Cornous Environmental Sciences
Volume: 1, Issue: 1, 2024 (December), Pages: 25-29
DOI: https://doi.org/10.37446/ces/ra/1.1.2024.25-29
Review Article

Impact of short-term air pollution exposure on cognitive performance

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Received: 21 June 2024 / Accepted: 28 November 2024 / Published: 31 December 2024

Short-term exposure to air pollution has become a growing public health concern due to its potential impact on cognitive performance. This review article explores recent findings on how exposure to common air pollutants such as PM2.5, NOx, and O_3 affects cognitive function in both children and adults. The review synthesizes evidence from epidemiological and experimental studies, discusses plausible biological mechanisms, and highlights critical research gaps. A better understanding of this association is crucial for developing strategies to mitigate cognitive impairments due to environmental pollution. The review was conducted using a non-systematic narrative approach. Literature searches were performed across PubMed, Scopus, and Web of Science databases for studies published in English. Relevant empirical and review studies were selected based on their focus on short-term air pollution exposure and cognitive outcomes.

Keywords: *air pollution, cognitive performance, short-term exposure, PM2.5, neuroinflammation, environmental health*

Introduction

Air pollution is a global health issue that affects millions of people every day. Among its various harmful components, fine particulate matter (PM2.5) is especially concerning due to its ability to harm both physical and mental health. PM2.5 particles, measuring 2.5 micrometres or smaller, can travel deep into the lungs and enter the bloodstream, thereby affecting multiple organ systems, including the brain (Zhou et al., 2023). While the long-term effects of air pollution on neurodegenerative diseases are well established, recent research has shown that even short-term exposure can impair cognitive functioning and decision-making abilities (Gao et al., 2021). Short-term exposure to PM2.5 has been linked to a range of cognitive issues, such as reduced attention span, slower processing speed, and impaired memory (Ke et al., 2022). These cognitive disruptions are particularly problematic in settings where high-level mental performance is crucial, such as schools and workplaces. Studies have demonstrated that increased levels of PM2.5 negatively impact students' academic performance and reduce employee productivity, posing a significant public health concern (Koivuranta et al., 2024). Experimental research further supports these findings, showing that brief exposure to elevated pollution levels diminishes executive function and decision-making ability (Shehab & Pope, 2019). Although the respiratory effects of air pollution are widely recognized, its influence on brain function remains an emerging field of study. PM2.5 affects cognition through several biological pathways, including neuroinflammation, oxidative stress, and vascular injury, all of which can impair brain health (Zhou et al., 2023). Upon inhalation, PM2.5 may increase blood-brain barrier permeability, allowing toxic substances to reach the central nervous system (Sharma et al., 2009). Once inside the brain, these toxins can trigger oxidative stress and disrupt cellular energy metabolism, leading to

neuronal damage and cognitive decline (Zhang et al., 2016). Additionally, environmental stressors like noise pollution may amplify these effects, underlining the need for a comprehensive pollution control strategy (Thompson et al., 2022). Daily exposure occurs through various routes—commuting in traffic, living in urban areas, or working in poorly ventilated indoor spaces (Shehab & Pope, 2019). Studies confirm that PM2.5 from ambient and indoor sources, such as vehicle emissions and candle burning, can lead to measurable reductions in cognitive performance (Zhou et al., 2021; Koivuranta et al., 2024). These effects have broad implications for learning, productivity, and public health, particularly for vulnerable groups such as students, professionals, and the elderly. Additionally, emerging research has also explored the gendered implications of environmental pollution, particularly in low- and middle-income countries, where women's reproductive health is adversely affected by climate-related pollution and displacement (Afzal et al., 2024; Afzal & Das, 2023). The present review aims to (1) synthesize existing evidence on the impact of short-term air pollution exposure, especially PM2.5, NOx, and O_3 on cognitive function, and (2) identify key biological mechanisms and knowledge gaps relevant to public health research and policy.

Methodology

This review is based on a non-systematic narrative synthesis of the literature. A comprehensive search of the PubMed, Scopus, and Web of Science databases was conducted to identify peer-reviewed articles published between 2010 and 2024. The search included keywords such as 'air pollution', 'cognitive performance', 'short-term exposure', 'PM2.5', 'NOx', and 'O_3'. Inclusion criteria focused on studies that examined the short-term effects of air pollution on cognitive functioning in both children and adults. Review articles and epidemiological studies were prioritized. The review methodology was guided in part by the systematic principles outlined by Afzal et al. (2021), especially in structuring the search and screening process.

