

Supplemental information

**Ambient fine particulate exposure and subcortical
gray matter microarchitecture in 9- and 10-year-old
children across the United States**

Kirthana Sukumaran, Carlos Cardenas-Iniguez, Elisabeth Burnor, Katherine L. Bottenhorn, Daniel A. Hackman, Rob McConnell, Kiros Berhane, Joel Schwartz, Jiu-Chiuan Chen, and Megan M. Herting

Table S1. PLSC loadings and bootstrap ratios of RSI subcortical gray matter variables and one-year air pollution exposure variables, related to Results.

	Loadings (Dim1)	Bootstrap Ratios (Dim1)
Restricted Isotropic Diffusion (RNI) - Left Hemisphere		
cerebellum	0.13	1.22
thalamus	0.21	1.84
caudate	0.13	1.19
putamen	0.23	2.07
pallidum	0.25	2.10
hippocampus	0.11	0.97
amygdala	0.19	1.76
accumbens	0.29	2.64
Restricted Isotropic Diffusion (RNI) - Right Hemisphere		
cerebellum	0.1	0.99
thalamus	0.32	2.89
caudate	0.23	2.10
putamen	0.21	1.85
pallidum	0.21	1.84
amygdala	0.24	2.20
hippocampus	0.07	0.68
accumbens	0.37	3.285
Restricted Isotropic Diffusion (RNI) - Brainstem		
brainstem	0.34	3.13
Restricted Isotropic Diffusion (RND) - Left Hemisphere		
cerebellum	0.07	0.69
thalamus	-0.07	-0.61
caudate	-0.03	-0.31
putamen	0.04	0.39
pallidum	-0.03	-0.26
hippocampus	0.08	0.76
amygdala	0.08	0.70

accumbens	0.09	0.90
Restricted Isotropic Diffusion (RND) - Right Hemisphere		
cerebellum	0.07	0.712
thalamus	0.02	0.20
caudate	0.04	0.40
putamen	0.08	0.78
pallidum	-0.03	-0.32
hippocampus	-0.04	-0.41
amygdala	0.16	1.49
accumbens	0.07	0.67
Restricted Isotropic Diffusion (RND) - Brainstem		
brainstem	0.17	1.65
Annualized Air Pollution		
PM2.5	0.74	2.84
NO2	0.57	2.36
O3	-0.36	-1.36

Table S2. Effect size estimates for first latent dimension across 10-fold iterations used during cross-validation, related to results.

Fold	Effect Size (%)
1	69.00
2	72.27
3	71.09
4	66.78
5	66.88
6	74.42
7	70.61
8	73.83
9	64.24

Table S3. Gray matter microarchitecture and general cognitive ability (PC1) as outcome, related to Table 2.

Predictors	RNI Thalamus rh			RNI Accumbens lh			RNI Accumbens rh			RNI Brainstem		
	Estimates	std. Error	CI	Estimates	std. Error	CI	Estimates	std. Error	CI	Estimates	std. Error	CI
Intercept	-3.83 ***	0.17	-4.17 -- 3.49	-3.49 ***	0.15	-3.78 -- 3.20	-3.45 ***	0.15	-3.73 -- 3.16	-3.93 ***	0.20	-4.33 -- 3.53
Brain Regions												
RNI Thalamus rh	1.41 ***	0.39	0.64 -- 2.18									
RNI Accumbens lh				0.36	0.36	-0.34 -- 1.07						
RNI Accumbens rh							0.12	0.36	-0.58 -- 0.83			
RNI Brainstem										1.39 **	0.43	0.54 -- 2.24
Sex [Ref:Female]												
Male	0.06 ***	0.01	0.04 -- 0.09	0.06 ***	0.01	0.04 -- 0.09	0.06 ***	0.01	0.04 -- 0.09	0.06 ***	0.01	0.03 -- 0.09
Interview Age	0.02 ***	0.00	0.02 -- 0.03	0.02 ***	0.00	0.02 -- 0.03	0.02 ***	0.00	0.02 -- 0.03	0.02 ***	0.00	0.02 -- 0.03
Race/ Ethnicity [Ref : White]												
African-American	-0.45 ***	0.03	-0.50 -- 0.40	-0.44 ***	0.03	-0.49 -- 0.39	-0.44 ***	0.03	-0.49 -- 0.39	-0.45 ***	0.03	-0.50 -- 0.40
Hispanic	-0.18 ***	0.02	-0.23 -- 0.14	-0.18 ***	0.02	-0.23 -- 0.14	-0.18 ***	0.02	-0.23 -- 0.14	-0.18 ***	0.02	-0.23 -- 0.14
Asian	0.08	0.05	-0.02 -- 0.18	0.08	0.05	-0.02 -- 0.18	0.08	0.05	-0.02 -- 0.19	0.09	0.05	-0.01 -- 0.19
Other ^a	-0.08 ***	0.03	-0.13 -- 0.03	-0.08 **	0.03	-0.13 -- 0.03	-0.08 **	0.03	-0.13 -- 0.03	-0.08 ***	0.03	-0.13 -- 0.03
Parental Education Attainment [Ref: HS Diploma]												
HS Diploma/GED	0.23 ***	0.04	0.14 -- 0.31	0.23 ***	0.04	0.15 -- 0.31	0.23 ***	0.04	0.15 -- 0.31	0.23 ***	0.04	0.15 -- 0.31
Some College	0.41 ***	0.04	0.33 -- 0.48	0.41 ***	0.04	0.33 -- 0.48	0.41 ***	0.04	0.33 -- 0.48	0.41 ***	0.04	0.33 -- 0.48
Bachelor	0.59 ***	0.04	0.51 -- 0.67	0.59 ***	0.04	0.51 -- 0.67	0.59 ***	0.04	0.51 -- 0.67	0.59 ***	0.04	0.51 -- 0.67
Post Graduate Degree]	0.73 ***	0.04	0.65 -- 0.82	0.74 ***	0.04	0.65 -- 0.82	0.74 ***	0.04	0.65 -- 0.82	0.74 ***	0.04	0.65 -- 0.82
Household Income [Ref: <50K]												
>=50K & <100K	0.16 ***	0.02	0.11 -- 0.20	0.16 ***	0.02	0.11 -- 0.20	0.16 ***	0.02	0.11 -- 0.20	0.16 ***	0.02	0.11 -- 0.20
>=100K	0.23 ***	0.02	0.18 -- 0.28	0.23 ***	0.02	0.18 -- 0.28	0.23 ***	0.02	0.18 -- 0.28	0.23 ***	0.02	0.18 -- 0.28
Don't Know or Refuse	0.02	0.03	-0.04 -- 0.07	0.01	0.03	-0.04 -- 0.07	0.01	0.03	-0.04 -- 0.07	0.01	0.03	-0.04 -- 0.07
Parental Employment [Ref:Working Full time/Part time]												
unemployed	-0.02	0.03	-0.09 -- 0.04	-0.02	0.03	-0.09 -- 0.04	-0.02	0.03	-0.09 -- 0.04	-0.02	0.03	-0.09 -- 0.04

