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Environmental pollutants PM2.5, PM10, carbon monoxide (CO), nitrogen dioxide (NO_2), sulfur dioxide (SO_2), and ozone (O_3) impair human cognitive functions

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Abstract. – OBJECTIVE: Environmental pollution is an emerging global public health problem across the world and causes serious threats to ecosystems, human health, and the planet. This study is designed to explore the impact of environmental pollution particulate matter PM2.5, PM10, carbon monoxide (CO), nitrogen dioxide (NO_2), sulfur dioxide (SO_2), and ozone (O_3) on cognitive functions in students from schools located in or away from air-polluted areas.

SUBJECTS AND METHODS: In this study, two schools were selected: one was located near a traffic-polluted area (school #1), and the second was in an area away from the traffic-polluted area (school #2). In this study, a total of 300 students were recruited: 150 (75 male and 75 female) students from school #1 located in a traffic-polluted area, and 150 students (75 male and 75 female) from school #2 located away from a traffic-polluted area. The overall average age of students was 13.53±1.20 years. The students were selected based on age, gender, health status, height, weight, BMI, ethnicity, and homogenous socio-economic and educational status. The pollutants PM2.5, PM10, CO, NO_2, O_3, and SO_2 were recorded in the surrounding environment. The overall mean concentration of environmental pollutants in school #1 was 35.00±0.65 and in school #2 was 29.95±0.32. The levels of airborne particles were measured, and the cognitive functions were recorded using the Cambridge Neuropsychological Test Automated Battery (CANTAB). The students performed the cognitive functions tasks, including the attention switching task (AST), choice reaction time (CRT), and motor screening task (MOT).

RESULTS: The results revealed that the AST-Mean 928.34±182.23 *vs.* 483.79±146.73 (*p*=0.001), AST-mean congruent 889.12±197.12 *vs.* 473.30±120.11 (*p*=0.001), AST-mean in-congruent 988.98±201.27 *vs.* 483.87±144.57 (*p*=0.001), CRT-Mean 721.36±251.72 *vs.* 418.17±89.71 (*p*=0.001), and MOT-Mean 995.07±394.37 *vs.* 526.03±57.83 (*p*=0.001) were significantly delayed among the students who studied in school located in the traffic polluted area compared to students who studied in school which was located away from the traffic-polluted area.

CONCLUSIONS: Environmental pollution was significantly higher in motor vehicle-congested areas. Cognitive functions were impaired among the students who were studying in a school located in a polluted area. The results further revealed that the students studying in schools located in environmentally polluted areas have attention, thinking and decision-making abilities related to cognitive function impairment.

Key Words:
Environmental Pollution, Air Pollution, Cognitive Functions, Students, Schools, Riyadh, Saudi Arabia.

Introduction

Environmental pollution is a genuine issue affecting the health and well-being of nations

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worldwide. It includes various forms, from air and water pollution to soil pollution. While swift industrialization has brought immense benefits to human society, with advancements in medical sciences, health, education, and economies, it is also a fact that industrialization polluted the environment and posed significant risks to human health. Vehicle emissions, industrial activities, power plants, and burning fossil fuels cause the most prevalent form of environmental pollution. The air pollutants not only affect the quality of the air we breathe but also contribute to a myriad of health issues[1].

The various pollution sources, including air, water, and soil, change the environment's arrangement and composition. The composition of air pollution can vary based on the geographical location, weather conditions, population, and human activities in each area[2]. There are multiple sources of air pollution, both natural and human-made, which contaminate the environment. Industrial emissions have been recognized as a substantial contributor to environmental degradation and climate change. Industrial emissions pose significant challenges to environmental and human well-being. Industrial activities including manufacturing, power generation, and chemical production release pollutants, particulate matter PM2.5, PM10, carbon monoxide (CO), nitrogen dioxide (NO_2), sulfur dioxide (SO_2), ozone (O_3), and volatile organic compounds (VOCs). These gases and chemical substances contaminate the environment.