Results

Mechanisms connecting air pollution to cognitive impairment

Short-term exposure to air pollution impairs cognition through neuroinflammation, vascular dysfunction, and direct neurotoxicity. Pollutants can penetrate the blood-brain barrier, disrupting brain function (Figure 1). These mechanisms are linked to developmental delays in children and accelerated cognitive decline in older adults (Clifford et al., 2016).

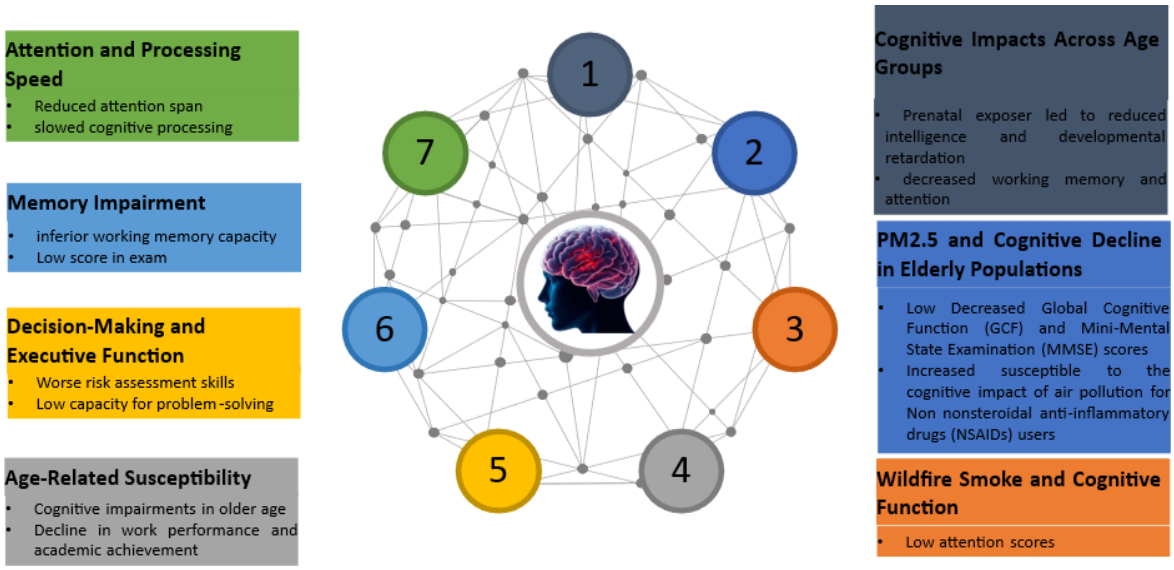

Figure 1. Effect of Short-Term Air Pollution and Cognitive Function

Attention and processing speed

Brief exposure to PM2.5 reduces attention span and slows processing speed. A 10 µg/m³ rise in PM2.5 within three hours before testing led to poorer attention performance (Cleland et al., 2022). Urban youth exposed to high pollution reported more attention lapses than peers in cleaner areas (Shehab & Pope, 2019).

Memory impairment

Air pollution negatively affects working memory, crucial for everyday tasks. Young adults exposed to high PM2.5 levels for hours showed reduced memory capacity (Koivuranta et al., 2024). Similarly, students exposed to indoor PM2.5 during exams scored lower than peers in cleaner settings (Zhou et al., 2023).

Decision-making and executive function

Executive function, including impulse control and decision-making, is impaired by brief PM2.5 exposure. High pollution levels reduce risk assessment and problem-solving abilities (Ke et al., 2022). Cognitive test scores dropped by 117 points within 24 hours of wildfire smoke exposure, a major PM2.5 source (Cleland et al., 2022).

Age-related susceptibility

Young adults (18–29) are also vulnerable to air pollution-related cognitive impairments. Developing brains may be more sensitive, leading to temporary but significant deficits (Gao et al., 2021). These impairments can affect academic success and job performance, potentially influencing long-term career outcomes and economic productivity (Thompson et al., 2023).

Wildfire smoke and cognitive function

Wildfire smoke significantly impacts cognitive function. A study using a brain-training game found that a 10 µg/m³ PM2.5 increase within three hours lowered attention scores. Participants exposed to intense wildfire smoke the day before scored 117 points lower on cognitive tests than unexposed individuals (Cleland et al., 2022).

PM2.5 and cognitive decline in elderly populations

Research on elderly populations found that 28-day PM2.5 exposure led to cognitive decline. Data from the Veterans Affairs Normative Aging Study showed reduced global cognitive function (GCF) and MMSE scores. High exposure reduced GCF by 0.499 points and raised poor MMSE risk by 63%. NSAID non-users were more vulnerable (Gao et al., 2021).

