Particle Pollution and Cognition: Evidence from Sensitive Cognitive Tests in Brazil
Bedi et al., (2021) [*JAERE*]

SFU Mini Course

Myra Yazbeck

University of Ottawa

Motivation

The literature on the link between pollution and cognition

- is still in its nascent phase.
  - pollution and academic achievement (Zhang et al. 2018; Austin et al. 2019; Roth 2019; Gilraine 2020)
  - pollution and worker productivity (Graff Zivin and Neidell 2012; Chang et al. 2016, 2019)
- mainly focuses on fine particulate matter (PM2.5).
  - outdoor $\xrightarrow{\text{easy penetration}}$ indoor
  - $\approx$ 4% of the diameter of a human hair
- overlooks whether and how the effect of PM2.5 on cognition varies across cognitive domains.

Research Question (1/2)

- Are the effects of PM2.5 on cognition wide-ranging or specific to certain cognitive domains?
- The relevance of this question goes beyond academic performance.
  - productivity in labor markets (complex vs less complex tasks)

Research Question (2/2)

- This paper examines the effect of short-term exposure to PM2.5 on cognition as measured by
  - domain-specific and sensitive (reaction times in milliseconds) individual-level cognitive tests.
- The tests were administered to students at the University of Sao Paulo (USP), Brazil.
- The main identification strategy is Ordinary Least Squares (OLS); Instrumental Variables (IV) is employed as a robustness check.

Overview of Results

- Exposure to high levels of PM2.5 reduces cognitive performance on a tests designed to involve “higher mental processes” (fluid reasoning).
- There is no evidence that PM2.5 exposure affects performance on the other cognitive tests.

Contributions (1/3)

- Uncover the impact of exposure to high levels of PM2.5 on a specific cognitive domain: fluid reasoning
  - fluid reasoning
    - independent of acquired or crystalized (or cumulative measures of) intelligence
    - predicts performance in schools and cognitively demanding occupations (Ferrer et al., 2009)

Contributions (2/3)

- Introduce a new (potentially) human capital-dampening mechanism
  - prior mechanism: student absenteeism (Currie et al., 2009)
  - new mechanism: dampening effect on fluid reasoning

Contributions (3/3)

- Add to the literature on the effect of air pollution on the cognitive performance of skilled individuals who have important impacts on economies and societies.
  (Heyes et al., 2019; Archsmith et al., 2018; Allen et al., 2016)

Environmental Conditions

- Source: Sao Paulo state government agency (CETESB)
- PM2.5 levels monitored at a site on the USP campus
- Daily averages computed based on hourly measures
- Daily data on temperature and humidity measured by a monitor in Pinheiros (district in Sao Paolo)
- Wind speed and direction (for robustness check)

Cognitive Tests (1/2)

- 464 participating USP students (unaware of the study's purpose) and they were **incentivized** according to their performance.
- Cognitive tests administered in 54 (on-campus) lab sessions during April 2016 - July 2018
- Test implemented using computers
- Each session
  - 60 minutes
  - five cognitive tests (+ demographic survey)
    - simple attention
    - complex or sustained attantion
    - arithmentic processing speed
    - working memory
    - fluid reasoning

Congintive Tests (2/2)

- Cognitive tests administered in the following fixed order (randomly determined prior to session 1)
  - Simple Visual Reaction Time Task (SRTT) $\rightarrow$ Simple attention
  - Continuous Performance Test (CPT) $\rightarrow$ Complex attention
  - Mental Arithmetic Test (MATH) $\rightarrow$ Arithmetic processing speed
  - Visual Digital Span Test (DS) $\rightarrow$ Working memory
  - Baddeley's Grammatical Reasoning Test (BAD) $\rightarrow$ Fluid reasoning
- Note: The final selection of specific test was ad hoc

Congintive Tests (2/2)

- Simple attention: Click on a target (20 trials).
- Complex attention: Sequence of letters and participant needs to click when X appears.
- Arithmetic processing speed: 20 subtractions, student click only if answer is correct.
- Working memory: Random digits are presented, students are asked to recall them after they disappear.
- Fluid reasoning: Statements are presented paired with letters (A and B), students are asked to judge whether a statement involving the letters is true or false.