RNI Accumbens lh				0.57	0.42	-0.25 - 1.39						
RNI Accumbens rh							0.49	0.42	-0.32 - 1.31			
RNI Brainstem										0.51	0.50	-0.47 - 1.50
Sex [Ref:Female]												
Male	-0.06 ***	0.02	-0.09 - 0.03	-0.06 ***	0.02	-0.09 - 0.03	-0.06 ***	0.02	-0.09 - 0.03	-0.06 ***	0.02	-0.10 - 0.03
Interview Age	0.02 ***	0.00	0.02 - 0.02	0.02 ***	0.00	0.02 - 0.02	0.02 ***	0.00	0.02 - 0.02	0.02 ***	0.00	0.02 - 0.02
Race/ Ethnicity [Ref : White]												
African-American	-0.19 ***	0.03	-0.25 - 0.13	-0.18 ***	0.03	-0.24 - 0.12	-0.18 ***	0.03	-0.24 - 0.12	-0.18 ***	0.03	-0.24 - 0.12
Hispanic	-0.02	0.03	-0.07 - 0.03	-0.02	0.03	-0.07 - 0.03	-0.02	0.03	-0.07 - 0.03	-0.02	0.03	-0.07 - 0.04
Asian	0.23 ***	0.06	0.11 - 0.35	0.23 ***	0.06	0.12 - 0.35	0.23 ***	0.06	0.12 - 0.35	0.24 ***	0.06	0.12 - 0.35
Other ^a	-0.02	0.03	-0.07 - 0.04	-0.02	0.03	-0.07 - 0.04	-0.01	0.03	-0.07 - 0.04	-0.01	0.03	-0.07 - 0.04
Parental Education Attainment [Ref: HS Diploma]												
HS Diploma/GED	0.07	0.05	-0.02 - 0.17	0.08	0.05	-0.02 - 0.17	0.08	0.05	-0.02 - 0.17	0.08	0.05	-0.02 - 0.17
Some College	0.10 *	0.04	0.02 - 0.19	0.10 *	0.04	0.02 - 0.19	0.10 *	0.04	0.02 - 0.19	0.10 *	0.04	0.02 - 0.19
Bachelor	0.16 ***	0.05	0.07 - 0.25	0.16 ***	0.05	0.07 - 0.25	0.16 ***	0.05	0.07 - 0.25	0.16 ***	0.05	0.07 - 0.25
Post Graduate Degree]	0.17 ***	0.05	0.08 - 0.27	0.17 ***	0.05	0.08 - 0.27	0.17 ***	0.05	0.08 - 0.27	0.17 ***	0.05	0.08 - 0.27
Household Income [Ref: <50K]												
>=50K & <100K	0.04	0.03	-0.01 - 0.09	0.04	0.03	-0.01 - 0.09	0.04	0.03	-0.01 - 0.09	0.04	0.03	-0.01 - 0.09
>=100K	0.07 *	0.03	0.01 - 0.12	0.07 *	0.03	0.01 - 0.12	0.07 *	0.03	0.01 - 0.12	0.06 *	0.03	0.01 - 0.12
Don't Know or Refuse	0.00	0.03	-0.06 - 0.07	0.00	0.03	-0.06 - 0.07	0.00	0.03	-0.06 - 0.07	0.00	0.03	-0.06 - 0.07
Parental Employment [Ref:Working Full time/Part time]												
unemployed	-0.02	0.04	-0.09 - 0.05	-0.02	0.04	-0.10 - 0.05	-0.02	0.04	-0.10 - 0.05	-0.02	0.04	-0.10 - 0.05
other	0.00	0.02	-0.04 - 0.04	0.00	0.02	-0.04 - 0.04	0.00	0.02	-0.04 - 0.04	0.00	0.02	-0.04 - 0.04
Perceived Neighborhood Safety	0.02 *	0.01	0.00 - 0.04	0.02 *	0.01	0.00 - 0.04	0.02 *	0.01	0.00 - 0.04	0.02 *	0.01	0.00 - 0.04
MRI Mean Head Motion	-0.16 ***	0.04	-0.23 - 0.09	-0.17 ***	0.04	-0.24 - 0.10	-0.17 ***	0.04	-0.24 - 0.10	-0.17 ***	0.04	-0.23 - 0.10
Handedness [Ref: Right]												
Left	-0.05	0.03	-0.10 - 0.01	-0.04	0.03	-0.10 - 0.01	-0.04	0.03	-0.10 - 0.01	-0.04	0.03	-0.10 - 0.01
Mixed	-0.06 **	0.02	-0.11 - 0.02	-0.06 **	0.02	-0.11 - 0.02	-0.06 **	0.02	-0.11 - 0.02	-0.06 **	0.02	-0.11 - 0.02

MRI Manufacturer [Ref: GE]												
Philips	-0.16	0.10	-0.36 -- 0.03	-0.07	0.09	-0.25 -- 0.11	-0.07	0.09	-0.25 -- 0.11	-0.08	0.09	-0.26 -- 0.10
Siemens	-0.21 **	0.07	-0.34 -- 0.08	-0.17 **	0.07	-0.30 -- 0.04	-0.18 **	0.07	-0.30 -- 0.05	-0.19 **	0.07	-0.32 -- 0.06
Random Effects												
Within variance (σ^2)	0.22			0.22			0.22			0.22		
Between variance (τ_{00})	0.28 _{rel_family_idsite_names}			0.28 _{rel_family_idsite_names}			0.28 _{rel_family_idsite_names}			0.28 _{rel_family_idsite_names}		
	0.01 _{site_names}			0.01 _{site_names}			0.01 _{site_names}			0.01 _{site_names}		
ICC	0.58			0.58			0.58			0.58		
N (Family IDs)	7206			7206			7206			7206		
N(Sites)	21			21			21			21		
N(Observations)	8226			8226			8226			8226		
Marginal R ² / Conditional R ²	0.086 / 0.615			0.086 / 0.613			0.086 / 0.613			0.086 / 0.613		
p<0.05 ** p<0.01 *** p<0.001												

Note: In the table columns Thalamus_lh, Accumbens_lh, Accumbens_rh and Brainstem represent four multiple linear regression models. Marginal R² refers to R² of fixed effects whereas Conditional R² refers to R²(Fixed effects+ Random effects).