The World Health Organization has declared that environmental pollution is a silent killer and causes about 7 million deaths each year, or 15.5 people per minute[8]. Moreover, about 92% of people do not breathe safe air. Pollution affects both human health and global economies as 400 billion US dollars are spent on subsidizing fossil fuel use[3]. Environmental pollution is a leading risk factor for several illnesses, mainly respiratory[4,5], coronary artery diseases[6], endocrine[7], diabetes mellitus[8], nervous system disorders[9], lung inflammation[10], and cancer[11].

The rapid economic development, population growth, and migration of people towards metropolitan cities increase motor vehicle fleet size and environmental pollution. Evidence suggests that motor vehicles generate massive quantities of carbon dioxide, carbon monoxide, nitrogen oxide, hydrocarbons, and particulate matter PM2.5, and PM10, which contaminate the environment and cause environmental pollution. These environmental pollutants provoke numerous health hazards. In many countries, several schools are located near industrial areas, busy traffic roads, or traffic-related polluted areas. Exposure of children and adolescents to these environmental pollutants, particularly during their physiological developmental age period, increases the risk of health-associated issues. In the current global situation of environmental pollution, this study is essential to understand the hazardous effects of environmental pollution on cognitive functions. This study aimed to assess the effect of environmental pollution, PM2.5, PM10, CO, NO_2, SO_2, and O_3 on cognitive functions in students from schools located in air-polluted areas.

Subjects and Methods

This matched case-control, cross-sectional study was conducted in the Department of Physiology, College of Medicine, King Saud University, Riyadh, Saudi Arabia.

Selection of Schools

In this study, two different schools located in two separate areas of Riyadh, Saudi Arabia were selected. The first school was situated near a motor vehicle-polluted area, within 200 m of the main traffic road. This school was considered a motor vehicle pollutant-exposed school (exposed group, school #1). The second school was located away from motor vehicle-polluted areas, at a minimum of 1,500 m away from the main traffic road. This school was considered less exposed to motor vehicle pollutants (control group, school #2).

Selection of Students

The students in both schools were selected based on their voluntary involvement and health status, matched by age, height, weight, gender, socioeconomic and cultural background, and the admission criteria of their schools. For example, a student who attends school #1 was matched to a student at school #2 with the same age, gender, height, weight, socioeconomic status, and class level. This matching was to ensure valid and reliable comparisons between the two groups.

Exclusion Criteria

The known cases of gross anemia, obesity, and diabetes mellitus were excluded as these conditions weaken cognitive functions. Students with extraordinary grades or dropouts in their examinations were excluded from the study to minimize variations in knowledge and skills. The students suffering from known cases of chronic debilitating diseases, cigarette, and shisha smokers were excluded[4]. Students whose family members, such as father or mother, were cigarette smokers were also excluded from the study to minimize the passive smoking effect on cognitive functions. Furthermore, students with a history of vision problems, anxiety, attention deficit, musculoskeletal disorders, and who had a sleep disturbance history were also excluded from the study. Furthermore, students living or working in or near any factory producing dust or fumes or residing near a motorway were also excluded from the study[4].

Assessment of Air Pollutant Exposure

The airborne particles were determined through integrated sampling systems, air pollutants were recorded every hour over 24 hours. PM2.5, PM10, CO, NO2, SO2, and O3 were measured using the MP101M (2.5), MP101M (10), CO12e, AC32e, AF22e, O342e, Air Quality Monitors. The air pollutants data were obtained from the National Center for Environmental Compliance (NCEC), Riyadh, Saudi Arabia. Moreover, on a daily basis, air pollutants were recorded from the Air Quality Index (AQI)[12]. All these methods and sources were used to obtain the air pollutant data.

Cognitive Function Test

The cognitive functions were recorded using the Cambridge Neuropsychological Test Automated Battery (CANTAB). The investigators briefed the study participants on how the system operated. All the children and adolescents performed the attention switching task (AST), choice reaction time (CRT), and motor screening task (MOT) tasks.

Attention-Switching Task (AST)

AST is a cognitive function test used in neurosciences to determine the ability to shift attention while thinking between different concepts, tasks, or stimulus dimensions simultaneously. AST evaluates cognitive flexibility, namely the ability to shift attention between tasks. It assesses the executive functions and cognitive control processes related to the prefrontal cortex. The task-switching process elicits the same neural activity patterns as working memory processing[13-15]. AST is based on a cue that appears on the screen, and their location or direction displayed on the screen[16].

