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Labor Productivity and Cognitive Performance of Workers Exposed to Air Pollution in Work Environments: A Narrative Review of the Literature

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ABSTRACT

Introduction: Various studies on workplace pollution have identified adverse effects on workers' mental health. **Objective:** To analyze research reporting the impact of air pollution in work environments on workers' cognitive performance and labor productivity. **Materials and Methods:** A narrative review of the literature, analyzing studies on the topic across various databases. The PRISMA method was applied for the information selection process, considering inclusion and exclusion criteria. The ATLAS.ti software was used exclusively for the management of conceptual data. **Results and Discussion:** An association was found among the reviewed studies, with common analytical focal points identified in six thematic categories (labor productivity, cognitive performance, psychopathologies, air pollution, neurotoxic agents, and exposed workers). There was a degree of research co-occurrence and partial agreement regarding the relationship between air pollution, labor productivity, cognitive processes, and psychopathologies. **Conclusion:** Exposure to air pollution significantly influences mental and cognitive health, depending on the work performed. This exposure in the workplace can affect cognitive functioning and processes such as memory, attention capacity, and learning, as well as increase the predisposition to psychological disorders.
Keywords: occupational disease; air pollution; cognitive dysfunction; mental health.

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Productividad laboral y rendimiento cognitivo de trabajadores expuestos a ambientes laborales con contaminación del aire. Revisión narrativa de la literatura

RESUMEN

Introducción: Diversas investigaciones sobre la contaminación en entornos laborales han identificado efectos adversos en la salud mental de los trabajadores.

Objetivo: Analizar las investigaciones que informan sobre el impacto en el rendimiento cognitivo y la productividad laboral de trabajadores expuestos a la contaminación del aire de ambientes laborales contaminados.

Materiales y métodos: Revisión narrativa de la literatura, que analizó las investigaciones sobre el tema en diferentes bases de datos. Se implementó el método PRISMA para el proceso de selección de la información, teniendo en cuenta criterios de exclusión e inclusión, para el análisis se utilizó el software ATLAS.ti., como base exclusiva de la gestión de datos conceptuales.

Resultados y Discusión: Se evidenció una asociación entre las investigaciones consultadas, focos de interés analítico en común respecto a seis categorías temáticas identificadas (productividad laboral, rendimiento cognitivo, psicopatologías, contaminación del aire, agentes neurotóxicos y trabajadores expuestos), con un grado de coocurrencia investigativa y acuerdo parcial entre los resultados encontrados de la relación entre la contaminación y la productividad laboral, los procesos cognitivos y las psicopatologías.

Conclusión: La exposición a la contaminación del aire influye de forma significativa en la salud mental y cognitiva, según sea la labor que se desarrolle. Esta exposición en el entorno laboral puede afectar el funcionamiento cognitivo y de procesos como la memoria, la capacidad de atención y el aprendizaje, así como aumentar la predisposición a trastornos psicológicos.

Palabras clave: enfermedad laboral; contaminación del aire; disfunción cognitiva; salud mental.

Produtividade laboral e desempenho cognitivo de trabalhadores expostos a ambientes de trabalho com poluição do ar. Revisão narrativa da literatura.

RESUMO

Introdução: Diversas pesquisas sobre a poluição em ambientes de trabalho identificaram ambientes adversos na saúde mental dos trabalhadores.

Objetivo: Analisar as pesquisas que informam sobre o impacto no desempenho cognitivo e na produtividade laboral de trabalhadores expostos a poluição do ar em ambientes de trabalho contaminados.

Materiais e métodos: Revisão narrativa da literatura, que analisou as pesquisas sobre o tema em diferentes bases de dados. Foi implementado o método PRISMA para o processo de seleção das informações, levando em conta critérios de exclusão e inclusão. Para a análise foi utilizado o *software* ATLAS.ti., como base exclusiva para a gestão de dados conceituais.

Resultados e discussão: Evidenciou-se uma associação entre as pesquisas consultadas, foco de interesse analítico em comum em relação a seis categorias temáticas identificadas (produtividade laboral, desempenho cognitivo, psicopatologias, poluição do ar, agentes neurotóxicos e trabalhadores expostos), com um grau de concorrência investigativa e acordo parcial entre os resultados encontrados sobre a relação entre poluição e produtividade laboral, processos cognitivos y psicopatologias.