Abbreviations: ABCD, Adolescent Brain Cognitive Development; GED, General Educational Development; HS, high school; MRI, magnetic resonance imaging; NA, not applicable; std, standard; CI, confidence Interval; rni, restricted isotropic diffusion; lh, left hemisphere; rh, right hemisphere;

“Other” race/ethnicity category includes subjects who were parent-identified as American Indian/Native American, Alaska Native, Native Hawaiian, Guamanian, Samoan, Other Pacific Islander, Asian Indian, Chinese, Filipino, Japanese, Korean, Vietnamese, Other Asian, or Other Race

Table S5. Gray matter microarchitecture and learning and memory(PC3) as outcome, related to Table 2.

Predictors	RNI Thalamus rh			RNI Accumbens lh			RNI Accumbens rh			RNI Brainstem		
	Estimates	std. Error	CI	Estimates	std. Error	CI	Estimates	std. Error	CI	Estimates	std. Error	CI
Intercept	-1.71 ***	0.17	-2.05 -- 1.37	-1.37 ***	0.15	-1.66 -- 1.08	-1.35 ***	0.15	-1.64 -- 1.06	-1.55 ***	0.21	-1.96 -- 1.15
Brain Regions												
RNI Thalamus rh	1.42 ***	0.40	0.64 -- 2.21									
RNI Accumbens lh				0.40	0.37	-0.32 -- 1.13						
RNI Accumbens rh							0.31	0.37	-0.41 -- 1.03			
RNI Brainstem										0.72	0.45	-0.16 -- 1.60
Sex [Ref:Female]												
Male	-0.11 ***	0.01	-0.14 -- 0.09	-0.11 ***	0.01	-0.14 -- 0.09	-0.11 ***	0.01	-0.14 -- 0.09	-0.11 ***	0.01	-0.14 -- 0.09
Interview Age	0.01 ***	0.00	0.01 -- 0.01	0.01 ***	0.00	0.01 -- 0.01	0.01 ***	0.00	0.01 -- 0.01	0.01 ***	0.00	0.01 -- 0.01

Race/ Ethnicity [Ref : White]												
African-American	-0.36 ***	0.03	-0.41 -- 0.31	-0.35 ***	0.03	-0.40 -- 0.30	-0.35 ***	0.03	-0.40 -- 0.30	-0.35 ***	0.03	-0.41 -- 0.30
Hispanic	-0.09 ***	0.02	-0.14 -- 0.05	-0.09 ***	0.02	-0.14 -- 0.05	-0.09 ***	0.02	-0.14 -- 0.05	-0.09 ***	0.02	-0.14 -- 0.05
Asian	-0.00	0.05	- 0.11 – 0.1 0	-0.00	0.05	- 0.11 – 0.10	-0.00	0.05	- 0.11 – 0. 10	-0.00	0.05	- 0.11 – 0.1 1
Other ^a	-0.08 **	0.03	-0.13 -- 0.03	-0.08 **	0.03	-0.13 -- 0.03	-0.08 **	0.03	-0.13 -- 0.03	-0.08 **	0.03	-0.13 -- 0.03
Parental Education Attainment [Ref: HS Diploma]												
HS Diploma/GED	0.07	0.04	- 0.01 – 0.1 6	0.08	0.04	- 0.01 – 0.16	0.08	0.04	- 0.01 – 0. 16	0.08	0.04	- 0.01 – 0.1 6
Some College	0.12 **	0.04	0.04 – 0.2 0	0.12 **	0.04	0.04 – 0.20	0.12 **	0.04	0.04 – 0. 20	0.12 **	0.04	0.04 – 0.2 0
Bachelor	0.24 ***	0.04	0.15 – 0.3 2	0.24 ***	0.04	0.15 – 0.32	0.24 ***	0.04	0.15 – 0. 32	0.24 ***	0.04	0.15 – 0.3 2
Post Graduate Degree]	0.34 ***	0.04	0.25 – 0.4 2	0.34 ***	0.04	0.26 – 0.43	0.34 ***	0.04	0.26 – 0. 43	0.34 ***	0.04	0.26 – 0.4 3
Household Income [Ref: <50K]												
>=50K & <100K	0.07 **	0.02	0.02 – 0.1 1	0.07 **	0.02	0.02 – 0.11	0.07 **	0.02	0.02 – 0. 11	0.07 **	0.02	0.02 – 0.1 1
>=100K	0.10 ***	0.03	0.05 – 0.1 5	0.10 ***	0.03	0.05 – 0.15	0.10 ***	0.03	0.05 – 0. 15	0.10 ***	0.03	0.05 – 0.1 5
Don't Know or Refuse	-0.01	0.03	- 0.07 – 0.0 5	-0.01	0.03	- 0.07 – 0.05	-0.01	0.03	- 0.07 – 0. 05	-0.01	0.03	- 0.07 – 0.0 5
Parental Employment [Ref:Working Full time/Part time]												
unemployed	-0.01	0.03	- 0.08 – 0.0 6	-0.01	0.03	- 0.08 – 0.06	-0.01	0.03	- 0.08 – 0. 06	-0.01	0.03	- 0.08 – 0.0 6
other	-0.01	0.02	- 0.04 – 0.0 3	-0.01	0.02	- 0.04 – 0.03	-0.01	0.02	- 0.04 – 0. 03	-0.01	0.02	- 0.04 – 0.0 3
Perceived Neighborhood Safety	0.01	0.01	- 0.01 – 0.0 2	0.01	0.01	- 0.01 – 0.02	0.01	0.01	- 0.01 – 0. 02	0.01	0.01	- 0.01 – 0.0 2
MRI Mean Head Motion	-0.07 *	0.03	-0.13 -- 0.01	-0.08 **	0.03	-0.15 -- 0.02	-0.08 **	0.03	-0.14 -- 0.02	-0.08 *	0.03	-0.14 -- 0.02
Handedness [Ref: Right]												
Left	-0.09 **	0.03	-0.14 -- 0.03	-0.08 **	0.03	-0.14 -- 0.03	-0.08 **	0.03	-0.14 -- 0.03	-0.08 **	0.03	-0.13 -- 0.03
Mixed	-0.00	0.02	- 0.04 – 0.0 4	-0.00	0.02	- 0.04 – 0.04	-0.00	0.02	- 0.04 – 0. 04	-0.00	0.02	- 0.04 – 0.0 4
MRI Manufacturer [Ref: GE]												
Philips	-0.16 *	0.07	-0.30 -- 0.02	-0.07	0.06	- 0.19 – 0.06	-0.06	0.06	- 0.19 – 0. 06	-0.09	0.07	- 0.22 – 0.0 4
Siemens	-0.04	0.05	- 0.14 – 0.0 5	-0.01	0.05	- 0.10 – 0.08	-0.01	0.04	- 0.10 – 0. 07	-0.03	0.05	- 0.12 – 0.0 6
Random Effects												
Within variance (σ^2)	0.14			0.14			0.14			0.14		
Between variance (τ_{00})	0.27 <small>rel_family_idsite_names</small>			0.27 <small>rel_family_idsite_names</small>			0.27 <small>rel_family_idsite_names</small>			0.27 <small>rel_family_idsite_names</small>		
	0.01 <small>site_names</small>			0.01 <small>site_names</small>			0.01 <small>site_names</small>			0.01 <small>site_names</small>		
ICC	0.67			0.66			0.67			0.66		