Figure 1. Cognitive Tests

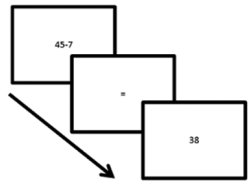
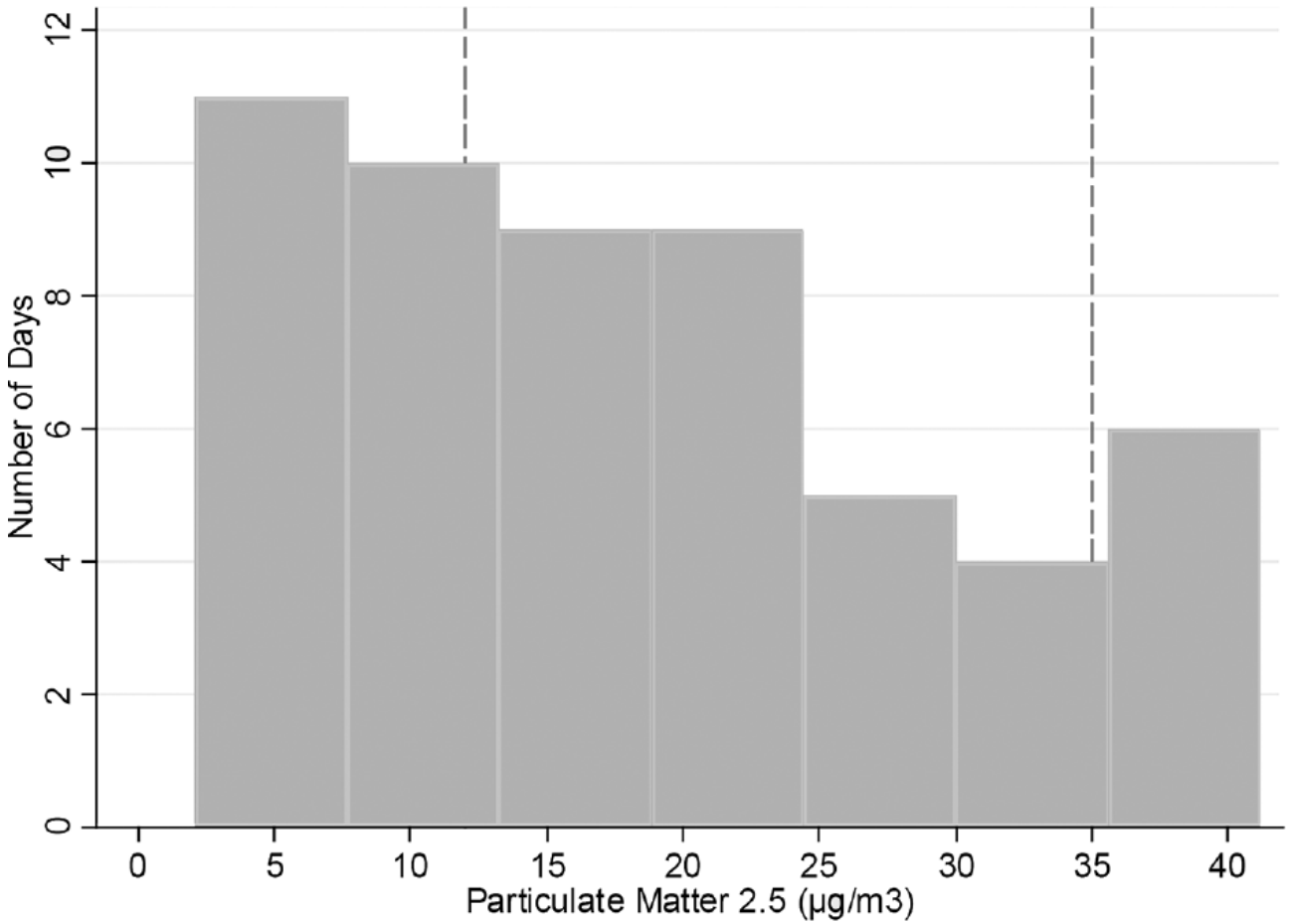
Simple Visual Reaction Time Task (**SRTT**) *Test lasts 20 trials* **Measures Simple Attention**	 Task: Hit mouse button as soon as red dot appears
Continuous Performance Test (**CPT**) *Test consists of 30 blocks of 31 letters with 8 targets ("X")* **Measures Complex or Sustained Attention**	P K X Task: Hit mouse button if and only when X appears
Mental Arithmetic Test (**MATH**) *Test consists of 20 subtraction problems* **Measures Arithmetic Processing Ability**	 Task: Hit mouse button if and only if solution is correct
Visual Digit Span Test (**DS**) *Test lasts 14 trials* **Measures Working Memory**	7 3 9 4 Task: Enter the digits presented in forward order
Baddeley's Grammatical Reasoning Test (**BAD**) *Test lasts 3 minutes* **Measures Fluid Reasoning Ability**	A is followed by B - AB T F Task: Select whether statement is true or false