Conclusão: A exposição á polução do ar influencia de forma significativa a saúde mental e cognitiva, dependendo da natureza do trabalho realizado. Essa exposição no ambiente do trabalho pode afetar o funcionamento cognitivo e processos como a memória, a capacidade de atenção e o aprendizado, além de aumentar a predisposição a transtornos psicológicos.

Palavras-chave: doença ocupacional; polução do ar; disfunção cognitiva; saúde mental.

INTRODUCTION

Workers or individuals exposed to air pollution, neurotoxic agents, and particularly fine particulate matter experience negative health effects related to respiratory diseases, cardiovascular conditions, and cancer (1). Similarly, the literature supports that these agents contribute to alterations in brain plasticity, lead to neuronal death, impair neuronal repair capacity, and cause neurological and cognitive deficits in learning and memory mechanisms (2). This directly impacts human health by increasing the incidence of chronic degenerative diseases, psychiatric disorders, or mental health impairments (3). Such negative impacts on human cognition harm normal functionality and labor productivity, a topic that has been addressed in various studies and literature reports.

For these reasons, there is growing interest in the links between air pollution exposure and various negative outcomes in workers' mental health. This has become a subject of study in recent decades, as it represents a public health issue affecting millions of people worldwide, undermining well-being and optimal work performance, and generating unforeseen organizational costs (4).

During industrial and artisanal processes, a large quantity of fine particles is released, which primarily enters the body through the respiratory tract (5), resulting in the accumulation of unwanted metals or substances in the body (6). Studies show that the most frequently reported neurotoxic metals entering the bodies of exposed workers include aluminum, iron, copper, zinc, manganese, lithium, chromium, cobalt, lead, cadmium, arsenic, and mercury (7). These fine particulate elements enter the body through airborne circulation and reach the frontal cortical areas of the brain via the olfactory bulb (8).

The excessive accumulation of these agents in the central nervous system can predispose individuals to cognitive function deterioration (9) and, in the long term, cause social or occupational dysfunction, as well as effects like dementia. This is because the neurotoxicity of many metals is linked to neurodegenerative diseases and cognitive decline (10). Additionally, exposure to high levels of fine particles increases the risk of anxiety and depression (11,12).

Among the most notable elements is aluminum, which is used in industrial production and everyday life. Some studies have found that aluminum and its compounds are neurotoxic (13). It can inhibit hippocampal nerves and cause neurodegenerative diseases similar to Alzheimer's disease (14). Moreover, manganese fumes in the breathing zone have shown results confirming neurobehavioral and neurocognitive deterioration in exposed workers (15). Other findings indicate that low doses of ozone are associated with

respiratory tract diseases, leading to the loss of synaptic plasticity due to chronic oxidative stress from inhalation (16). The onset and progression of neurodegenerative diseases can occur with prolonged exposure (3).

In Colombia, reports are available regarding air and water pollution, as well as waste management in the workplace, linked to economic activities such as coal mining, ferronickel, emerald and gold extraction, among others (17). The mining and industrial sectors in Colombia have played a significant socioeconomic role; however, they contribute to air pollution through the production of neurotoxic agents and gases (18). Additionally, water pollution is reported due to fine particles and pollutants released by industries and both legal and illegal processes (19).

Given these circumstances, it is crucial to understand the research landscape surrounding this issue and explore the existing studies on the impact of workplace air pollution on employees' cognitive performance. The objective of this review was to analyze studies that report on the effects of air pollution in the workplace on the cognitive performance of workers exposed to it.

MATERIALS AND METHODS

Through a narrative review, the four authors reviewed, interpreted, and analyzed studies on the subject from databases such as PubMed, Lilacs, SciELO, ScienceDirect, Ovid, Psicodoc, and BVSalud. Information was gathered on the identified problem using health science descriptors (DeCS and MeSH), including terms like pollution, cognition, cognitive performance, neurotoxic agents, and workers. These descriptors helped systematically identify relevant studies from reliable sources to ensure the validity of the research.

