Science Advances

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Supplementary Materials for

Childhood lead exposure is associated with lower cognitive functioning at older ages

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Table S1. Growth curve modeling predicting cognitive function by childhood lead exposure, adult education and health outcomes, Health and Retirement Study, 1998-2016 (N=7,432 person-wave observations). AIC = Akaike information criterion; BIC = Bayesian information criterion; ref. = reference; *p < .05. **p < .01. ***p < .001

	Model 0		Model 1		Model 2		Model 3		Model 4	
	Intercept	Slope	Intercept	Slope	Intercept	Slope	Intercept	Slope	Intercept	Slope
Fixed Effects										
Age (centered)	-0.050***		-0.050***		-0.049***		-0.062***		-0.066***	
Age-squared	-0.001***		-0.001***		-0.001***		-0.001***		-0.001***	
Lead	0.075	0.002	0.087	0.002	0.054	0.002	0.066	0.002	0.063	0.001
Acidic/Alkaline Water	0.083	0.010	0.112	0.009	0.096	0.012	0.097	0.010	0.106	0.011
Lead X Acidic/Alkaline Water	**-0.361****	**-0.006**	**-0.408****	-0.006	**-0.268***	-0.009	**-0.261***	-0.006	**-0.271***	-0.005
Educational Attainment (ref.= <High School)										
High School					0.491***	-0.005	0.448***	-0.006	0.453***	-0.005
Some College					0.693***	-0.003	0.624***	-0.006	0.627***	-0.005
College +					0.955***	0.001	0.829***	-0.005	0.830***	-0.004
Income							0.019***	0.001	0.019***	0.001
Wealth							0.024***	0.001*	0.023***	0.002*
Stroke									-0.156**	-0.009
Hypertension									0.014	0.010**
Heart diseases									0.011	0.000
Covariates										
Female	0.133**	-0.004	0.136**	-0.004	0.201***	-0.004	0.217***	-0.002	0.211***	-0.002
Race/Ethnicity (ref.=NH-White)										
Non-Hispanic, Black	-0.582***	-0.015*	-0.513***	-0.015*	-0.424***	-0.014	-0.344***	-0.009	-0.358***	-0.011
Hispanic	-0.268	-0.005	-0.284*	-0.004	-0.168	-0.004	-0.132	-0.003	-0.141	-0.003
Other	-0.497*	-0.001	-0.512*	-0.000	-0.169	0.001	-0.130	0.005	-0.138	0.009
Childhood SES (ref.=0)										
1			-0.037	-0.001	0.045	-0.001	0.045	-0.001	0.046	-0.001
2			-0.097	0.003	0.084	0.005	0.084	0.005	0.083	0.006
3+			-0.014	-0.002	0.171**	-0.002	0.176**	-0.001	0.169**	-0.002
Poor Childhood Health			-0.161	0.001	-0.083	0.002	-0.064	0.003	-0.060	0.003
Southern Born			-0.156**	0.003	-0.109*	0.003	-0.109*	0.004	-0.094	0.004
Intercept	0.289***		0.341***		-0.389***		-0.608***		-0.599***	
Variance components										
Variance of random intercept	0.378***		0.373***		0.298***		0.288***		0.283***	
Variance of random slope	0.001***		0.001***		0.001***		0.001***		0.001***	
Residual variance	0.313***		0.313***		0.313***		0.312***		0.312***	
Goodness-of-fit										
AIC	15255.47		15258.05		15070.48		15022.62		15004.94	
BIC	15400.65		15472.37		15326.28		15306.08		15329.87	

Table S2. Logit and OLS predicting differences in adult education, SES and cardiovascular health outcomes by childhood lead exposure, Health and Retirement Study, 1998 (N=1,089). [a] High school or more is reference group. All models adjust for age, sex and race/ethnicity. Because our growth curve results only identified level differences in cognitive performance by childhood lead exposure, not slope differences in the rate of cognitive change, we fit models with adulthood SES and health outcomes at baseline.
*p<0.05; **p<0.01; ***p<0.001.

	Less than High School[a]	Income	Wealth
	OR	Beta	Beta
Lead	0.701	-0.610***	-0.037
Acidic/Alkaline Water	0.677	-0.569	-0.438
Lead X Acidic/Alkaline Water	**4.663***	0.466	0.146
Constant	0.019	13.478	4.245
R^2	0.110***	0.129***	0.128***
	Stroke	Hypertension	Heart Diseases
	OR	OR	OR
Lead	1.180	1.029	1.058
Acidic/Alkaline Water	2.347	0.804	1.023
Lead X Acidic/Alkaline Water	0.391	0.855	1.094
Constant	0.002	0.065**	0.000
R^2	0.056*	0.027***	0.062**

Table S3. Decomposition of the effect of childhood lead exposure on cognitive functioning using the Karlson, Holm and Breen method, Health and Retirement Study (N=1,089). Note: We included all the proposed mediators in one model and compared it with the restricted model that accounts for childhood lead exposure and covariates including age, sex, race/ethnicity, childhood SES, childhood health and place of birth. Because our growth curve results only identified level differences in cognitive performance by childhood lead exposure, not slope differences in the rate of cognitive change, we fit models with adulthood SES and health outcomes at baseline. *p<0.05; **p<0.01; ***p<0.001.