N (Family IDs)	7206	7206	7206	7206
N(Sites)	21	21	21	21
N(Observations)	8226	8226	8226	8226
Marginal R ² / Conditional R ²	0.121 / 0.706	0.121 / 0.705	0.121 / 0.706	0.121 / 0.706
p<0.05 ** p<0.01 *** p<0.001				

Note: In the table columns Thalamus_lh, Accumbens_lh, Accumbens_rh and Brainstem represent four multiple linear regression models. Marginal R² refers to R² of fixed effects whereas Conditional R² refers to R²(Fixed effects+ Random effects).

Abbreviations: ABCD, Adolescent Brain Cognitive Development; GED, General Educational Development; HS, high school; MRI, magnetic resonance imaging; NA, not applicable; rni, restricted isotropic diffusion; lh, left hemisphere; rh, right hemisphere; std, standard; CI, confidence Interval

^a“Other” race/ethnicity category includes subjects who were parent-identified as American Indian/Native American, Alaska Native, Native Hawaiian, Guamanian, Samoan, Other Pacific Islander, Asian Indian, Chinese, Filipino, Japanese, Korean, Vietnamese, Other Asian, or Other Race

Table S6. Gray matter microarchitecture and internalizing problems as outcomes, related to Table 2.

Predictors	RNI Thalamus rh			RNI Accumbens lh			RNI Accumbens rh			RNI Brainstem		
	Estimates	std. Error	CI	Estimates	std. Error	CI	Estimates	std. Error	CI	Estimates	std. Error	CI
Intercept	53.54 ***	2.21	49.21 – 57.87	51.88 ***	1.66	48.63 – 55.14	52.90 ***	1.69	49.59 – 56.20	47.24 ***	2.12	43.08 – 51.39
Brain Regions												
RNI Thalamus rh	2.11	5.00	-7.69 – 11.92									
RNI Accumbens lh				9.14 *	3.85	1.58 – 16.69						
RNI Accumbens rh							5.38	4.07	-2.60 – 13.36			
RNI Brainstem										18.40 ***	4.42	9.74 – 27.06
Race/ Ethnicity [Ref : White]												
African-American	-2.91 ***	0.54	-3.97 – -1.85	-2.94 ***	0.53	-3.99 – -1.89	-2.92 ***	0.54	-3.97 – -1.87	-3.01 ***	0.53	-4.06 – -1.97
Hispanic	0.41	0.45	-0.48 – 1.29	0.37	0.45	-0.51 – 1.25	0.39	0.45	-0.50 – 1.27	0.37	0.45	-0.51 – 1.25
Asian	-1.87	1.06	-3.96 – 0.21	-1.91	1.06	-3.99 – 0.17	-1.90	1.09	-4.03 – 0.23	-1.80	1.07	-3.89 – 0.29
Other ^a	-1.02 *	0.52	-2.04 – 0.00	-1.05 *	0.52	-2.07 – 0.04	-1.03 *	0.52	-2.05 – 0.02	-1.05 *	0.52	-2.06 – 0.03
Parental Education Attainment [Ref: HS Diploma]												
HS Diploma/GED	0.78	0.82	-0.82 – 2.38	0.75	0.80	-0.83 – 2.33	0.75	0.81	-0.84 – 2.35	0.75	0.81	-0.84 – 2.34
Some College	1.93 *	0.77	0.42 – 3.44	1.91 *	0.75	0.43 – 3.38	1.91 *	0.76	0.41 – 3.41	1.93 *	0.76	0.44 – 3.42
Bachelor	1.38	0.82	-0.23 – 3.00	1.37	0.80	-0.21 – 2.95	1.36	0.82	-0.24 – 2.97	1.38	0.82	-0.21 – 2.98