The selection criteria refined the information search and allowed for the nomination of articles useful for the investigation. Included were experimental, correlational, and non-experimental studies: exploratory, descriptive, cross-sectional, case studies, mixed-methods, pilot studies, systematic reviews, and meta-analyses. Excluded were studies older than 15 years from the defined search period (August to October 2023), those that did not address cognitive performance, or that focused on workplace or health factors unrelated to air pollution or exposure to neurotoxic agents. Studies unavailable in full text were also excluded. This approach maintained the quality of the review process.

Subsequently, the four authors implemented the PRISMA method as a detailed article selection strategy. Additionally, relevant and coherent articles were explored and selected using an MS Excel matrix, which also helped discard studies not aligned with the review's objectives. These

processes identified over 2,700 articles, from which 61 met all the inclusion criteria and were deemed relevant to the investigation. For the analysis, the documents were organized in an MS Excel matrix containing year, database, study type, country, language, title, and abstract. Finally, an exploratory statistical analysis was conducted (Tables 1, 2, and 3).

Table 1. Publication Years of Selected Articles

Years	Frequency	Percentage
2009-2012	10	16.4 %
2013-2016	11	18.0 %
2017-2020	19	31.1 %
2021-2023	21	34.4 %

Table 2. Databases of Publication for Selected Articles

Databases	Frequency	Percentage
Ovid	19	30.6 %
ScienceDirect	16	25.8 %
PubMed	15	24.2 %
BVSalud	10	16.1 %
Psycodoc	1	1.6 %
Lilacs	1	1.6 %

Table 3. Study Type of Selected Articles

Study Type	Frequency	Percentage
Experimental, correlational, and cross-sectional studies	26	42.6 %
Systematic reviews and meta-analyses	24	39.3 %
Exploratory and descriptive studies	6	9.8 %
Case, mixed-method, and pilot studies	5	8.2 %

In order to establish relationships among the studies, common analytical focal points, research co-occurrence, and agreement or disagreement among the various results presented by the authors, ATLAS.ti 23, a free version of the software, was used. Traditionally employed for qualitative data management, particularly for handling original narratives from participants across different qualitative approaches, the software also supports researchers in literature reviews due to its wide compatibility with various file types. For this review, ATLAS.ti was chosen as the exclusive tool for ***managing conceptual data***, which strategically helped determine the content of the included studies, organize the main thematic categories, and assess their co-occurrence (Table 4).

Table 4. Co-occurrence of Thematic Categories

Categories	Cognitive Processes	Cognitive Performance	Psychopathologies
Pollution	108	67	69
Labor Productivity	290	56	34
Exposed Workers	53	51	17

These thematic categories (deductive) were determined based on the most common terms found in the research background and the most frequent terms identified through exploratory analysis using the ATLAS.ti software. Each category contained its respective concepts (codes), in

English due to the nature of the publication, as listed below:

- Cognitive Performance: *cognitive performance, cognitive impairment, behavioral, neuropsychological, neurodegeneration*.

- Psychopathologies: *brain damage, depression, anxiety, stress, Alzheimer's, mental health*).

- Cognitive Processes: *central nervous system, cognitive functions, learning, cognition, memory, attention, language, processing speed*.

- Work Productivity: *working, work productivity, productivity*.

- Exposed Workers: *occupational exposure, exposed workers, occupational risk*.

- Pollution: *work environment, neurotoxicity, negative effects, neurotoxic agents, particulate matter, fine particles, pesticides*.

RESULTS

An initial statistical analysis was conducted on the 61 articles to establish a comprehensive understanding of the material included in the review. It was found that the oldest publication year was 2009, and the most recent was 2023. Since 2017, as noted by King and colleagues (4), there has been a growing interest in the relationship between air pollution exposure and its impacts on workers' health. This interest peaked in 2021, with 34.4% of the publications affirming that the topic is gaining importance due to its relevance in occupational health, public health, and the well-being of workers, as well as the general population, due to environmental impact.

Most of the articles were published in the databases Ovid, ScienceDirect, and PubMed, which focus on health-related topics, are open access, and are primarily in English. These results demonstrate the research impact in other countries where this topic has been explored for its value and importance. In contrast, Spanish-speaking countries still have limited research on this issue, making it necessary to initiate projects that explore these subjects (17).