Choice Reaction Time (CRT)

This task evaluates the decision-making abilities and the reaction time to respond to specific stimuli with multiple options or choices. The process is based on the choices between arrows displayed on the screen. CRT is recorded once the person presses the right or left button and evaluates correct and incorrect responses, as well as the latency or speed of the participant's reaction[16]. This test is documented as a marker of a higher cognitive function and provides insight into how the brain perceives, processes, and responds to stimuli.

Motor Screening Task (MOT)

MOT is a reaction time test; it assesses psychomotor functions, speed, and accuracy. This is an important fine and gross motor skill test to assess the visuomotor accuracy-tracking tasks[17]. It is essential for understanding the attention and abilities of the sensorimotor function or comprehension[18]. It provides an overall evaluation of lack of comprehension and measures the individual response time to a visual stimulus[17].

Statistical Analysis

The data were analyzed using the Statistical Package for Social Sciences (SPSS for Windows, version 21.0; IBM, Armonk, NY, USA). The descriptive statistics were presented as means and standard deviations (Mean±SD); an unpaired Student's *t*-test (parametric test) was applied to evaluate the difference in the means between the variables. The level of significance was considered at $p < 0.05$.

Results

Environmental Pollutants Concentration in School Localities

In this study, two schools were selected, one in a traffic-polluted area (school #1) and the second in an area away from the traffic-polluted area (school #2). Motor vehicle-allied environmental pollutants were recorded. The pollutants were recorded, including PM2.5, PM10, CO, NO_2, O_3, SO_2, and total pollutants (Table I).

The mean concentration of PM 2.5 in school #1 was 110.64 ± 33.61, significantly higher compared to school #2 (108.86 ± 25.04) (p=0.004). Similarly, the mean concentration of PM 10 in school #1 (60.22 ± 46.04) was significantly higher compared to school #2 (27.38 ± 18.62) (p=0.001). The concentration of NO_2 was 11.32±10.76, significantly higher in school #1 compared to school #2 (6.39 ± 3.52) (p=0.001). Moreover, the concentration of CO 7.32 ± 3.20 and

Table I. Comparison of environmental pollutant levels in school located in a motor vehicle polluted area compared to school located away from the motor vehicle polluted area.

Pollutants (24 hs/average)	School #1 Mean ± SD	School #2 Mean ± SD	Significance level
Particulate Matter PM2.5 μg/m^3	110.64 ± 33.61	108.86± 25.04	p=0.004
Particulate Matter PM10 μg/m^3	60.22± 46.04	27.38±18.62	p=0.001
Carbon Monoxide (CO) ppm	7.32 ± 3.20	6.62±4.15	p=0.394
Nitrogen dioxide (NO_2) DU	11.32±10.76	6.39±3.52	p=0.001
Ozone O_3 (DU)	18.11±6.84	28.09±16.65	p=0.001
Sulfur dioxide (SO_2) DU	2.36±1.38	2.33±1.15	p=0.548
Total air pollutants	35.00±0.65	29.95±0.32	p=0.001

School #1: Located in a traffic-polluted area; school # 2: located away from the traffic-polluted area.

SO_2 2.36 ± 1.38 in school #1 was high compared to school #2 carbon monoxide 6.62±4.15 and sulfur dioxide 2.33±1.15 but did not significantly high. However, the overall concentration of pollutants PM2.5, PM10, CO, NO_2, OZ, and SO_2 was 35.00±0.65 significantly higher in school #1 compared to school #2 (29.95±0.32) (p=0.001) (Table I).

Demographic Variables of the Students

In this study, 300 students were recruited, 150 (75 male and 75 female) students from a school located in a traffic polluted area, and 150 students (75 male and 75 female) from a school located away from a traffic polluted area. The students were selected based on age, gender, health status, height, weight, BMI, ethnicity, and homogenous socioeconomic and educational status. These anthropometric variables were recorded. Tables II and III demonstrate the demographic variables of the students belonging to school #1 and school #2. The overall mean age of students was 13.53±1.20 years. The average age of students from school #1 was (n=150, mean=13.56; SD=1.27), while the mean age of students from school #2 was (n=150, mean=13.50; SD=1.17). A visual inspection of histograms for age (mean = 13.53; SD=1.20) of students, normal Q-Q plots, and the box plots showed that age data in years were normally distributed for students in both schools.