Post Graduate Degree]	1.01	0.84	-0.63 – 2.65	0.99	0.82	-0.61 – 2.59	0.99	0.83	-0.63 – 2.62	1.01	0.83	-0.61 – 2.63
Household Income [Ref: <50K]												
>=50K & <100K	0.05	0.47	-0.86 – 0.97	0.07	0.46	-0.84 – 0.98	0.07	0.47	-0.85 – 0.98	0.05	0.47	-0.86 – 0.97
>=100K	-1.30 *	0.51	-2.31 – -0.30	-1.28 *	0.51	-2.28 – -0.28	-1.29 *	0.51	-2.30 – -0.28	-1.32 *	0.51	-2.33 – -0.31
Don't Know or Refuse	-0.81	0.60	-1.99 – 0.37	-0.80	0.60	-1.98 – 0.37	-0.81	0.60	-1.99 – 0.37	-0.83	0.60	-2.01 – 0.34
Parental Employment [Ref:Working Full time/Part time]												
unemployed	1.56 *	0.64	0.31 – 2.81	1.55 *	0.64	0.30 – 2.79	1.55 *	0.64	0.30 – 2.80	1.58 *	0.64	0.33 – 2.83
other	1.46 ***	0.35	0.76 – 2.15	1.46 ***	0.35	0.77 – 2.16	1.46 ***	0.36	0.76 – 2.15	1.45 ***	0.35	0.75 – 2.14
Perceived Neighborhood Safety	-0.94 ***	0.15	-1.25 – -0.64	-0.94 ***	0.15	-1.24 – -0.64	-0.94 ***	0.15	-1.24 – -0.64	-0.94 ***	0.15	-1.24 – -0.64
MRI Mean Head Motion	0.36	0.45	-0.53 – 1.24	0.29	0.45	-0.59 – 1.17	0.31	0.45	-0.57 – 1.20	0.40	0.45	-0.48 – 1.28
Handedness [Ref: Right]												
Left	0.75 *	0.35	0.06 – 1.43	0.75 *	0.35	0.07 – 1.44	0.75 *	0.35	0.06 – 1.44	0.73 *	0.35	0.05 – 1.42
Mixed	0.79 **	0.28	0.25 – 1.33	0.78 **	0.28	0.24 – 1.33	0.79 **	0.28	0.25 – 1.33	0.79 **	0.28	0.25 – 1.33
MRI Manufacturer [Ref: GE]												
Philips	-1.58	1.06	-3.67 – 0.50	-1.70	0.99	-3.65 – 0.25	-1.60	1.01	-3.58 – 0.39	-2.27 *	1.01	-4.26 – -0.29
Siemens	0.01	0.72	-1.40 – 1.42	0.13	0.70	-1.24 – 1.50	0.07	0.70	-1.31 – 1.45	-0.34	0.70	-1.72 – 1.04
Random Effects												
Within variance (σ^2)	0.01			0.01			0.01			0.01		
Between variance (τ_{00})	89.79 _{rel_family_idsite_names}			89.80 _{rel_family_idsite_names}			89.79 _{rel_family_idsite_names}			89.82 _{rel_family_idsite_names}		
	0.29 _{site_names}			0.29 _{site_names}			0.29 _{site_names}			0.29 _{site_names}		
ICC	1.00			1.00			1.00			1.00		
N (Family IDs)	7656			7656			7656			7656		
N(Sites)	21			21			21			21		
N(Observations)	8794			8794			8794			8794		
Marginal R ² / Conditional R ²	0.035 / 1.000			0.035 / 1.000			0.035 / 1.000			0.036 / 1.000		
p<0.05 ** p<0.01 *** p<0.001												

Note: In the table columns Thalamus_lh, Accumbens_lh, Accumbens_rh and Brainstem represent four multiple linear regression models. Marginal R² refers to R² of fixed effects whereas Conditional R² refers to R²(Fixed effects + Random effects)

Abbreviations: ABCD, Adolescent Brain Cognitive Development; GED, General Educational Development; HS, high school; MRI, magnetic resonance imaging; NA, not applicable; rni, restricted isotropic diffusion; lh, left hemisphere; rh, right hemisphere; std, standard; CI, confidence Interval

“Other” race/ethnicity category includes subjects who were parent-identified as American Indian/Native American, Alaska Native, Native Hawaiian, Guamanian, Samoan, Other Pacific Islander, Asian Indian, Chinese, Filipino, Japanese, Korean, Vietnamese, Other Asian, or Other Race

unemployed	1.45 *	0.62	0.25 – 2.66	1.46 *	0.62	0.25 – 2.67	1.48 *	0.62	0.27 – 2.69	1.45 *	0.62	0.24 – 2.66
other	1.03 **	0.34	0.36 – 1.69	1.02 **	0.34	0.36 – 1.69	1.02 **	0.34	0.35 – 1.68	1.03 **	0.34	0.37 – 1.70
Perceived Neighborhood Safety	-0.90 ***	0.15	-1.20 – -0.61	-0.91 ***	0.15	-1.20 – -0.61	-0.91 ***	0.15	-1.20 – -0.62	-0.90 ***	0.15	-1.19 – -0.61
MRI Mean Head Motion	0.40	0.44	-0.46 – 1.26	0.46	0.44	-0.41 – 1.32	0.49	0.44	-0.38 – 1.35	0.43	0.44	-0.43 – 1.29
Handedness [Ref: Right]												
Left	1.33 ***	0.34	0.66 – 2.00	1.32 ***	0.34	0.66 – 1.99	1.32 ***	0.34	0.65 – 1.99	1.33 ***	0.34	0.66 – 1.99
Mixed	0.02	0.27	-0.51 – 0.56	0.02	0.27	-0.52 – 0.56	0.01	0.27	-0.52 – 0.55	0.02	0.27	-0.51 – 0.56
MRI Manufacturer [Ref: GE]												
Philips	-1.12	0.94	-2.96 – 0.72	-1.09	0.90	-2.85 – 0.67	-0.97	0.91	-2.75 – 0.80	-1.52	0.91	-3.29 – 0.26
Siemens	0.19	0.63	-1.04 – 1.41	0.06	0.62	-1.16 – 1.28	0.09	0.62	-1.13 – 1.31	0.03	0.63	-1.19 – 1.26
Random Effects												
Within variance (σ^2)	0.02			0.02			0.02			0.02		
Between variance (τ_{00})	80.81 _{rel_family_idsite_names}			80.88 _{rel_family_idsite_names}			80.90 _{rel_family_idsite_names}			80.83 _{rel_family_idsite_names}		
	0.21 _{site_names}			0.21 _{site_names}			0.22 _{site_names}			0.21 _{site_names}		
ICC	1.00			1.00			1.00			1.00		
N (Family IDs)	7656			7656			7656			7656		
N(Sites)	21			21			21			21		
N(Observations)	8794			8794			8794			8794		
Marginal R ² / Conditional R ²	0.039 / 1.000			0.039 / 1.000			0.039 / 1.000			0.039 / 1.000		
p<0.05 ** p<0.01 *** p<0.001												

Note: In the table columns Thalamus_lh, Accumbens_lh, Accumbens_rh and Brainstem represent four multiple linear regression models. Marginal R² refers to R² of fixed effects whereas Conditional R² refers to R²(Fixed effects + Random effects)

Abbreviations: ABCD, Adolescent Brain Cognitive Development; GED, General Educational Development; HS, high school; MRI, magnetic resonance imaging; NA, not applicable; rni, restricted isotropic diffusion; lh, left hemisphere; rh, right hemisphere; std, standard; CI, confidence Interval

“Other” race/ethnicity category includes subjects who were parent-identified as American Indian/Native American, Alaska Native, Native Hawaiian, Guamanian, Samoan, Other Pacific Islander, Asian Indian, Chinese, Filipino, Japanese, Korean, Vietnamese, Other Asian, or Other Race

Table S8. Demographics of study dataset compared to full baseline ABCD Study dataset. Data are expressed as number (percentage) of participants unless otherwise indicated, related to STAR Methods.

