also increased with the increase in temperature (**Chan et al., 2018**).

Molecular effects of climate change on our behavior. Nowadays, we are facing many stressful environmental conditions, not only

extreme heat, but also floods, and droughts. To adapt to these conditions there are different responses (**Kristensen et al., 2020**). Firstly, it is well known that our DNA is mostly stable throughout our life. Therefore, to create a lasting evolutionary response to climate change, a genetic adaptation has to be passed on over generations (**Leonard, 2015; Kristensen et al., 2020**) This genetic adaptation doesn't always save the species from extinction, sometimes the species maladapt and that might even hasten the extinction process (**Leonard, 2015; Nadeau & Urban, 2019; Kristensen et al., 2020**). In that sense, it has been reported that the de novo mutations occurring in the genes of ectothermic organisms in response to unnatural global warming might not be favorable due to the thermodynamic limitations of the protein structure in response to extreme heat. Consequently, with the rapid increase in global temperatures, the enzymatic kinetics and protein stability will be affected also in humans, which in turn will be detrimental to human health and fitness (**Berger et al., 2021**). Moreover, the persistence of excessive environmental stresses over a long period is by itself a factor that would favor a maladaptive response. This maladaptation may lead to the development of mental health issues such as anxiety and mood disorders, e.g., depression, especially in individuals suffering from genetic vulnerabilities (**Tafet & Nemeroff, 2016**).

Secondly, humankind could accommodate and adapt to different stressors sooner through the transgenerational response. Here, the body has to acclimatize to the climatic changes through epigenetic adaptation (**Devaskar & Raychaudhuri, 2007; Kuzawa & Thayer, 2011; Kristensen et al., 2020**). In the early 1940s, Conrad Waddington defined epigenetics as 'the branch of biology which studies the causal interactions between genes and their products, which bring the phenotype into being' (**Waddington, 1942; Goldberg et al., 2007**). In other words, our genetic makeup will not change, but the DNA could be methylated or the histone proteins could be modified which in turn will activate or deactivate genes in response to external or internal factors (**Gibney & Nolan, 2010**). Likewise, the epigenetic response to climate change may be maladaptive due to extensive DNA methylation and in turn obstruction of gene expression (**McGuigan et al., 2021; Murray et al., 2022**).

Worth mentioning, that research

approaches aimed at detecting genetic and epigenetic human responses to climate change and global warming are difficult. It will take generations of observation and molecular testing and yet – without careful monitoring – one may not be certain whether this alteration is due to climate change or due to other stressors. More importantly, the moral and ethical restrictions to such studies together with the financial and logistic difficulties have been proven to be challenging so far (**Breton et al., 2021**). Nevertheless, the effect of genotype polymorphism or epigenetic modulation can be investigated on the protein level. This protein could be a hormone, metabolite, receptor, enzyme, or neurotransmitter among others, for instance, a genetic polymorphism in the neurotransmitter-metabolizing enzyme monoamine oxidase A (**Caspi et al., 2002**), a polymorphism in the serotonin transporter gene (**Gotlib et al., 2008**), and a polymorphism in the brain-derived neurotrophic factor, Val66Met gene (**Gatt et al., 2009**), among other genes that have been associated with behavioral, psychological and psychiatric issues. Also, among the key players in human response to climate change is the alteration of cortisol and adrenaline levels. In a small cohort of male participants, an investigation of the cognitive responses in correlation to heat exposure was performed in the UK. In this study, the plasma concentrations of the hormones; cortisol and adrenaline were indicators of cognitive activity in response to heat exposure. The affected hormone levels were associated with a deterioration in the routine central executive tasks and perceptions of mood state with heat exposure (**McMorris et al., 2006**).

2. The indirect impact of climate change:

a) The cycle of aggression and violence breeds violence. A study has shown that some male children who were abused at a young age, grow up to become violent offenders themselves. In this study, the violent behavior later in life was linked to a genetic polymorphism in the neurotransmitter-metabolizing enzyme monoamine oxidase. A (MAOA) gene, which led to lower activity of MAOA enzyme. This genetic risk factor was represented in 12% of maltreated children, however, they accounted for 44% of the total convictions of violent crime. Besides, 85% of the children who had both genetic and environmental risk factors developed some form of antisocial behavior (**Caspi et al., 2002**).

Another study confirmed this positive correlation between exposure to childhood abuse and being a perpetrator themselves in both males and females (Fagan, 2001). Moreover, a study investigating the cycle of violence showed that early childhood sexual abuse and adulthood violent behavior were positively correlated in male but not female victims (Glasser et al., 2001).

b) Impact of a sedentary lifestyle on social behavior and aggression. The impact of extreme temperature, pollution, and natural disasters on human physical activity was consistently negative (Bernard et al., 2021), this physical inactivity was especially worsened during the COVID-19 Pandemic (Balanzá-Martínez et al., 2020; Dong et al., 2020; Lippi et al., 2020; Stavridou et al., 2021). Consequently, it was found that this sedentary lifestyle is associated with increased aggression and anti-social behaviors (Robertson et al., 2013; Georgiev & Gontarev, 2019; Jochimek & Lada, 2019; García-Hermoso, Hormazabal-Aguayo, et al., 2020; Bernard et al., 2021).

c) Impact of Violent digital games & the digital age on social behaviors and aggression. “Climate change is forcing us indoors — and childhood will never be the same, ‘Go out and play’ was once the norm. Extreme weather is making that harder” (Haspel, 2021).

Another concerning issue is that global warming has made it consistently difficult to maintain the fitness of children now and in the foreseeable future due to extreme weather conditions (Morrison, 2022). This has pushed the children to an indoor lifestyle that in turn promoted video gaming and increased screen time (García-Hermoso, Hormazabal-Aguayo, et al., 2020). Video gaming has been flourishing since it is inception in the eighties, which has also increased during the COVID-19 pandemic (Haug et al., 2022).