Figure 2. Histogram of daily PM2.5 levels during test session days (2016–18)



Particulate Matter

- The figure shows the variation the paper exploits.
- Most of the variation tends to below the US EPA regulatory threshold of 35 $\mu g/m^3$.
- The study has 17 days of acceptable air quality PM2.5 $< 12\mu g/m^3$.
- The study has 31 days of moderate air quality $12\mu g/m^3 <$PM2.5 $< 35\mu g/m^3$.
- The study has 6 days of poor air quality PM2.5 $> 35\mu g/m^3$

Identification: Strategy (1/2)

- Baseling OLS analysis:

$$C_{it} = \alpha_0 + \alpha_1 PM2.5_t + X_t'\alpha_2 + \gamma_t + \varepsilon_{it} \quad (1)$$

- $C_{it} \rightarrow$ Cognitive performance measure for student i at time t
- $\text{PM2.5}_t \rightarrow$ Daily level of PM2.5
- $X_t \rightarrow$ Vector of meteorological controls (temperature, humidity, and their squares)
- $\gamma_t \rightarrow$ Fixed effects for year-month and day of week
- $\varepsilon_{it} \rightarrow$ Random error term
- Standard errors clustered at the session level

Identification: Strategy (2/2)

- To explore potentially nonlinear relationships, the authors replace PM2.5 in eq (1) with two indicator variables:
  - **Moderate daily PM2.5 levels:** $12\,\text{mg/m}^3 < \text{PM2.5} < 35\,\text{mg/m}^3$
  - **High daily PM2.5 levels:** $\text{PM2.5} > 35\,\text{mg/m}^3$
  - In comparison to **acceptable PM2.5 levels**.

Identification: Assumption (1/2)

- Plausibly exogenous variation in PM2.5 within the same location (USP campus).
  - Students characteristics are relatively balanced across the differently polluted days.
- Caveat 1: Bias due to participant-level unobserved heterogeneity and selection into tests as a function of environmental conditions
- Resolution 1: No bias (validated in the robustness check)
  - Results insensitive to including student characteristics in eq (1)
  - No evidence of academic ability-related selection when using individual-level GPA as a dependent variable in eq (1)

Identification: Assumption (2/2)

- Caveat 2: correlation of residual variation in PM2.5 exposure with PM2.5 conditions and unobserved student characteristics
- Resolution 2: IV strategy (wind-related variables)
  - wind speed, direction, and their lagged values

Main Results

Table 2: Effects of Particulate Matter 2.5 on Cognitive Performance (Baseline Specification) $\Rightarrow$