	Full Dataset (N=11876)	Study Dataset (N=8796)	P- value ^b
Age (months)			
Mean (SD)	119 (7.50)	119 (7.52)	0.073
Median [Min, Max]	119 [107, 133]	119 [107, 133]	
Sex			
Female	5680 (47.8%)	4257 (48.4%)	0.426
Male	6196 (52.2%)	4539 (51.6%)	
Race and Ethnicity			
Non-Hispanic White	6180 (52.0%)	4781 (54.4%)	<0.001
Black/African-American	1784 (15.0%)	1148 (13.1%)	
Hispanic	2411 (20.3%)	1786 (20.3%)	
Asian	252 (2.1%)	172 (2.0%)	
Other ^a	1247 (10.5%)	909 (10.3%)	
Missing	2 (0.0%)	0 (0%)	
Parental Education Attainment			
< HS Diploma	593 (5.0%)	385 (4.4%)	0.008
HS Diploma/GED	1132 (9.5%)	753 (8.6%)	
Some College	3079 (25.9%)	2239 (25.5%)	
Bachelor	3015 (25.4%)	2298 (26.1%)	
Post Graduate Degree	4043 (34.0%)	3121 (35.5%)	
Missing	14 (0.1%)	0 (0%)	
Parents' Employment			
Working Full time/Part time	8217 (69.2%)	6203 (70.5%)	0.095
Unemployed	674 (5.7%)	446 (5.1%)	

Other	2929 (24.7%)	2147 (24.4%)	
Missing	56 (0.5%)	0 (0%)	
Perceived Neighborhood Safety			
Mean (SD)	3.89 (0.976)	3.91 (0.958)	0.093
Median [Min, Max]	4.00 [1.00, 5.00]	4.00 [1.00, 5.00]	
Missing	8 (0.1%)	0 (0%)	
Household Income			
<\$50k	3223 (27.1%)	2234 (25.4%)	0.004
≥\$50k <\$100k	3071 (25.9%)	2315 (26.3%)	
≥\$100K	4564 (38.4%)	3551 (40.4%)	
Don't Know or Refuse	1016 (8.6%)	696 (7.9%)	
Missing	2 (0.0%)	0 (0%)	
Handedness			
Right	9428 (79.4%)	7069 (80.4%)	0.215
Left	848 (7.1%)	605 (6.9%)	
Mixed	1600 (13.5%)	1122 (12.8%)	
MRI manufacturer			
GE Medical Systems	2977 (25.1%)	1978 (22.5%)	<0.001
Philips	1521 (12.8%)	966 (11.0%)	
Siemens	7303 (61.5%)	5852 (66.5%)	
Missing	75 (0.6%)	0 (0%)	
Annual NO2 (ppb)			
Mean (SD)	18.6 (5.77)	18.7 (5.82)	0.17
Median [Min, Max]	18.8 [0.618, 37.9]	19.0 [0.729, 37.9]	
Missing	652 (5.5%)	0 (0%)	
Annual O3 (8-hr max, ppb)			
Mean (SD)	41.5 (4.41)	41.6 (4.44)	0.225
Median [Min, Max]	40.6 [29.8, 56.4]	40.7 [29.8, 56.4]	

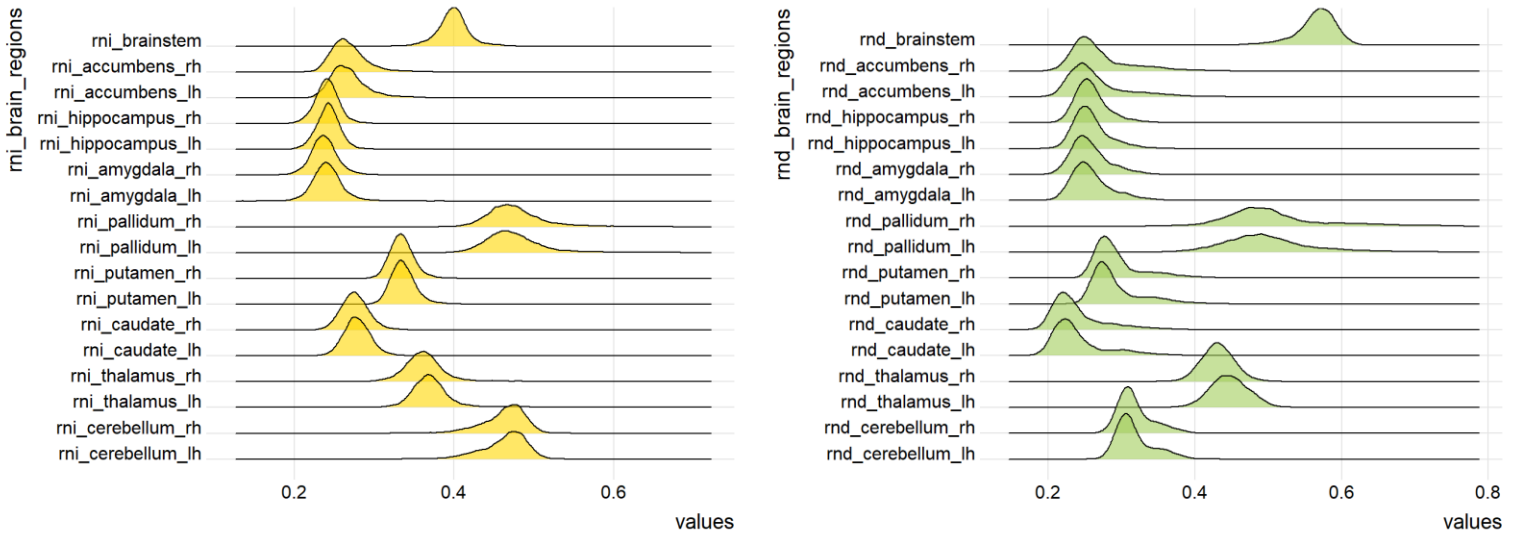
Missing	652 (5.5%)	0 (0%)	
Annual PM2.5 (µg/m3)			
Mean (SD)	7.66 (1.56)	7.62 (1.56)	0.032
Median [Min, Max]	7.73 [1.72, 15.9]	7.66 [1.72, 15.9]	
Missing	652 (5.5%)	0 (0%)	