To explain the association of online gaming with behavioral changes, one must elucidate two side effects of gaming. On one hand, online gaming has been correlated with increased aggression against others (Wallenius et al., 2007; Shao & Wang, 2019), and Attention deficit hyperactivity disorder (ADHD) behavior in children & adolescents (Nikkelen et al., 2014). Nikkelen et al. proved an association between a variant 5-HTTLPR (serotonin-transporter-linked promoter region) gene polymorphism and violent media use and ADHD. 5-HTTLPR polymorphism has been an

important player in psychological behaviors anxiety, implicit moral attitudes, and harmful behaviors (Martínez et al., 2020). Additionally, gaming has been also implicated in depressive symptoms (Canli & Lesch, 2007; Frodl et al., 2010; Goldman et al., 2010), which caused further deterioration in social behavior and ultimately led to aggression and violence. On the other hand, online gaming has been correlated with self-harm and suicide (Farhat et al., 2020; Förtsch et al., 2021; Hall et al., 2022).

d) Impact of climate change on food security. According to the UN Committee on World Food Security, “Food security exists when all people, at all times, have physical and economic access to sufficient, safe and nutritious food that meets their dietary needs and food preferences for an active and healthy life” (FAO, 2006). Scientists have been concerned with the issue of biodiversity, agricultural production, and food security for years (Morton, 2007; Reidsma et al., 2010; Vermeulen et al., 2012; Muluneh, 2021). In agriculture, climate change has led to changes in plant distribution where plants are expected to expand and move to new territories that would be favorable to their growth (Grabherr et al., 1994; Kullman, 2002; Penuelas & Boada, 2003; Van Der Putten, 2012). This problem doesn’t affect agricultural biodiversity per se, but it is true for zoology fields as well (Muluneh, 2021). Therefore, this continuous and destructive shift in the environmental ecosystem will also have consequences. The scarcity of resources and food insecurity which are already known causes of violent behavior will be observed more often in the upcoming decades if no intervention is undertaken (Cohen & Pinstrop-Andersen, 1999; Brück & d’Errico, 2019). Moreover, the animal kingdom has given evidence to implicate climate change in the alteration of the genetic and epigenetic processes in many species (Weyrich et al., 2019). For instance, warming the water habitat of one type of tropical fishes – *Julidochromis ornatus* – lead to increased aggression among them aiming to fight for nutrition and their decrease in number (Kua et al., 2020).

## CONCLUSION

The direct correlation between climate change and mental health, cognitive & behavioral issues is undeniable. Likewise, the correlation between mental health, cognitive &

behavioral issues, and our molecular biology is clear. However, international collaboration is needed for an intentional generational investigation and follow-up to correlate these two arms together. If the fate of humankind's evolution is left to randomly adapt and acclimatize to the unnatural and unpredicted rapid increase in global warming and climate change, that will put our human species at risk of extinction. Likewise, food security might not be a global problem now, however, with the unprecedented increase in temperature, our food biodiversity will be at risk if climate change is not controlled. Finally, strict measures and punitive international regulations must be placed to control the rate of increase in global temperature and climate change.

#### **ABBREVIATIONS**

5-HTTLPR: serotonin-transporter-linked promoter region  
 ADHD: Attention deficit hyperactivity disorder  
 COVID-19: Coronavirus disease of 2019  
 DNA: Deoxyribonucleic acid  
 MAOA: Monoamine oxidase A  
 SIDs: Sudden Infant Deaths  
 UN: United Nations

#### **CONFLICT OF INTEREST**

The authors declare that they have no competing interests".

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## العنف والتغيرات السلوكية نتيجة لتغير المناخ

دعاء توفيق و دينا على شكرى

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يهدف هذا البحث إلى إلقاء بعض الضوء على تأثير تغير المناخ على الصحة النفسية والسلوك والآليات الكامنة وراء ذلك. تغير المناخ هو عامل مخرب يحركه الإنسان و يؤثر في أسلوب حياتنا وصحتنا ورفاهيتنا. ويتكيف البشر مثل الكائنات الأخرى مع الضغوطات طويلة المدى مثل الاحتباس الحراري من خلال التكيفات الوراثية والتخلقية. ومع ذلك فإن هذه التكيفات ليست دائماً إيجابيه، فالنتيجة تعتمد على العديد من العوامل، بما في ذلك الحجم والمعدل الذي يتم بموجبه فرض هذا التغيير على الجسم. وقد تم إجراء تحقيق شامل في تأثير تغير المناخ على العديد من الأمراض البشرية مثل الورم الميلانيني، والعنف وإساءة معاملة الأطفال وغيرها. ومع ذلك فإنه من الصعب التحقيق في التغيرات الجزيئية المباشرة في البشر استجابة لتغير المناخ. و ترجع هذه الصعوبة بشكل أساسي إلى القيود الأخلاقية والحاجة إلى دراسات الأحيال. بالإضافة إلى ذلك فإنه لا يمكن تجاهل التأثير غير المباشر لتغير المناخ على البشر. وقد دفعت الحرارة الشديدة الكثيرين إلى أسلوب الحياة في الأماكن المغلقة، مما أدى إلى نمط حياة أكثر خمولاً وقضاء وقتاً أطول أمام الشاشات، وكلاهما ارتبط بزيادة الاكتئاب والقلق والسلوك المعادي للمجتمع. أخيراً، يؤثر تغير المناخ بشكل واضح على أمننا الغذائي الذي يمثل سبباً آخر غير مباشر للسلوكيات العدوانية.