The majority (42.6%) of the 61 selected articles are experimental, mostly correlational studies, in which the variables of exposure to toxic agents in the workplace are associated with cognitive effects. In the same vein, systematic reviews and meta-analyses, which evaluate research on this topic, account for 39.3%. Other study types represent a smaller percentage, all detailed in Table 5. This indicates that the association between pollution and cognitive performance in the workplace has been a topic of interest in the research field, as it is a relatively recent subject.

Table 5. Study Type of Selected Articles

Study Type	Frequency	Percentage
Exploratory and descriptive studies	6	9.8%
Case, mixed-method, and pilot studies	5	8.2%
Systematic reviews and meta-analyses	24	39.3 %
Experimental, correlational, and cross-sectional studies	26	42.6 %

From the conceptual exploratory analysis conducted using ATLAS.ti, the most frequent terms were related to *exposure*, *health*, *cognition*, *workers*, *pollution*, *effects*, among others. These terms aligned with the most common ones found in the background research (Figure 1).

Figure 1. Word Cloud

According to the Oxford Advanced Learner's Dictionary (20), the categories are defined as follows:

• Labor Productivity: Understood as the ability in the work environment or the optimal level of production of human talent, where individuals utilize their skills, knowledge, and abilities to generate results and contribute to organizational success. The articles that address these categories are numbered between 21 and 32.

• Cognitive Processes: Defined as the abilities to assimilate and process data, assessing and systematizing the information accessed through experience, perception, or other means. These processes involve various faculties, such as intelligence, attention, memory, and language. The articles in which these categories are evidenced are numbered between 33 and 43.

• Cognitive Performance: Refers to the adequate, efficient, and effective functioning of an individual's cognitive abilities and processes. The articles that cover these categories are 1 and 44–61.

• Psychopathologies: These include mental disorders and abnormal psychological phenomena related to an individual's mental processes. The articles associated with these categories are numbered 5, 12, and 62–72.

• Exposed Workers: Refers to members of an organizational structure who come into contact with physical, chemical, or biological agents in their work environment, which may pose health risks. The articles that focus on these categories are numbered between 21 and 32.

• Pollution: Refers to the presence of physical, chemical, or biological agents in the work environment that can be harmful to workers' health. The articles covering these categories are 1, 33–43, 44–61, and 62–72.

During the analysis of thematic categories from the included studies, a high degree of association was found between work productivity and pollution, and cognitive processes. Among these processes, memory, attention, learning, and processing speed were most frequently mentioned as being affected by changes in workers' productivity. The analysis also revealed that pollution plays a significant role in cognitive performance and decline, which is related to the development or presence of psychopathologies, such as stress and depression, that affect the mental health of exposed workers. All of this affirms the relationship between the selected studies in terms of analytical and research focal points.

DISCUSSION

Pollution and Cognitive Performance

According to the World Health Organization, exposure to air pollution reduces average life expectancy by 66%, and fine particulate matter, the most harmful pollutant, can lead to both physical health issues and cognitive decline due to systemic oxidative stress and inflammation. This results in deficits in cognitive performance and mental health issues, increasing the risk of Parkinson's disease, dementia, and impairing executive functions (1,44–48).

A relationship was found between the thematic categories of cognitive performance and pollution, indicating that a substantial body of literature links exposure to pollutants with cognitive effects (49–53). For example, there is evidence of a connection between exposure to fine particulate matter and a decline in learning, working memory, and orientation. Specifically, for every 10-part-per-billion increase in ozone, verbal fluency and executive function worsen (53–55). Similarly, other studies confirm the association between air pollution exposure and psychological and physiological effects, such as reduced sleep quality and functional capacity, due to increased concentrations of carbon dioxide, mercury, and arsenic in work environments (57–61).

Air Pollution and Labor Productivity

Air pollution was shown to impact affective well-being and cognitive functioning, leading to a 57% reduction in work productivity by increasing work disability rates due to flu-like, respiratory, and cardiac symptoms. Additionally, workers exposed to moderate or high levels of pollution experience reduced working hours due to workplace contamination (21–23). Air pollution decreases

productivity and increases presenteeism (24,25). A negative correlation of −1 was found between changes in work productivity and cognitive performance in workers due to exposure to air pollutants. The higher the pollution, the lower the cognitive performance, and consequently, the lower the work productivity (26–32).