The average height of students at school #1 was n=150, mean =161.32; SD=9.62 and school #2 was (n=150, mean =162.09; SD=9.17). While the mean weight of students at school #1 was n=150, mean=62.50; SD=121.33; and school #2 was n=150, mean=62.91; SD=17.71. Moreover, the BMI of students at school #1 was mean=23.79; SD=6.72 and school #2 was mean=23.91; SD=6.39. The age, height, weight, and BMI matching of the students in both schools was non-significant. It shows that the students in both schools were very well-matched for age, gender, height, weight, and BMI.

Table II. Comparison of cognitive functions test parameters among the students who studied in a school located in a traffic-polluted area compared to those who studied in a school located away from the traffic-polluted area (n=300).

Parameters	School	Mean ± SD	Levene's test		*t*-test for equality of means			
			F	Sig.	*t*	*df*	Sig. 2-tailed	Mean Difference ± Std. Error Difference
AST-Mean	1	928.34± 182.23	2.889	0.001	23.271	298	0.001	444.553 ± 19.103
	2	483.79 ± 146.73						
AST-Mean Congruent	1	889.12 ± 197.12	43.832	0.001	22.062	298	0.001	415.813 ± 18.847
	2	473.30 ± 120.11						
AST-Mean in Congruent	1	988.98 ± 201.27	11.47	0.001	24.961	298	0.001	505.11 ± 20.233
	2	483.87 ± 144.57						

School #1 located in a traffic-polluted area, and school #2 located away from the traffic-polluted area.

Cognitive Function Test

The cognitive functions test parameters were recorded using the CANTAB. The students performed the tasks, including the AST and MOT. The MOT was recorded to screen the visual movement and overall comprehension. The findings were presented as the standard score of mean latency. The student's response was based on recalling the test pattern in forward or reverse order.

AST-Mean 928.34±182.23 *vs.* 483.79±146.73 (p=0.001); AST-mean congruent 889.12 ±197.12 *vs.* 473.30±120.11 (p=0.001), AST-mean in-congruent 988.98±201.27 *vs.* 483.87±144.57 (p=0.001), CRT-Mean 721.36±251.72 *vs.* 418.17±89.71 (p=0.001), MOT-Mean 995.07±394.37 *vs.* 526.03±57.83 (p=0.001) were significantly delayed among the students who studied in school #1 located in the traffic-polluted area as compared to students who studied in a school which was situated away from the traffic-polluted area (p=0.001) (Table II).

The independent sample's t-test proceeded with students in schools #1 and 2 as independent variables and CRT, and MOT scores as the dependent variables. The t-test results indicated that CRT score (n =150, M= 721.36, SD=251.72) were significantly reduced from the CRT score of students in school #2 (n =150, M=418.17, SD=89.71); t (298) =13.89, p<.001 (Table III). Similarly, the score of MOT had a significant value (p<.001). The cognitive functions parameter decreased among students studying in school #1 in the traffic polluted area.

Discussion

Environmental pollution has been an emerging global public health problem across the world. The swift urbanization and industrial revolution increased ecological pollution to a dangerous level. The numerous pollutant sources change the environment's arrangement and composition. Environmental pollution and its associated diseases are caused by type, nature, size, concentration, and duration of exposure to airborne pollutants in breathing zone[19]. The literature also highlights that environmental pollution causes respiratory[4,5], and coronary artery diseases[6], and environmental pollutants have a positive linkage with pandemics such as the COVID-19 pandemic[20]. This study investigated the impact of PM2.5, PM10, CO, NO_2, SO_2, and O_3 on cognitive functions in students studying in schools located in air-polluted areas.

Meo et al[4] performed a pilot study and investigated the impact of air pollution on cognitive function and found that cognitive functions MOT mean latency was delayed among the students who were studying in a school situated in a traffic polluted area. Gawryluk et al[21] conducted a study on air pollution exposure and functional MRI imaging. It was identified that diesel exhaust (DE) exposure caused impaired functional connectivity. Impaired brain connectivity causes harmful impacts on the various body organs. Schikowski et al[22] reported that air pollution caused a cognitive decline.

