

Fine particulate matter exposure and cognitive decline in six U.S. metropolitan areas: The Multi-Ethnic Study of Atherosclerosis (MESA)



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Main Takeaway

Long-term PM_{2.5} exposure was linked with faster decline in Digit Span Backward scores.

Longer averaging windows and lagged exposure definitions did not appear more etiologically relevant.

Background

Air pollution is recognized as an important modifiable risk factor for cognitive impairment and dementia.¹ However, the etiologically relevant exposure window for the air pollution impact remains largely unknown.

We evaluate how different long-term fine particulate matter (PM_{2.5}) exposure windows affect cognitive trajectories in a longitudinal, multi-ethnic cohort in the U.S.

Methods

Study Design: MESA, a prospective cohort study, enrolled adults aged 45-84 with diverse racial/ethnic background from six cities (New York, NY; Baltimore, MD; Chicago, IL; Los Angeles, CA; St. Paul, MN; Winston-Salem, NC) in the U.S. Cognitive data were collected at 4 exams spanning 15 years, including *Exam 5 (2010–2012)*, *Exam 6 (2016–2018)*, *MIND A (2019–2022)*, and *Exam 7/MIND B (2022–2024)*.²

Air Pollution Exposure: PM_{2.5}, estimated using validated spatiotemporal models, linked to participants’ geocoded addresses.^{3,4} Long-term exposure was characterized using *1-, 5-, 10-, 20-, and 30-year averaging windows time-varying, with additional analyses using a 10-year lag*.

Outcomes: *Cognitive Abilities Screening Instrument (CASI), Digit Symbol Coding (DSC), Digit Span (DS; forward & backward)*. All outcomes were standardized to z-scores using the baseline distribution.

Covariates: demographics (age, sex, race/ethnicity), lifestyle and behavior factors (smoking, physical activity, BMI), socioeconomic factors (education, income, marital status), APOE alleles, comorbidities.

Statistical Analysis: Linear mixed-effects models with participant-specific random intercepts. Sensitivity analyses include repeated analysis among participants with at least one follow up visit.

Results

Table 1. Study characteristics for MESA participants (N = 3949).

Variables	Total (N=3949)	Variables	Total (N=3949)
Age (years)	69.6 (9.32)	Education level	
Sex		below high school	536 (13.6 %)
Female	2112 (53.5 %)	High school	702 (17.8 %)
Male	1837 (46.5 %)	Some college	1143 (28.9 %)
Race/Ethnicity		College and above	1563 (39.6 %)
Non-Hispanic White	1616 (40.9 %)	Smoking status	
Non-Hispanic Black	998 (25.3 %)	Never	1794 (45.4 %)
Hispanic/Latino	884 (22.4 %)	Former	1848 (46.8 %)
Chinese	451 (11.4 %)	Current	307 (7.8 %)
Language		PA (MET-hours/week)	45.4 (57.5)
English	3218 (81.5 %)	Marital status	
Spanish	419 (10.6 %)	Single/divorced	1567 (39.7 %)
Chinese	312 (7.9 %)	Married	2288 (57.9 %)
Site		APOE ε4 allele	
New York	693 (17.5 %)	Non-carrier	2724 (69.0 %)
Baltimore	462 (11.7 %)	Carrier	984 (24.9 %)
Chicago	738 (18.7 %)	Missing	241 (6.1 %)
Los Angeles	711 (18.0 %)	Hypertension	
Minneapolis–St. Paul	694 (17.6 %)	No	1598 (40.5 %)
Winston-Salem	651 (16.5 %)	Yes	2349 (59.5 %)
BMI	28.4 (5.60)	Diabetes	
Income level		No	3147 (79.7 %)
Low	1748 (44.3 %)	Yes	763 (19.3 %)
Middle	1381 (35.0 %)		
High	697 (17.7 %)		