Cognitive Processes and Pollution

Regarding cognition and neurotoxic substances, studies have identified the impact on the central nervous system (33–35). In a 2018 study by Ma and colleagues (36), it was confirmed that manganese exposure alters GABA concentrations in the brain, with a significant increase observed in 45% of the subjects analyzed. Other studies support this evidence, noting that pollutants such as black carbon and nitrogen dioxide are among the most critical air contaminants. This demonstrates a link between exposure to these pollutants and decreased cognitive performance, as they cause oxidative stress, systemic neuroinflammation, and vascular damage (37–39). Likewise, for Clifford and colleagues (40), the association between exposure to airborne particles and deficits in language and verbal memory was evident.

Wang and colleagues (41) also demonstrated that exposure to elements like cadmium can cause persistent impairments in hippocampus-dependent learning and memory (42). In line with this conclusion, other authors have linked the consequences of lead exposure to hippocampus-dependent learning and memory, as it affects neurogenesis (43). It was found that lead impacts the survival and proliferation of subventricular neural stem cells by inhibiting neurogenesis in the hippocampus and olfactory bulb (37).

Psychopathologies and Exposed Workers

Regarding psychopathologies and exposed workers, Shi and colleagues (12) documented a significant association between fine particles of organic carbon, elemental carbon, copper, nickel, and zinc with anxiety and depression. Exposure to pollution was found to be related to stress, which negatively impacts the mental health of workers, many of whom are concerned about occupational diseases. Additionally, the interaction of stress symptoms had physiological consequences, such as reduced verbal fluency, altered sensorimotor processing, and changes in sleep efficiency. The study also considers the role of factors such as the work environment, regulations, work schedules, and longer workdays. It concludes that stress can lead to emotional, cognitive, behavioral, and physical responses (62).

In another study, Bjørklund and colleagues (63) reported the presence of anxiety and depression among workers occupationally exposed to

mercury, linked to the handling of this material during their work shifts. Mostovenko and colleagues (64) associated nanoparticle-induced neurotoxicity with neurodegenerative disorders. Similarly, Shang and colleagues (5) indicated that occupational exposure to lead is linked to neurodegenerative diseases, and aluminum exposure may even predispose individuals to Alzheimer's disease (65).

Blood concentrations of metals such as zinc, magnesium, lead, lithium, and even iron can influence mood and anxiety levels, supporting the possibility that a broader range of metal nanoparticles can lead to neurobehavioral consequences (66,67). Occupational exposure to metals may cause subtle cognitive dysfunction, underscoring the need for cognitive testing at the start of employment and at regular intervals throughout the work period (68,69).

Although the study findings show the effects of workplace exposure to pollutants, it is necessary to monitor occupational health and safety systems, control exposure levels to substances, and evaluate their impact on occupational health. While immediate visible effects may not always be present, long-term concerns can become significant, not only reducing productivity but also increasing the financial burden on employers and diminishing the quality of life for employees, as the risk of developing psychological and physiological diseases, such as those mentioned, increases (70-72).

CONCLUSIONS

Air pollution has become one of the greatest threats to public health. Moreover, pollution plays a critical role in cognitive performance and decline, as it is linked to the development or presence of psychopathologies that affect the mental health of exposed workers. The literature review revealed that exposure to air pollution significantly influences mental and cognitive health, depending on the type of work performed. This exposure in the workplace can lead to brain inflammation and oxidative stress, which may impair cognitive functioning and processes such as memory, attention, and learning, as well as increase the predisposition to psychological disorders.

However, further research is needed, especially in Latin American countries, as current evidence is not yet conclusive due to the limited quantity and quality of studies available in major scientific databases.

One limitation of this research was the unavailability of some full-text documents and the scarcity of studies conducted in the Latin American region.

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ETHICAL CONSIDERATIONS

The intellectual property rights of the reviewed studies were respected.

CONFLICT OF INTERESTS

The authors of this review declare no conflicts of interest.

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