Lopuszanska et al[23] reported that air pollution hurts the central nervous system, and exposure to NO_2 was related to impaired working memory, general cognitive functions, and psychomotor functions. Moreover, PM2.5 was linked with working memory problems, short-term memory, attention, processing speed, and fine motor function. The literature demonstrates that rising levels of air pollutants were associated with a negative impact on the brain white matter.

Ke et al[24] conducted a study and found that exposure to PM2.5 particles for three days was related to reduced congruent and incongruent tasks and executive control. The results provide

Table III. Comparison of cognitive functions test parameters among the students who studied in a school located in a traffic-polluted area compared to the students who studied in a school located away from the traffic-polluted area (n=300)

Parameters	School	Mean ± SD	Levene's Test		*t*-test for equality of means			
			F	Sig.	*t*	*df*	Sig. 2-tailed	Mean Difference ± Std. Error Difference
CRT-Mean (ms)	1	721.36 ± 251.72	89.726	0.000	13.89	298	0.001	303.186 ± 21.819
	2	418.17 ± 89.71						
MOT-Mean (Mean latency	1	995.07 ± 394.37	247.166	0.000	14.41	298	0.001	469.040 ± 32.544
	2	526.03 ± 57.83						

School #1 located in a traffic-polluted area, and school #2 located away from the traffic-polluted area.

evidence that PM2.5 caused executive dysfunction and neuron activity impairments. Cleland et al[25] evaluated the relationship between daily PM2.5 and wildfire smoke exposure and cognitive performance in adults. The authors reported that prolonged exposure to PM2.5 causes adverse impacts on cognitive performance and reduces attention in adults within a few hours and days of exposure to pollution.

The results of the present study revealed that environmental pollutants cause impaired cognitive functions among the students studying in a school located in an air-polluted area. In short, the present study findings suggested that exposure to air pollution induced reduced cognitive function, with the most probable mechanisms involved being neuroinflammation, neuronal damage, and impaired cognitive functions[26-29].

The pathophysiology of mechanisms depends on the nature and types of air pollutants and the period of exposure. The microglial activation and inflammation cause white matter damage, changes in dopamine and glutamate neurotransmitters, and altered synaptic plasticity[29,30]. The brain microglial activation releases pro-inflammatory cytokines and free radicals, promoting oxidative stress[19], and can cause myelination damage and neuronal and white matter damage[30,31]. This study offers a new insight into the effects induced by exposure to air pollutants associated with underlying mechanisms in cognitive function impairment (Figure 1).

Study Strengths and Limitations

Similar to other studies, this study has some strengths and limitations. This study investi-

