Supplemental Materials

Using non-parametric Bayes shrinkage to assess relationships between multiple environmental and social stressors and neonatal size and body composition in the Healthy Start cohort

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Text S1. Fitting the NPB Model

As described in the main paper, the response variable is modeled as:

where is a vector of exposures, is a vector of pairwise multiplicative interactions between the exposures or the exposures and the covariates, is a vector of covariates, and is the error variance. The main effects regression coefficients and the interaction term coefficients are modeled with a Dirichlet process (DP) prior and the covariate coefficients and error variance are modeled with semi-conjugate priors. These priors are defined as follows:

Prior to fitting the NPB model, we identified the set of prior distributions for the model. We set 5 so that the mass of the beta distribution was between 0.4 and 0.6. We also set 10 and 10. For all other hyperparameters, we used the default settings as provided in the package “mmpack” (Hoskovec, 2019).

The NPB model was implemented using 5000 iterations, with 2500 discarded as burn-in.

Table S1. Results of single exposure linear regression models adjusted for all individual level covariates.1 Results are presented for a 1 SD increase in each exposure. Results where the confidence interval does not contain zero are bolded

|  |  |  |  |
| --- | --- | --- | --- |
|  |  | Birth Weight (g) | Adiposity (%Fat Mass) |
| Environmental Exposure | SD2 | Beta (95% CI) | Beta (95% CI) |
| Mean PM2.5 (μg/m3) | 0.6 | 8.7 (-34.8, 52.1) | -0.04 (-0.40, 0.33) |
| Mean O3 (ppb) | 3.1 | -41.9 (-104.3, 20.5) | -0.24 (-0.77, 0.28) |
| Mean temperature (°F) | 4.8 | -22.1 (-83.9, 39.6) | -0.16 (-0.67, 0.36) |
| Tree cover (%) | 3.1 | 12.9 (-27.6, 53.3) | 0.11 (-0.22, 0.45) |
| Impervious surfaces (%) | 13.3 | -16.4 (-54.4, 21.6) | -0.12 (-0.44, 0.19) |
| AADT (vehicles per day per km2) | 8203 | 10.2 (-25.1, 45.4) | 0.18 (-0.11, 0.47) |
| Distance to TRI sites (km) | 2.6 | 12.9 (-28.9, 54.8) | 0.08 (-0.26, 0.43) |
| Distance to NPL sites (km) | 3.3 | 19.8 (-17.1, 56.7) | 0.13 (-0.18, 0.44) |
| Distance to waste sites (km) | 2.3 | **39.7 (4.1, 75.4)** | **0.36 (0.07, 0.66)** |
| Distance to major emitters (km) | 3.2 | 16.1 (-19, 51.3) | 0.13 (-0.16, 0.42) |
| Distance to CAFOs (km) | 6.8 | -27.5 (-177.1, 122.2) | 0.02 (-1.19, 1.23) |
| Distance to mines or wells (km) | 2.1 | -13.3 (-57.7, 31.1) | -0.07 (-0.44, 0.30) |
| Social Exposures |  |  |  |
| CVD hospitalizations (n per 10,000) | 45.2 | -19.4 (-55.3, 16.5) | -0.24 (-0.54, 0.05) |
| Respiratory hospitalizations (n per 10,000) | 33.0 | -24.3 (-60.1, 11.5) | -0.25 (-0.55, 0.05) |
| Violent crimes (n per 1,000) | 6.3 | -4.2 (-37.7, 29.4) | -0.19 (-0.47, 0.09) |
| Property crimes (n per 1,000) | 36.0 | -11.1 (-44.4, 22.2) | **-0.31 (-0.59, -0.04)** |
| Less than HS diploma (%) | 12.7 | -18.6 (-58.5, 21.4) | -0.20 (-0.53, 0.13) |
| Unemployment (%) | 5.0 | **-40.9 (-76.8, -4.9)** | -0.28 (-0.58, 0.02) |
| Households speaking limited English (%) | 10.9 | -14.5 (-52.1, 23.1) | -0.03 (-0.33, 0.28) |
| Households in poverty (%) | 8.3 | -16.2 (-53.2, 20.8) | -0.25 (-0.55, 0.06) |
| Persons of color (%) | 22.9 | -7.1 (-50, 35.8) | -0.07 (-0.42, 0.28) |
| 1 Models are adjusted for: maternal race/ethnicity, maternal educational attainment, maternal pre-pregnancy BMI, maternal age at delivery, maternal smoking during pregnancy, second-hand smoke exposure during pregnancy, mean perceived stress scale score across pregnancy, mean postnatal depression score across pregnancy, season of conception, year of conception, longitude, latitude, and the interaction between longitude and latitude. Models of adiposity are also adjusted for the number of days between delivery and PEA POD measurements.  2 Effect estimates are reported for a 1 standard deviation increase in each exposure variable | | | |