	%
Decomposition of total effect of childhood lead exposure on cognitive functioning	
Total effect	-
Direct effect	74.31%
Indirect effect	25.69%
Decomposition of indirect effect by educational, SES, and cardiovascular health pathways	
Education pathway	24.28%
Income pathway	1.00%
Wealth pathway	2.16%
Stroke pathway	-0.07%
Hypertension pathway	-1.46%
Heart disease pathway	-0.22%

Table S4. Growth curve modeling predicting cognitive function by childhood lead exposure, adult education and health outcomes with the stricter specification of acidic water (pH ≤ 6.4) and alkaline water (pH ≥ 8.6), Health and Retirement Study, 1998-2016 (N=7,432 person-wave observations). AIC = Akaike information criterion; BIC = Bayesian information criterion; ref. = reference; *p < .05. **p < .01. ***p < .001.

	Model 0		Model 1		Model 2		Model 3		Model 4	
	Intercept	Slope	Intercept	Slope	Intercept	Slope	Intercept	Slope	Intercept	Slope
Fixed Effects										
Age (centered)	-0.049***		-0.049***		-0.048***		-0.061***		-0.065***	
Age-squared	-0.001***		-0.001***		-0.001***		-0.001***		-0.001***	
Lead	0.064	0.002	0.073	0.002	0.047	0.001	0.061	0.001	0.057	0.001
Acidic/Alkaline Water	0.089	0.001	0.123	0.001	0.103	0.003	0.104	0.001	0.123	0.002
Lead X Acidic/Alkaline Water	**-0.374***	-0.000	**-0.423***	-0.001	**-0.287+**	-0.001	**-0.292+**	0.002	**-0.307***	0.002
Educational Attainment (ref.= <High School)										
High School					0.497***	-0.005	0.454***	-0.007	0.459***	-0.005
Some College					0.699***	-0.003	0.628***	-0.006	0.632***	-0.005
College +					0.959***	0.001	0.831***	-0.006	0.832***	-0.004
Income							0.019***	0.001	0.019***	0.001
Wealth							0.024*	0.001*	0.023**	0.002*
Stroke									-0.156**	-0.010
Hypertension									0.014	0.010**
Heart diseases									0.010	0.000
Covariates										
Female	0.133**	-0.004	0.136**	-0.004	0.200***	-0.004	0.217***	-0.002	0.211***	-0.002
Race/Ethnicity (ref.=NH-White)										
Non-Hispanic, Black	-0.582***	-0.015*	-0.516***	-0.016*	-0.426***	-0.014	-0.345***	-0.009	-0.359***	-0.011
Hispanic	-0.270	-0.005	-0.287*	-0.005	-0.172	-0.004	-0.136	-0.003	-0.144	-0.004
Other	-0.487*	-0.000	-0.505*	0.001	-0.162	0.002	-0.124	0.006	-0.132	0.009
Childhood SES (ref.=0)										
1			-0.037	-0.001	0.045	-0.001	0.045	-0.001	0.046	-0.001
2			-0.100	0.003	0.083	0.005	0.083	0.005	0.082	0.006
3+			-0.011	-0.002	0.173**	-0.002	0.178**	-0.001	0.170**	-0.002
Poor Childhood Health			-0.163*	0.001	-0.085	0.001	-0.066	0.003	-0.062	0.003
Southern Born			-0.149**	0.002	-0.105	0.003	-0.104	0.004	-0.090	0.004
Intercept	0.290***		0.342***		-0.393***		-0.614***		-0.604***	
Variance components										
Variance of random intercept	0.380**		0.374***		0.298***		0.288***		0.283***	
Variance of random slope	0.001***		0.001***		0.001***		0.001***		0.001***	
Residual variance	0.313***		0.313***		0.313***		0.312***		0.312***	
Goodness-of-fit										
AIC	15258.99		15261.81		15072.51		15023.89		15006.47	
BIC	15404.18		15476.13		15328.31		15307.34		15331.41	

Table S5. Growth curve modeling predicting cognitive function by childhood lead exposure, adult education and health outcomes with the inclusive specification of acidic water (pH ≤ 6.6) and alkaline water (pH ≥ 8.4), Health and Retirement Study, 1998-2016 (N=7,432 person-wave observations). AIC = Akaike information criterion; BIC = Bayesian information criterion; ref. = reference; *p < .05. **p < .01. ***p < .001.