Abbreviations: ABCD, Adolescent Brain Cognitive Development; GED, General Educational Development; HS, high school; MRI, magnetic resonance imaging

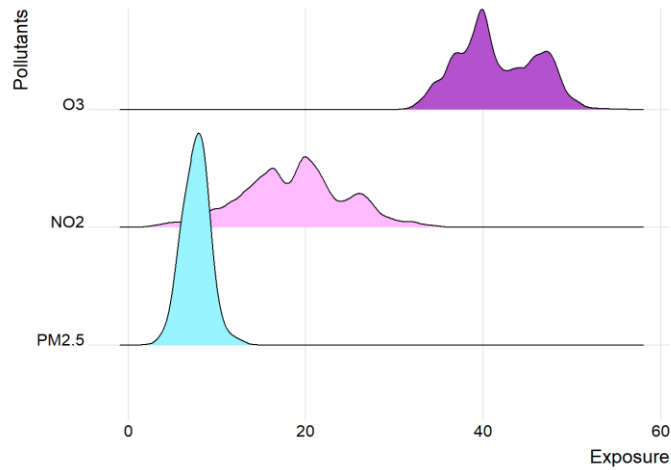
^a The "Other" race/ethnicity category includes subjects who were parent-identified as American Indian/Native American, Alaska Native, Native Hawaiian, Guamanian, Samoan, Other Pacific Islander, Asian Indian, Chinese, Filipino, Japanese, Korean, Vietnamese, Other Asian, or Other Race

^b P-value from the Pearson χ -squared test comparing the distributions of categorical variables between the full ABCD baseline dataset and the final analytic dataset or P-value from the ANOVA test comparing means of continuous variables between the full ABCD baseline dataset and the final analytic dataset.

Figure S1. Density distribution plots visualizing distribution of restriction spectrum imaging variables (3a) and one-year pollutant exposures (3b) included in the analysis, related to Results.



3a. Restriction spectrum imaging variables



3b. Pollutant Exposures

Figure S2. Scree Plot of the number of latent dimensions in PLSC plotted alongside the percentage of variance explained (left axis) and inertia (right axis), referring to the sum of squared singular values of each latent dimension. Kaiser criterion line (violet line) is used to identify the number of latent dimensions above average (when the sum of squared singular values is greater than 1), related to Results

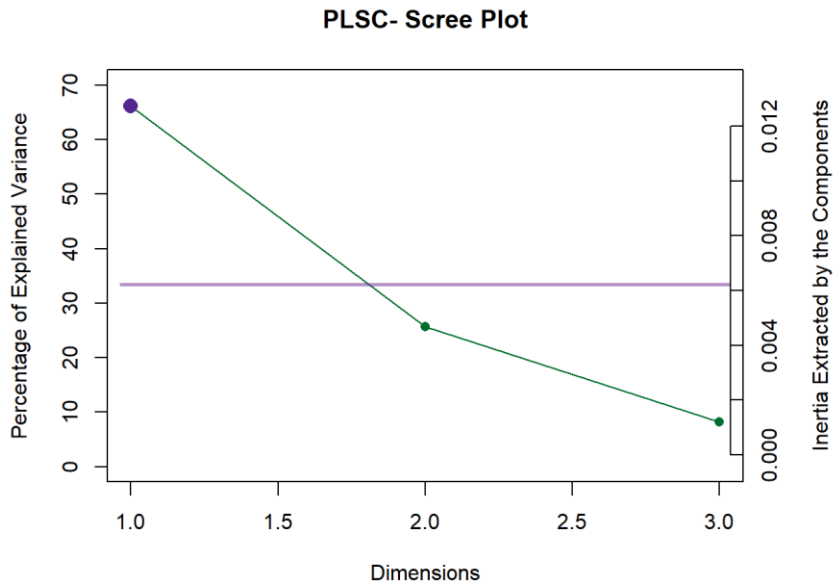


Figure S3. Permutation test for the inertia explained by latent dimension 1 across 10,000 permuted samples.

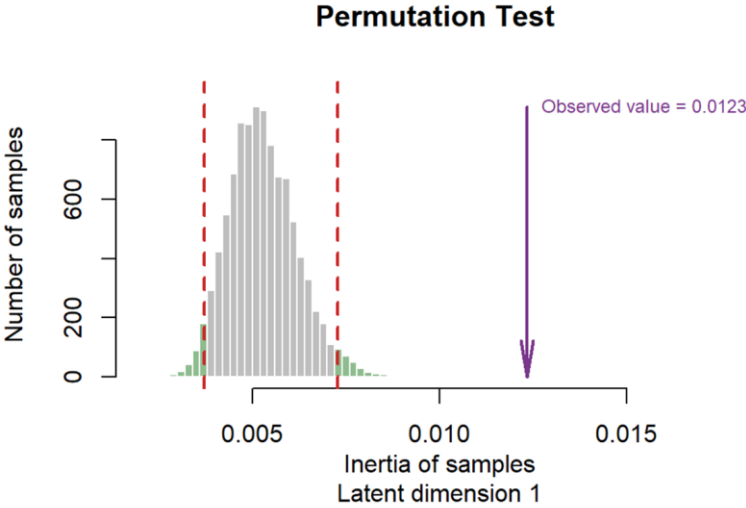
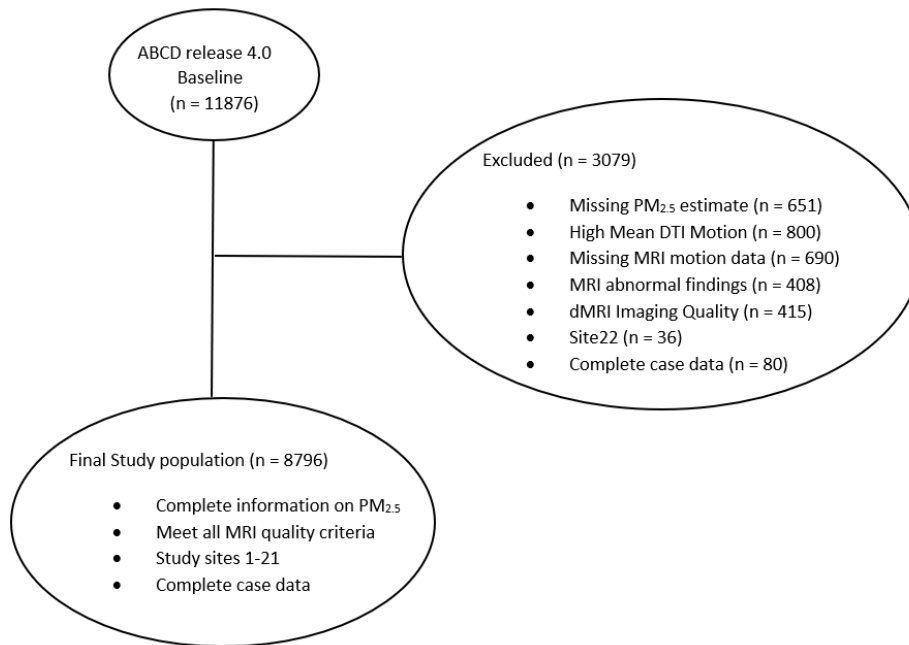
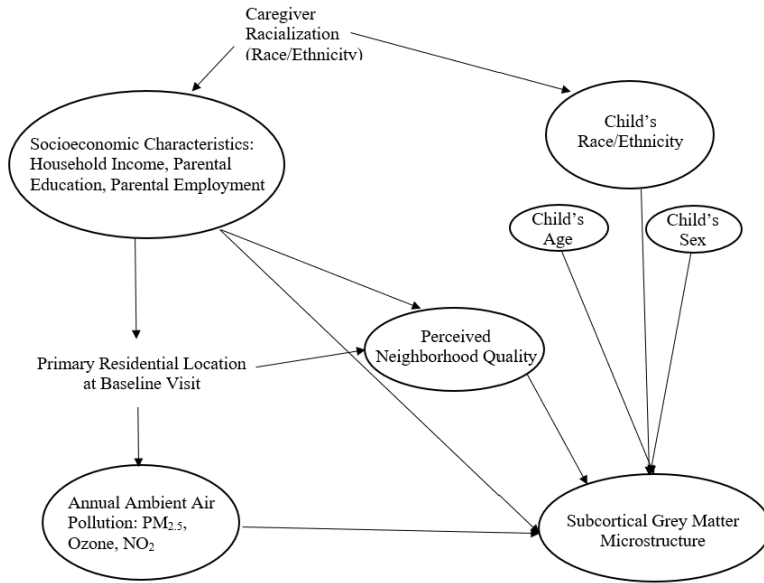