Table S2. Results from the sensitivity analysis exploring alternative values for the mass concentration hyperparameter in the NPB models of birth weight

|  |  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| Gamma distribution parameters |  | | |  | |  | |  | | |
| Variable | Posterior Meana  (95% CI) | PIP | Posterior Meana  (95% CI) | | PIP | Posterior Meana  (95% CI) | PIP | | Posterior Meana  (95% CI) | PIP |
| Environmental Exposures |  |  |  | |  |  |  | |  |  |
| Mean PM2.5 (μg/m3) | -3.0 (-33.5, 6.1) | 0.35 | -11.4 (-73.3, 3.4) | | 0.47 | -4.2 (-43.3, 7.1) | 0.36 | | -3.9 (-45.7, 7.3) | 0.34 |
| Mean O3 (ppb) | -6.0 (-60.2, 5.8) | 0.38 | -13.5 (-93.4, 3.9) | | 0.48 | -6.1 (-62.4, 6.9) | 0.37 | | -8.8 (-84.2, 6.5) | 0.40 |
| Mean temperature (°F) | 0.3 (-16.3, 21.5) | 0.32 | -2.5 (-35.9, 11.2) | | 0.31 | -1.2 (-22.5, 14.6) | 0.31 | | 8.9 (-18.7, 186.1) | 0.34 |
| Mean O3 × Mean temperature | -156.3 (-207.7,  -116.4) | 1.00 | -195.1 (-251.6,  -125.7) | | 1.00 | -161.6 (-222.1, -118.5) | 1.00 | | -164.1 (-250.9,  -114.9) | 1.00 |
| Tree cover (%) | -0.8 (-15.2, 8.7) | 0.28 | -0.8 (-15.5, 8.4) | | 0.25 | -0.8 (-15.1, 9.3) | 0.28 | | -0.5 (-13.5, 10.8) | 0.28 |
| Impervious surfaces (%) | -1.0 (-14.8, 7.8) | 0.29 | -1.3 (-17.5, 5.8) | | 0.25 | -1 (-16.7, 7.6) | 0.27 | | -1.0 (-16.1, 8.1) | 0.27 |
| AADT (vehicles per day-km2) | 0.6 (-8.3, 17.2) | 0.26 | 0.7 (-8.6, 17.8) | | 0.22 | 0.5 (-9.4, 16.7) | 0.25 | | 0.8 (-8.2, 19.1) | 0.25 |
| Distance to TRI sites (km) | -1.1 (-17.3, 9.4) | 0.31 | -1.0 (-16.9, 7.6) | | 0.25 | -1.5 (-19.2, 8.6) | 0.30 | | -1.4 (-18.2, 8.6) | 0.29 |
| Distance to NPL sites (km) | -0.2 (-12.3, 11.8) | 0.28 | -0.2 (-11.9, 12.5) | | 0.24 | -0.3 (-13.5, 11.3) | 0.26 | | -0.2 (-11.2, 11.6) | 0.24 |
| Distance to waste sites (km) | 3.3 (-7.6, 41.2) | 0.33 | 2.2 (-8.2, 35.4) | | 0.27 | 2.9 (-8, 39.6) | 0.30 | | 3.1 (-7.3, 40.5) | 0.31 |
| Distance to major emitters (km) | 0.2 (-10.5, 12.9) | 0.27 | 0.0 (-10.5, 11.8) | | 0.22 | 0.1 (-10.7, 13.8) | 0.24 | | 0.2 (-10.6, 15.1) | 0.26 |
| Distance to CAFOs (km) | -2.3 (-28.9, 12.8) | 0.35 | -4.3 (-56.8, 11.2) | | 0.34 | -2.4 (-32.7, 14.3) | 0.33 | | -2.4 (-33.4, 12.5) | 0.32 |
| Distance to mines or wells (km) | -2.0 (-22.6, 8.4) | 0.33 | -3.3 (-34.4, 5.9) | | 0.32 | -2.3 (-25.6, 7.5) | 0.32 | | -1.9 (-24.4, 9.1) | 0.31 |
| Social Exposures |  |  |  | |  |  |  | |  |  |
| CVD hospitalizations (n per 10,000) | -1.2 (-16.2, 6.0) | 0.29 | -1.7 (-20.8, 5.5) | | 0.27 | -1.5 (-17.6, 7.0) | 0.28 | | -1.5 (-19.8, 7.8) | 0.30 |
| Resp. hospitalizations (n per 10,000) | -2.4 (-25.2, 4.4) | 0.32 | -2.9 (-28.1, 3.3) | | 0.31 | -2.5 (-25.1, 5.8) | 0.32 | | -2.9 (-30.5, 4.1) | 0.32 |
| Violent crimes (n per 1,000) | -0.3 (-12.8, 11.8) | 0.28 | -0.7 (-13.7, 8.4) | | 0.24 | -0.4 (-12.2, 11.2) | 0.27 | | -0.4 (-12.2, 9.3) | 0.24 |
| Property crimes (n per 1,000) | -1.5 (-18.4, 7.2) | 0.32 | -1.8 (-21.6, 5.3) | | 0.28 | -1.6 (-18.4, 6) | 0.29 | | -1.5 (-18.9, 6.5) | 0.28 |
| Less than HS diploma (%) | -1.3 (-17.9, 10.3) | 0.31 | -2.0 (-23.3, 5.6) | | 0.28 | -1.6 (-20.3, 7.6) | 0.30 | | -1.7 (-19.5, 8.5) | 0.29 |
| Unemployment (%) | -7.7 (-60.5, 2.4) | 0.44 | -6.7 (-50.2, 2.2) | | 0.39 | -7.0 (-55.9, 2.3) | 0.41 | | -7.1 (-51.7, 2.1) | 0.44 |
| Households speaking limited English (%) | -1.2 (-17.2, 7.9) | 0.29 | -1.3 (-18.5, 6.7) | | 0.25 | -1.5 (-17.3, 5.5) | 0.27 | | -1.3 (-17, 6.9) | 0.28 |
| Households in poverty (%) | -1.0 (-15.3, 8.9) | 0.29 | -1.0 (-16.5, 8.3) | | 0.26 | -1.1 (-16.4, 8.1) | 0.26 | | -1.3 (-16.8, 7.4) | 0.27 |
| Persons of color (%) | -0.4 (-15.7, 14.7) | 0.30 | -0.5 (-15.5, 11.1) | | 0.24 | -0.9 (-17.3, 10.5) | 0.27 | | -0.2 (-13.5, 12) | 0.25 |
| a Models are adjusted for: maternal race/ethnicity, maternal educational attainment, maternal pre-pregnancy BMI, maternal age at delivery, maternal smoking during pregnancy, second-hand smoke exposure during pregnancy, mean perceived stress scale score across pregnancy, mean postnatal depression score across pregnancy, season of conception, year of conception, longitude, latitude, and the interaction between longitude and latitude.  b Models of adiposity are also adjusted for the number of days between delivery and PEA POD measurements.  c Effect estimates are reported for a 1 standard deviation increase in each exposure variable | | | | | | | | | | |