	SRTT (m = .669)		CPT (m = .986)		MATH (m = .637)		DS (m = 7.120)		BAD (m = .687)	
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)
PM2.5/10	.062		.001		−.000		.100		−.021*	
	(.126)		(.001)		(.002)		(.066)		(.012)	
	.779		**.289**		**.865**		**.289**		**.289**	
1 if 12 < PM2.5 < 35		−.302		.000		.001		−.080		−.060***
		(.315)		(.002)		(.004)		(.131)		(.021)
		.792		**.831**		**.792**		**.792**		**.035**
1 if PM2.5 > 35		.462		.003		.003		.083		−.173***
		(.612)		(.003)		(.007)		(.222)		(.029)
		.792		**.792**		**.792**		**.792**		**.001**
R^2	.057	.063	.112	.112	.044	.044	.056	.055	.107	.118
N	464	464	464	464	464	464	464	464	464	464

Note. Standard errors that were computed to allow for clustering at the session level are in parentheses. Regression set-specific q-value is below parentheses reported in bold. Estimates for controls not shown: year-month fixed effects, day of week fixed effects, temperature and its square, and relative humidity and its square. m = sample mean.

Main Results

For the BAD test

- Linear specification
  - A 10-unit increase in PM2.5 levels reduces performance on the BAD test by a marginally significant 2 percentage points (3% of the sample mean).
- Nonlinear specification
  - Relative to a day with acceptable PM2.5 levels, performance on a day with moderate and poor PM2.5 levels falls by nearly 6 and 17 percentage points, respectively (9% and 25% of the sample mean, respectively).
- The BAD results from the nonlinear specification survive adjustment for multiple hypothesis testing, with both q-values being below 5%.

Other Results

- Explore the importance of academic ability-related selection: use GPA as an outcome variable.
- The effect of PM2.5 is small and statistically insignificant.

Other Results

Table 5. Test of Selection

	GPA (m = 6.906)	
PM2.5/10	−.140	
	(.093)	
1 if 12 < PM2.5 < 35		−.081
		(.275)
1 if PM2.5 > 35		−.528
		(.433)
R^2	.545	.546
N	455	455

Note. Standard errors are clustered at the session level. Controls not shown: year-month fixed effects, day of week fixed effects, temperature and its square, relative humidity and its square, public high school dummy, private high school dummy, major cohort size, major fixed effects, and entrance year fixed effects. m = sample mean.

Other Results

- Explore the potential endogeneity of PM2.5: use lagged wind speed as an instrument.
- Results are fairly similar but only marginally significant.

Other Results

Table 8. The Effects of Particulate Matter 2.5 on Measured Cognitive Performance (Baseline Specification, IV Estimation)

	SRTT (m = .676) (1)	CPT (m = .986) (2)	MATH (m = .637) (3)	DS (m = 7.130) (4)	BAD (m = .686) (5)
PM2.5/10	−.002	.001	−.002	−.159*	−.031**
	(.164)	(.001)	(.002)	(.094)	(.014)
	.990	**.640**	**.640**	**.228**	**.130**
First-stage Kleibergen-Paap rk Wald *F*-statistic	91.184	91.184	91.184	91.184	91.184
Hausman test for endogeneity *p*-value	.509	.852	.532	.002	.345
N	455	455	455	455	455

Note. Standard errors that were computed to allow for clustering at the session level are in parentheses. Regression set-specific *q*-value is below parentheses reported in bold. Estimates for controls not shown: year-month fixed effects, day of week fixed effects, temperature and its square, and relative humidity and its square. PM2.5 is instrumented with lagged wind speed. m = sample mean.

Conclusion

- This paper investigate the short-term effect of PM2.5 on cognitive performance.
- Results suggest that one cognitive domain (fluid reasoning) may be more affected by high PM2.5 exposure than are other cognitive domains (e.g., attention and memory).
- The impact of PM2.5 on complex cognitive functions may be greater than on less complex functions, especially among high-ability individuals (e.g., students in this study).
- The exact mechanisms are unclear and require further investigation.