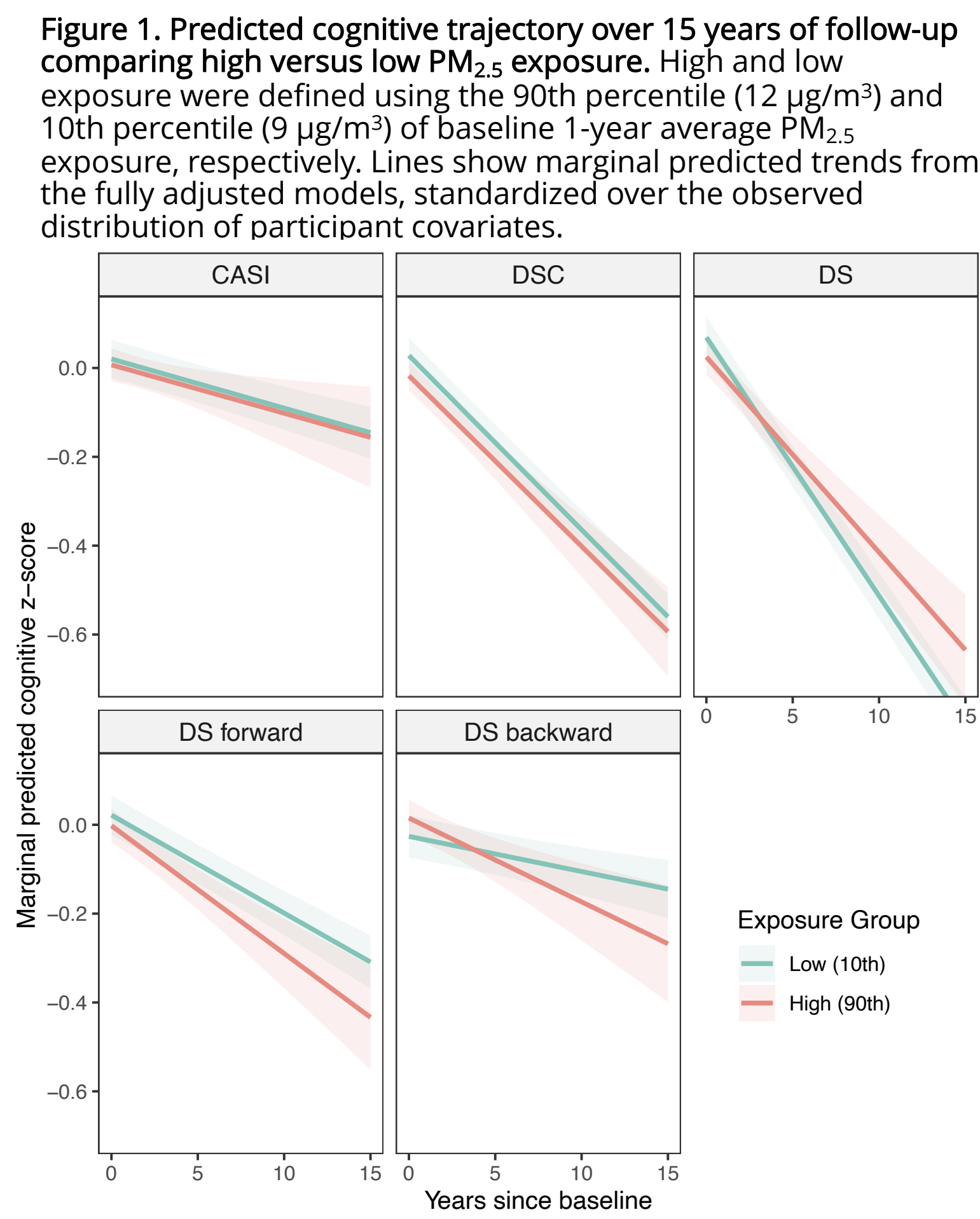
Continuous variables reported as mean (SD); categorical variables as n (%). BMI: body mass index; PA: physical activity.

Table 2. Associations between time-varying PM_{2.5} exposure and cognitive decline (z-score) using different averaging windows: (a) with no lag and (b) with a 10-year lag.

(a) Outcome	1-year	5-year	10-year	20-year	30-year
CASI	0.001 (-0.050, 0.052)	0.016 (-0.032, 0.064)	0.034 (-0.010, 0.079)	0.056 (0.006, 0.106)	0.030 (-0.017, 0.077)
DSC	0.005 (-0.038, 0.049)	0.005 (-0.036, 0.046)	0.004 (-0.033, 0.042)	-0.001 (-0.043, 0.040)	-0.005 (-0.044, 0.035)
DS	0.095 (0.038, 0.151)	0.171 (0.118, 0.224)	0.220 (0.171, 0.269)	0.298 (0.243, 0.353)	0.212 (0.160, 0.264)
DS Forward	-0.045 (-0.097, 0.008)	-0.024 (-0.074, 0.025)	-0.008 (-0.053, 0.038)	0.005 (-0.046, 0.057)	-0.010 (-0.058, 0.038)
DS Backward	-0.073 (-0.132, -0.014)	-0.064 (-0.120, -0.008)	-0.056 (-0.108, -0.004)	-0.070 (-0.128, -0.011)	-0.060 (-0.115, -0.006)

(b) Outcome	1-year	5-year	10-year	20-year
CASI	0.062 (0.019, 0.106)	0.055 (0.012, 0.098)	0.044 (0.002, 0.086)	0.019 (-0.023, 0.060)
DSC	-0.005 (-0.041, 0.031)	-0.009 (-0.045, 0.026)	-0.007 (-0.042, 0.028)	-0.009 (-0.044, 0.026)
DS	0.301 (0.254, 0.349)	0.281 (0.233, 0.328)	0.245 (0.199, 0.291)	0.164 (0.118, 0.210)
DS Forward	0.012 (-0.032, 0.057)	0.017 (-0.027, 0.062)	0.009 (-0.034, 0.052)	-0.011 (-0.053, 0.032)
DS Backward	-0.056 (-0.107, -0.005)	-0.050 (-0.100, 0.000)	-0.051 (-0.099, -0.002)	-0.048 (-0.096, 0.000)

Estimates are from the fully adjusted model adjusting for baseline age, sex, race/ethnicity, language of administration, visit type (in-person or telephone), body mass index, education, marital status, income, smoking status, physical activity, APOE genotype, and field site. Point estimates and 95% confidence intervals are reported as the cognitive z-score change over 10 years per interquartile range increase in PM_{2.5} (2 µg/m³).



Discussion

- The observed longitudinal association was most evident for DS Backward, suggesting that working memory may be more sensitive to long-term PM_{2.5} exposure.
- Similar results were observed among participants with at least one follow-up visit.

Conclusion

In our analyses, we found significantly faster DS Backward decline associated with long-term PM_{2.5} exposure among MESA participants. However, no evidence suggested that longer averaging windows or lagged exposure definitions were more etiologically relevant to cognitive decline.

Reference

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