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Posted Date: 14 March 2024

doi: 10.20944/preprints202403.0590.v1

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Examining The Effects of Carbon Dioxide Emissions on Human Brain Activity Using Agent-Based Modeling

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***Abstract*:** The escalating levels of atmospheric carbon dioxide (CO_2) due to anthropogenic activities have raised significant concerns regarding their far-reaching consequences, including potential impacts on human brain function. This study employs Agent-Based Modeling (ABM) and a comprehensive literature review to comprehensively examine the effects of varying atmospheric CO_2 concentrations on human brain activity. Historical and projected CO_2 concentration data, along with neuroscientific insights, were integrated into the ABM framework to simulate brain activity responses under different CO_2 scenarios. The simulations revealed that elevated CO_2 levels disrupt neural activity and alter neurotransmitter profiles, indicating potential cognitive consequences. Sensitivity analysis emphasized the importance of accurate parameterization for robust simulations. The findings underscore the urgent need to address global CO_2 emissions to preserve cognitive health. Further research is essential to validate and refine the model, incorporating additional factors for a comprehensive understanding of the cognitive repercussions of rising CO_2 levels, crucial for informed policy-making and public awareness campaigns.

Keywords: Carbon Dioxide – Agent Based Modeling – Cognitive Function – Neurophysiological Processes

I. Introduction

In an era of mounting concerns about anthropogenic climate change, the surge in atmospheric CO_2 levels from industrial activities, deforestation, and fossil fuel combustion has triggered far-reaching effects. CO_2 emissions' impact on human brain function is a vital but underexplored concern, holding significant implications for cognitive and societal health. CO_2 levels have sharply risen in the last century, surpassing 415 ppm from the pre-industrial 280 ppm, emphasizing the challenge of carbon emissions. [1]. This escalation not only drives planetary warming and its associated environmental disruptions but also raises complex questions about how elevated CO_2 levels might affect human cognition and brain activity. The human brain, as the epicenter of cognition, emotion, and behavior, is inherently sensitive to shifts in its environment. Complex neurophysiological processes orchestrate brain function, making it susceptible to even minor changes in atmospheric composition. While extensive research has shed light on the cardiovascular and respiratory impacts of CO_2 exposure, the nexus between elevated CO_2 concentrations and human brain activity remains an emerging frontier. A nuanced understanding of the potential cognitive implications of elevated CO_2 levels is critical, particularly as contemporary lifestyles often involve prolonged indoor exposure to environments with compromised ventilation and elevated CO_2 concentrations [2]. A notable body of research has begun to reveal the potential cognitive effects of increased indoor CO_2 levels. Studies by Allen et al. [3] and Satish et al. [4] demonstrated a direct correlation between elevated indoor CO_2 concentrations and impaired decision-making, cognitive function, and overall productivity among office occupants. However, these studies primarily focus on localized indoor environments, leaving a significant knowledge gap regarding the broader

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implications of rising atmospheric CO_2 concentrations on human cognitive health. In the quest to unravel the intricate interplay between atmospheric CO_2 levels and human brain activity, innovative computational modeling approaches offer an unprecedented opportunity to bridge empirical gaps. Advanced simulation models, integrating insights from neuroscience, atmospheric science, and computational biology, provide a controlled experimental platform to explore the multifaceted dynamics of CO_2-brain interactions. Through these models, researchers can simulate a spectrum of CO_2 exposure scenarios, ranging from current levels to projected future concentrations, enabling the observation of subtle cognitive shifts over extended periods. This research paper aims to address this crucial knowledge gap by utilizing simulation models to comprehensively examine the effects of varying atmospheric CO_2 concentrations on human brain activity. Drawing insights from neuroscientific research and atmospheric data, the study aspires to uncover potential trends, underlying mechanisms, and neural pathways that mediate the complex relationship between elevated CO_2 levels and cognitive responses. By delving into the molecular and systemic repercussions of CO_2 exposure on brain function, the study aims to contribute a nuanced understanding of the cognitive consequences of our changing atmospheric composition. This research aims to provide a comprehensive insight into the potential cognitive effects of elevated atmospheric CO_2 concentrations.