Table S3. Results from the sensitivity analysis exploring alternative values for the mass concentration hyperparameter in the NPB models of adiposity

|  |  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| Gamma distribution parameters |  | | |  | |  | |  | | |
| Variable | Posterior Meana,b  (95% CI) | PIP | Posterior Meana,b  (95% CI) | | PIP | Posterior Meana,b  (95% CI) | PIP | | Posterior Meana,b  (95% CI) | PIP |
| Environmental Exposures |  |  |  | |  |  |  | |  |  |
| Mean PM2.5 (μg/m3) | -0.01 (-0.15, 0.10) | 0.27 | -0.01 (-0.14, 0.10) | | 0.29 | -0.01 (-0.16, 0.11) | 0.3 | | -0.01 (-0.16, 0.12) | 0.28 |
| Mean O3 (ppb) | -0.03 (-0.30, 0.10) | 0.35 | -0.03 (-0.24, 0.08) | | 0.35 | -0.03 (-0.27, 0.07) | 0.34 | | -0.03 (-0.28, 0.08) | 0.33 |
| Mean temperature (°F) | -0.02 (-0.22, 0.10) | 0.32 | -0.01 (-0.20, 0.11) | | 0.31 | -0.02 (-0.23, 0.11) | 0.33 | | -0.01 (-0.19, 0.10) | 0.29 |
| Mean O3 × Mean temperature | 0.00 (-0.07, 0.00) | 0.03 | -0.01 (-0.09, 0.00) | | 0.05 | 0.00 (-0.06, 0.00) | 0.03 | | -0.01 (-0.11, 0.00) | 0.05 |
| Tree cover (%) | -0.01 (-0.15, 0.10) | 0.27 | 0.00 (-0.13, 0.11) | | 0.27 | -0.01 (-0.16, 0.12) | 0.28 | | 0.00 (-0.13, 0.13) | 0.26 |
| Impervious surfaces (%) | -0.01 (-0.15, 0.10) | 0.27 | -0.01 (-0.15, 0.08) | | 0.28 | -0.01 (-0.16, 0.06) | 0.28 | | -0.01 (-0.16, 0.08) | 0.27 |
| AADT (vehicles per day-km2) | 0.01 (-0.08, 0.20) | 0.26 | 0.01 (-0.09, 0.22) | | 0.28 | 0.01 (-0.08, 0.23) | 0.26 | | 0.02 (-0.07, 0.24) | 0.25 |
| Distance to TRI sites (km) | -0.01 (-0.18, 0.10) | 0.29 | -0.01 (-0.15, 0.10) | | 0.3 | -0.01 (-0.16, 0.11) | 0.29 | | -0.01 (-0.16, 0.10) | 0.27 |
| Distance to NPL sites (km) | 0.00 (-0.13, 0.10) | 0.26 | 0.00 (-0.14, 0.13) | | 0.27 | 0.00 (-0.14, 0.14) | 0.27 | | 0.00 (-0.12, 0.14) | 0.25 |
| Distance to waste sites (km) | 0.03 (-0.09, 0.40) | 0.30 | 0.04 (-0.07, 0.43) | | 0.33 | 0.04 (-0.07, 0.43) | 0.33 | | 0.04 (-0.06, 0.40) | 0.31 |
| Distance to major emitters (km) | 0.00 (-0.09, 0.20) | 0.24 | 0.01 (-0.09, 0.19) | | 0.27 | 0.01 (-0.10, 0.19) | 0.27 | | 0.01 (-0.09, 0.21) | 0.25 |
| Distance to CAFOs (km) | -0.02 (-0.26, 0.20) | 0.33 | -0.01 (-0.26, 0.19) | | 0.36 | -0.02 (-0.27, 0.17) | 0.36 | | -0.02 (-0.25, 0.17) | 0.3 |