Cognitive impacts across age groups

A meta-analysis by Clifford et al. (2016) found cognitive impacts of air pollution across all age groups. Prenatal and early childhood exposure reduced intelligence and caused developmental delays. Adults experienced decreased working memory and attention, while older adults faced accelerated cognitive aging and an increased risk of dementia due to high pollution levels (Figure 2).

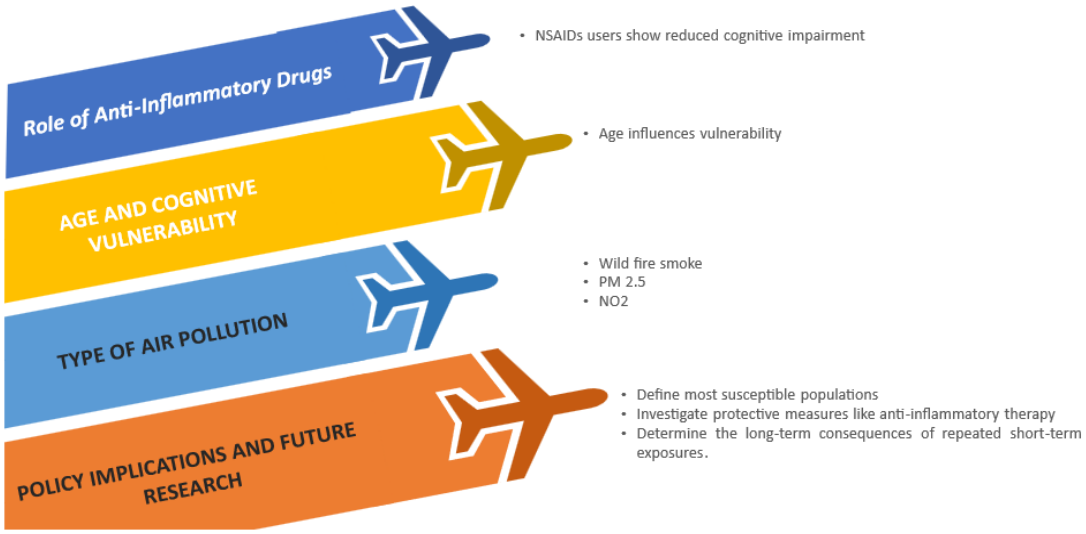

Figure 2. Modifying Factors in the Air Pollution-Cognition Relationship

Role of anti-inflammatory drugs

NSAID use is linked to reduced cognitive impairment from air pollution, supporting the idea that inflammation drives pollution-related cognitive decline. Anti-inflammatory therapy may help protect brain function (Gao et al., 2021).

Age and cognitive vulnerability

Younger adults (18–29) and older adults (70+) face greater cognitive decline after short-term PM2.5 exposure, highlighting the need for targeted protective strategies in these high-risk age groups (Cleland et al., 2022).

Type of air pollution

Different air pollutants affect cognition uniquely. PM2.5 impairs attention and processing speed, while nitrogen dioxide (NO_2) lowers cognitive test scores in all ages (Clifford, 2016). Wildfire smoke is especially harmful due to its toxic chemical mix.

Policy implications and future research

Growing evidence links air pollution to cognitive impairment, urging policymakers to reduce emissions and improve air quality. Future research should identify vulnerable populations, assess protective strategies like anti-inflammatory therapy, examine repeated short-term exposure effects, and explore how indoor pollution and air filtration influence cognitive health (Clifford, 2016; Gao et al., 2021).

Conclusion

Short-term air pollution harms cognitive function, particularly in older adults, wildfire smoke-exposed individuals, and those not using anti-inflammatory drugs. Global action through policy changes, medical strategies, and education is vital. Future research should explore protective interventions to mitigate cognitive decline and boost resilience in vulnerable populations.

Acknowledgment

None

Funding

The authors received no financial support for the research, authorship, and/or publication of this article

Author contributions

Dr. Aashima Magotra and Dr. Shereen Khan contributed equally as first authors. Dr. Aashima Magotra led the drafting and writing of the manuscript. Dr. Shereen Khan contributed to the conceptualization and literature review. Alok Arshey served as the second author and was responsible for critically reviewing and editing the manuscript. All authors approved the final version of the manuscript.

Conflict of interest

The authors declare no conflict of interest.

Ethics approval

Not applicable.

AI tool usage declaration

The authors did not use any AI and related tools to write this manuscript.

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