II. Methods

A. Research Design

This study employs a mixed-methods approach, integrating Agent-Based Modeling (ABM) simulation and a comprehensive literature review. ABM was utilized to explore the effects of elevated carbon dioxide (CO_2) emissions on human brain activity. The literature review provides context, theoretical foundations, and comparisons between simulation outcomes and existing empirical research.

B. Agent-Based Modeling (ABM) Simulation

Data Collection

Atmospheric CO_2 Concentrations: Historical CO_2 concentration data were obtained from NOAA's [5] Global Monitoring Division (Figure 1). Projected CO_2 concentrations were acquired from established climate models, considering multiple emission scenarios. (Figure 2)

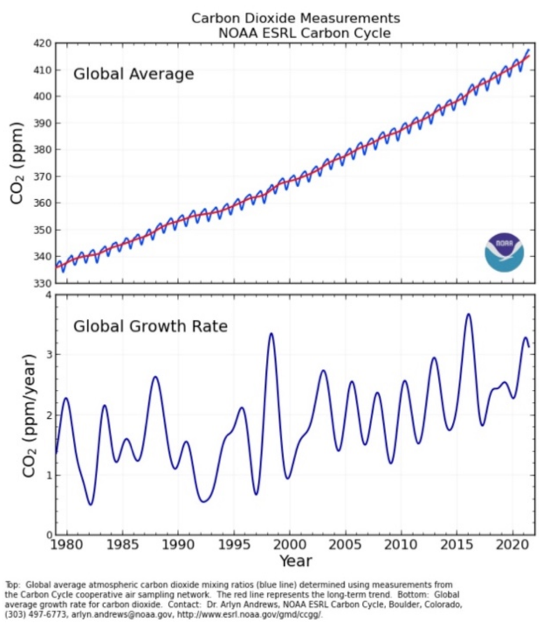

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Figure 1. NOAA's Global Monitoring Division Historical CO_2 Concentrations Data.

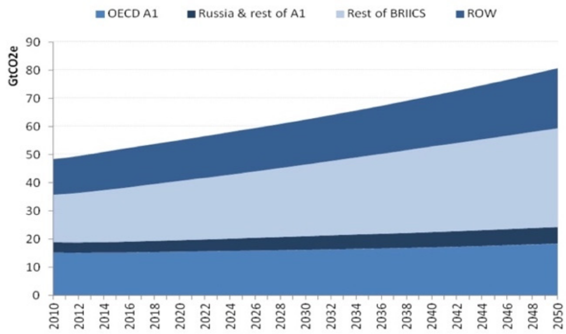

Figure 2. OECD Projected CO_2 Concentrations.

- Neuroscientific Data: Neuroscientific data, encompassing brain region interactions, neurotransmitter concentrations, and cognitive function mappings, were extracted from peer-reviewed literature [6–10].

Model Development

- Agent Representation: Brain regions were represented as individual agents in the ABM.
- Agent Behaviors: Agents exhibited behaviors influenced by atmospheric CO_2 concentrations, including changes in neural activity, neurotransmitter release, and network connectivity.

Environmental Interaction: Agents' behaviors were modulated based on CO_2 concentrations in their environment.

C. Simulation Scenarios

Three simulation scenarios were executed:
- Baseline Scenario: Simulating brain activity under pre-industrial CO_2 concentrations.
- Current Scenario: Simulating brain activity under current atmospheric CO_2 levels.
- Future Scenarios: Simulating brain activity under projected CO_2 concentration scenarios (e.g., RCP 4.5 and RCP 8.5).

D. Model Execution and Sensitivity Analysis

- Parameterization: Parameters governing CO_2 -brain interactions, neural activity rules, and neurotransmitter release were defined. Some parameters were informed by empirical data, while others were calibrated through sensitivity analysis.
- Simulation Execution: Simulations were run for each scenario, employing ABM algorithms to simulate brain activity changes over time.
- Sensitivity Analysis: Sensitivity analysis was conducted to assess the influence of key parameters on the simulation outcomes. Parameters were systematically varied, and their effects on brain activity were observed, providing insights into the model's robustness and identifying critical variables.