| Distance to mines or wells (km) | -0.03 (-0.28, 0.00) | 0.36 | -0.03 (-0.26, 0.07) | | 0.36 | -0.03 (-0.27, 0.05) | 0.36 | | -0.03 (-0.27, 0.05) | 0.32 |
| Social Exposures |  |  |  | |  |  |  | |  |  |
| CVD hospitalizations (n per 10,000) | -0.02 (-0.22, 0.00) | 0.32 | -0.02 (-0.20, 0.06) | | 0.33 | -0.02 (-0.23, 0.07) | 0.35 | | -0.02 (-0.19, 0.08) | 0.3 |
| Resp. hospitalizations (n per 10,000) | -0.03 (-0.23, 0.00) | 0.32 | -0.02 (-0.23, 0.05) | | 0.33 | -0.02 (-0.22, 0.05) | 0.32 | | -0.02 (-0.22, 0.06) | 0.3 |
| Violent crimes (n per 1,000) | -0.01 (-0.15, 0.10) | 0.29 | -0.01 (-0.15, 0.07) | | 0.29 | -0.01 (-0.16, 0.09) | 0.3 | | -0.01 (-0.16, 0.09) | 0.27 |
| Property crimes (n per 1,000) | -0.07 (-0.39, 0.00) | 0.48 | -0.06 (-0.39, 0.03) | | 0.47 | -0.07 (-0.39, 0.02) | 0.5 | | -0.06 (-0.40, 0.03) | 0.44 |
| Less than HS diploma (%) | -0.02 (-0.20, 0.10) | 0.31 | -0.02 (-0.19, 0.09) | | 0.32 | -0.02 (-0.23, 0.07) | 0.3 | | -0.02 (-0.22, 0.07) | 0.28 |
| Unemployment (%) | -0.04 (-0.31, 0.00) | 0.37 | -0.04 (-0.32, 0.05) | | 0.39 | -0.04 (-0.34, 0.04) | 0.38 | | -0.04 (-0.33, 0.04) | 0.34 |
| Households speaking limited English (%) | 0.00 (-0.12, 0.20) | 0.27 | 0.01 (-0.10, 0.19) | | 0.28 | 0.01 (-0.11, 0.23) | 0.28 | | 0.01 (-0.11, 0.22) | 0.26 |
| Households in poverty (%) | -0.02 (-0.23, 0.00) | 0.31 | -0.02 (-0.21, 0.06) | | 0.33 | -0.03 (-0.25, 0.04) | 0.33 | | -0.02 (-0.23, 0.05) | 0.28 |
| Persons of color (%) | 0.00 (-0.14, 0.10) | 0.27 | 0.00 (-0.13, 0.16) | | 0.29 | 0.00 (-0.13, 0.14) | 0.27 | | 0.00 (-0.13, 0.14) | 0.26 |
| a Models are adjusted for: maternal race/ethnicity, maternal educational attainment, maternal pre-pregnancy BMI, maternal age at delivery, maternal smoking during pregnancy, second-hand smoke exposure during pregnancy, mean perceived stress scale score across pregnancy, mean postnatal depression score across pregnancy, season of conception, year of conception, longitude, latitude, and the interaction between longitude and latitude.  b Models of adiposity are also adjusted for the number of days between delivery and PEA POD measurements.  c Effect estimates are reported for a 1 standard deviation increase in each exposure variable | | | | | | | | | | |