Figure S4. Flowchart of exclusion and inclusion criteria used to compile final sample for analyses, related to STAR Methods.



Abbreviations: ABCD, Adolescent Brain Cognitive Development; DTI, Diffusion Tensor Imaging; MRI, magnetic resonance imaging; dMRI, Diffusion magnetic resonance imaging; n, number of participants.

Figure S5. Directed Acyclic Graph of potential confounders that may predict subcortical grey matter neurodevelopment and one-year exposure to ambient air pollutants. Circles represent variables assessed in the dataset and included as covariates in final adjusted models, related to STAR Methods.



Supplemental Material Text:

1. Cross-Validation (CV) procedure and results:

Cross-Validation simulates replicability of models by partitioning the dataset and running models on subsets of the data [S1], thus avoiding overfitting of the PLSC model. Moreover, a 10-fold CV was chosen as it has been shown empirically to yield a less biased test error rate. In order to accomplish this, the residualized data blocks (i.e. representing brain variables and exposure variables after adjusting for key confounding and precision variables) were partitioned into 10 groups. For each iteration, a different fold was excluded from analysis (including permutation and bootstrapping procedures), thus ensuring that across 10 iterations, all folds would be equally represented in the CV procedures. Effect size estimates from all 10 iterations were gathered to visualize the robustness of results across the 10-folds.

In the CV analyses, the previously identified regions (i.e. bilateral nucleus accumbens, right thalamus, and brainstem) were found to contribute consistently towards the first latent dimension accounting on average for 69.6% of the variance [range: 66.6% - 74.4]. Some brain regions like the left putamen and right caudate were less consistently significant across CV folds.

2. Partial Least Square Correlation (PLSC) formal expression

PLSC [S2] decomposes the correlation (or dot product) between matrix $\mathbf{X}_{q \times m}$, where q represents number of participants ($N = 8096$), m represents the variables measuring diffusion across brain regions ($N = 34$) matrix $\mathbf{Y}_{q \times n}$, and n represents air pollution variables ($N = 3$), using Singular Value Decomposition (SVD) [S3, S4].

$$\mathbf{SVD}(\mathbf{X}^T \mathbf{Y}_{n \times m}) = \mathbf{U}_{n \times p} \mathbf{S}_{p \times p} \mathbf{V}_{p \times m}^T; \text{ where } n = 34, p = 3, m = 3$$

$$\mathbf{U}^T \mathbf{U} = \mathbf{V}^T \mathbf{V} = \mathbf{I} \text{ (where } \mathbf{I} \text{ is the identity matrix)}$$

Specifically, Residuals obtained from MLR models with RSI gray matter brain region as the outcome were stored in a matrix denoted by \mathbf{X} , whereas the residuals obtained from MLR models fitted on the outcome variables measuring air pollution exposure were stored in the matrix \mathbf{Y} . In order to make the matrices comparable, centering and normalization is performed on the \mathbf{X} and \mathbf{Y} matrices by subtracting the mean and dividing by the standard deviation for each observed value of the columns in the matrices.

The SVD decomposition provides us with three matrices: left singular matrix \mathbf{U} (describing variable loadings for RSI brain measures), right singular matrix \mathbf{V} (describing variable loadings for air pollution measures) and \mathbf{S} as a square matrix of all the singular values. The number of p , which is limited by the rank of $\mathbf{X}^T \mathbf{Y}$, describes the number of

latent dimensions found in this PLSC solution. The SVD procedure finds latent vectors with maximal covariance that are 1) uncorrelated and 2) normalized [S5]

Since the SVD is computed on the dot product of matrices \mathbf{X} and \mathbf{Y} , the resultant latent variables focus on shared information between \mathbf{X} and \mathbf{Y} which are obtained by projecting the original matrices onto their respective loadings. Thus, we obtain the latent variable for \mathbf{X} by computing $\mathbf{L}_x = \mathbf{X} \mathbf{U}$, and for \mathbf{Y} by computing $\mathbf{L}_y = \mathbf{Y} \mathbf{V}$. Each column of \mathbf{P} , \mathbf{Q} , \mathbf{L}_x , and \mathbf{L}_y corresponds to a latent dimension of the PLSC solution, and latent dimensions are organized in order of decreasing total covariance explained (i.e., the first column of these matrices will correspond to the first latent dimension).

References:

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