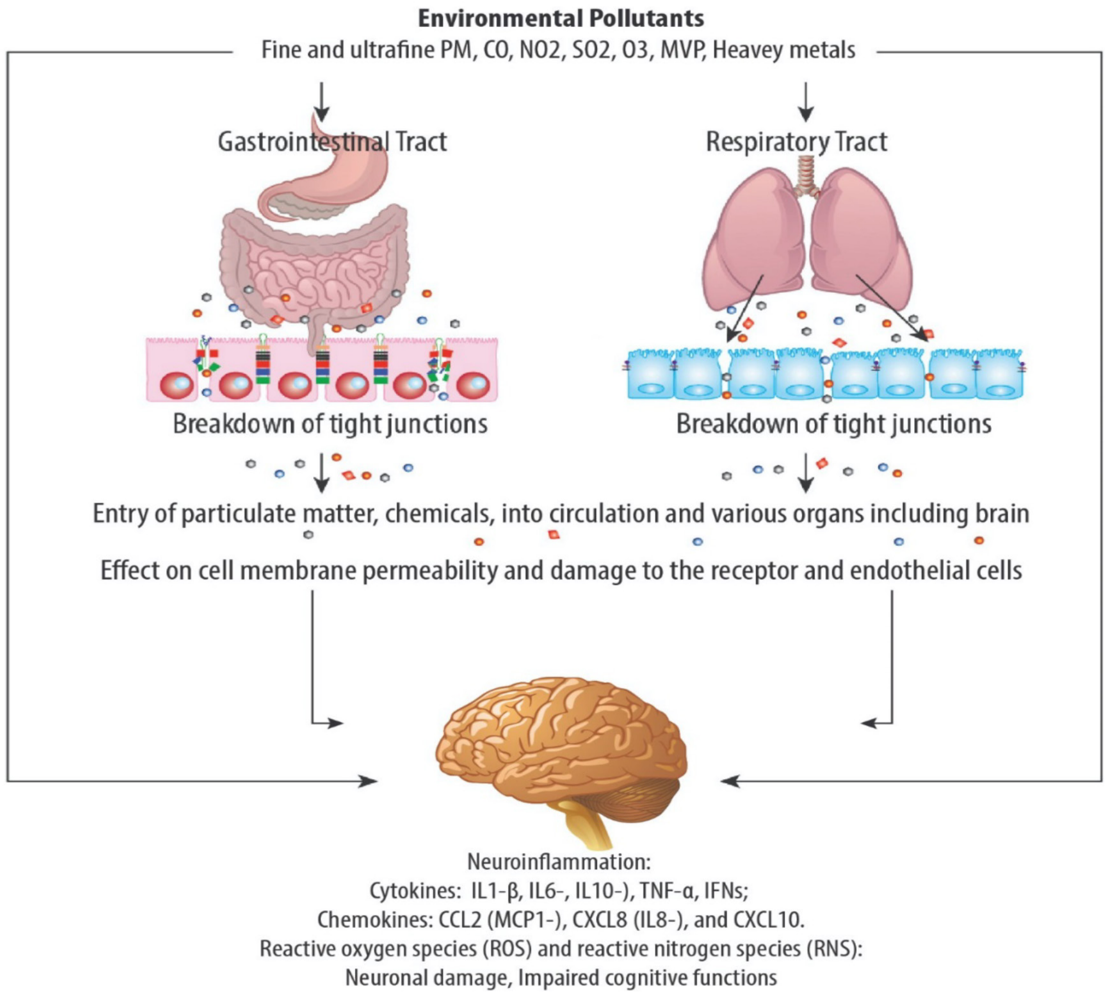

Figure 1. Air pollutants entry into the brain and pathophysiology of cognitive function impairment [Figure modified after permission from the author and publisher[19]].

gated the impact of environmental pollution on cognitive functions among school adolescents studying in schools located near and away from air-polluted areas. The mean concentrations of PM2.5, PM10, CO, NO_2, SO_2, and O_3 were recorded during the study period, and their effect was investigated. The first limitation of this study is that due to the COVID-19 pandemic and lockdowns worldwide, schools and universities were closed; hence, we delayed the research project. The second limitation is that due to the COVID-19 pandemic and lockdown, public activities were restricted. There was a reduction in air pollution because of decreased industrial economic activities, fewer vehicles on roads, and decreased energy consumption, reduced traffic emissions. These factors may reduce air pollution levels during the lockdown periods worldwide. It may minimize the actual impact of air pollutants on cognitive functions.

Conclusions

Environmental pollution was significantly higher in motor vehicle-congested areas. The cognitive function test parameters AST-mean, AST-mean congruent, AST-mean in-congruent, CRT-mean, and MOT-mean were significantly delayed among the students who studied in school located in the traffic-polluted area. The results further revealed that the students studying in schools located in environmentally polluted areas have attention, thinking and decision-making abilities related problems. Regional and international health officials must establish strict policies to minimize motor vehicle pollutants and develop strategies to control vehicle emissions and reduce pollution and disease burden.

Conflict of Interest

The authors declare that they have no conflict of interests.

Authors' Contributions

S.A.M.: study design, literature review, writing and editing the manuscript; MAS, FH: data checking and verification, JAK, ASM, AA: literature review, data collection and analysis.

Ethics Approval

Ethical approval was obtained from the Institutional Review Board, College of Medicine, King Saud University, Riyadh, KSA(Ref # 21/01099/IRB).

Informed Consent

Informed consent was obtained from the participants.

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Data Availability

Data may be provided to the corresponding author on reasonable request.

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