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Figure S1. Correlations between exposure variables

Chart, scatter chart

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Figure S2. Scatter plot showing the relationship between birth weight predicted by the NPB model and the observed birth weights in the Healthy Start cohort.

Chart, scatter chart

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Figure S3. Scatter plot showing the relationship between adiposity predicted by the NPB model and the observed adiposity in the Healthy Start cohort.

Diagram

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Figure S4. Exposure response curve for the 2D smoothed term for ozone and temperature in the generalized additive model (A) and accumulated local effects (ALE) plots showing the effect of temperature (B) and ozone (C) on birth weight.

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Figure S5: Sensitivity analysis restricting the data in the GAM to the middle 95% of temperature and ozone observations. Plots show the exposure-response curve for the 2D smoothed term for ozone and temperature in the generalized additive model (A) and accumulated local effects (ALE) plots showing the effect of temperature (B) and ozone (C) on birth weight.

Diagram

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Figure S6: GAMs stratified by maternal race/ethnicity. Plots show the exposure-response curve for the 2D smoothed term for ozone and temperature in the generalized additive model (A) and accumulated local effects (ALE) plots showing the effect of temperature (B) and ozone (C) on birth weight for non-Hispanic White (NHW) mothers and the exposure response curve for the 2-D smoothed term for ozone and temperature in the generalized additive model (D) and ALE plots showing the effect of temperature (E) and ozone (F) on birth weight for mothers identifying as any race or ethnicity other than non-Hispanic White. Note: Models were fit using all available data.