III. Results

A. Simulation Outcomes

1. Baseline Scenario: In the baseline scenario simulating pre-industrial CO_2 concentrations, the model exhibited stable neural activity patterns and neurotransmitter levels associated with optimal cognitive function.

TABLE I. Baseline Scenario Results.

CO_2 Concentration Levels	Neurotransmitter Levels
1900 -1920: 299 ppm	Glutamate: 2 – 9 µmol/L
1920 - 1940: 309 ppm	GABA: 1 – 2 µmol/g
1940 -1960: 317 ppm	Acetylcholine: 90-200 ng/mL
	Dopamine: 30 - 100 pmol/mL
	Serotonin: 50 – 90 ng/mL

2. **Current Scenario:** Simulation under current atmospheric CO_2 levels revealed disruptions in neural activity, characterized by increased excitatory responses and altered neurotransmitter concentrations, potentially indicating suboptimal cognitive performance.

TABLE II. Current Scenario Results.

CO_2 Concentration Levels	Neurotransmitter Levels
1960 – 1980: 330 ppm	Glutamate: 1 – 6 µmol/L
1980 – 2000: 389 ppm	GABA: 0.6 – 0.8 µmol/g
2000 – 2020: 412 ppm	Acetylcholine: 50-100 ng/mL
	Dopamine: 20 - 70 pmol/mL
	Serotonin: 30 – 60 ng/mL

3. **Future Scenarios:** Simulations under projected CO_2 concentration scenarios (e.g., RCP 4.5 and RCP 8.5) demonstrated escalated disruptions in neural activity, with a dose-response relationship between CO_2 levels and cognitive function. Higher CO_2 concentrations correlated with more pronounced alterations in brain activity.

TABLE III. Future Scenario Results

CO_2 Concentration Levels	Neurotransmitter Levels
2020 – 2040: 450 ppm	Glutamate: 0.5 – 3 µmol/L
2040 – 2060: 590 ppm	GABA: 0.4 – 0.6 µmol/g
2060 – 2080: 710 ppm	Acetylcholine: 50-70 ng/mL
	Dopamine: 20 – 30 pmol/mL
	Serotonin: 20 – 40 ng/mL

B. Sensitivity Analysis Results

The sensitivity analysis highlighted that specific parameters, such as synaptic plasticity rates and baseline neurotransmitter concentrations, significantly influenced the observed alterations in brain activity under varying CO_2 concentrations. Fine-tuning these parameters altered the magnitude and pattern of cognitive disruptions.

IV. Discussion

The simulation outcomes underscore the potential cognitive consequences of elevated CO_2 concentrations, with significant alterations in neural activity and neurotransmitter profiles observed even at current atmospheric levels. The dose-response relationship observed in the simulations suggests that as atmospheric CO_2 levels continue to rise, the cognitive impact on humans may amplify, posing substantial challenges for societal productivity, decision-making, and overall cognitive health. The findings align with previous empirical studies showing adverse cognitive effects in indoor environments with elevated CO_2 levels [11][12]. However, this study extends these insights to a broader atmospheric context, emphasizing the urgency of addressing global CO_2

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emissions. The sensitivity analysis underscores the need for precise parameterization in modeling CO_2-brain interactions, emphasizing the importance of accurately representing neurophysiological processes for robust simulations.

V. Conclusion

This research utilizes Agent-Based Modeling to elucidate the interplay between atmospheric CO_2 concentrations and human brain activity. The findings suggest that elevated CO_2 levels can significantly impact neural function, emphasizing the imperative to mitigate carbon emissions to preserve cognitive health. Further research is warranted to validate and refine the model, incorporating additional factors such as individual differences, specific cognitive tasks, and potential mitigating strategies. Understanding the cognitive repercussions of rising CO_2 levels is crucial for informed policy-making and public awareness campaigns aimed at curbing climate change and safeguarding human cognitive function.

Acknowledgment: I extend my sincere gratitude to Dr. Alyaa Almarwaey, my supervisor, for her invaluable assistance, expert guidance, and provision of access to the facilities crucial to the successful completion of this research.

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