	Model 0		Model 1		Model 2		Model 3		Model 4	
	Intercept	Slope	Intercept	Slope	Intercept	Slope	Intercept	Slope	Intercept	Slope
Fixed Effects										
Age (centered)	-0.050***		-0.050***		-0.049***		-0.095***		-0.099***	
Age-squared	-0.001***		-0.001***		-0.001***		-0.001***		-0.001***	
Lead	0.079	0.002	0.090*	0.002	0.059	0.002	0.072	0.002	0.069	0.001
Acidic/Alkaline Water	0.068	0.008	0.086	0.007	0.079	0.009	0.095	0.009	0.104	0.011
Lead X Acidic/Alkaline Water	**-0.343****	-0.006	**-0.377****	-0.005	**-0.253***	-0.007	**-0.262***	-0.006	**-0.272***	-0.006
Educational Attainment (ref.= <High School)										
High School					0.490***	-0.005	0.447***	-0.007	0.452***	-0.005
Some College					0.693***	-0.003	0.624***	-0.007	0.628***	-0.005
College +					0.955***	0.001	0.828***	-0.006	0.829***	-0.004
Income							0.019***	0.001	0.019***	0.001
Wealth							0.024***	0.002*	0.023***	0.002*
Stroke									-0.158***	-0.010
Hypertension									0.015	0.010**
Heart diseases									0.009	0.000
Covariates										
Female	0.132**	-0.004	0.135*	-0.004	0.200***	-0.004	0.217***	-0.002	0.211***	-0.002
Race/Ethnicity (ref.=NH-White)										
Non-Hispanic, Black	-0.584***	-0.015*	-0.514***	-0.016*	-0.425***	-0.014*	-0.345***	-0.009	-0.359***	-0.011
Hispanic	-0.267	-0.005	-0.282*	-0.004	-0.167	-0.004	-0.130	-0.002	-0.138	-0.003
Other	-0.493*	-0.001	-0.506*	0.000	-0.164	0.001	-0.127	0.005	-0.134	0.009
Childhood SES (ref.=0)										
1			-0.038	-0.001	0.044	-0.001	0.044	-0.001	0.045	-0.001
2			-0.097	0.003	0.084	0.005	0.083	0.005	0.082	0.006
3+			-0.013	-0.002	0.172**	-0.002	0.177**	-0.001	0.170**	-0.002
Poor Childhood Health			-0.155	0.001	-0.079	0.002	-0.059	0.003	-0.055	0.003
Southern Born			-0.157**	0.002	-0.111*	0.003	-0.110*	0.003	-0.096	0.004
Intercept	0.286***		0.339***		-0.392***		-0.613***		-0.604***	
Variance components										
Variance of random intercept	0.378***		0.373***		0.298***		0.288***		0.282***	
Variance of random slope	0.001***		0.001***		0.001***		0.001***		0.001***	
Residual variance	0.313***		0.313***		0.313***		0.312***		0.312***	
Goodness-of-fit										
AIC	15255.75		15258.64		15070.53		15021.82		15003.66	
BIC	15400.93		15472.96		15326.33		15305.28		15328.59	

Table S6. Growth curve modeling predicting cognitive function by childhood lead exposure, adult education and health outcomes with the inclusive specification of lead exposure (some lead pipes = 1), Health and Retirement Study, 1998-2016 (N=7,432 person-wave observations). AIC = Akaike information criterion; BIC = Bayesian information criterion; ref. = reference; *p < .05. **p < .01. ***p < .001.

	Model 0		Model 1		Model 2		Model 3		Model 4	
	Intercept	Slope	Intercept	Slope	Intercept	Slope	Intercept	Slope	Intercept	Slope
Fixed Effects										
Age (centered)	-0.054***		-0.055***		-0.054***		-0.067***		-0.072***	
Age-squared	-0.001***		-0.001***		-0.001***		-0.001***		-0.001***	
Lead	0.063	0.007	0.041	0.008*	0.019	0.008*	0.022	0.008*	0.019	0.007
Acidic/Alkaline Water	0.068	0.003	0.073	0.003	0.046	0.006	0.041	0.005	0.052	0.005
Lead X Acidic/Alkaline Water	**-0.266**	0.003	**-0.269**	0.003	**-0.146**	-0.000	**-0.129**	0.002	**-0.140**	0.003
Educational Attainment (ref.= <High School)										
High School					0.499***	-0.005	0.458***	-0.006	0.464***	-0.005
Some College					0.702***	-0.003	0.635***	-0.006	0.638***	-0.004
College +					0.962***	0.002	0.839***	-0.006	0.840***	-0.004
Income							0.019***	0.001*	0.019***	0.001
Wealth							0.024*	0.001*	0.023**	0.002*
Stroke									-0.155**	-0.009
Hypertension									0.015	0.010**
Heart diseases									0.012	0.000
Covariates										
Female	0.135**	-0.005	0.139**	-0.005	0.203***	-0.004	0.220***	-0.002	0.214***	-0.002
Race/Ethnicity (ref.=NH-White)										
Non-Hispanic, Black	-0.587***	-0.015*	-0.528***	-0.0167*	-0.433***	-0.015*	-0.355***	-0.011	-0.368***	-0.013
Hispanic	-0.282*	-0.005	-0.300*	-0.004	-0.177	-0.004	-0.143	-0.003	-0.152	-0.003
Other	-0.466*	0.0001	-0.479*	0.002	-0.138	0.003	-0.096	0.007	-0.104	0.011
Childhood SES (ref.=0)										
1			-0.039	-0.002	0.044	-0.001	0.044	-0.001	0.044	-0.001
2			-0.090	0.003	0.089	0.005	0.089	0.005	0.089	0.006
3+			-0.009	-0.002	0.175**	-0.001	0.181**	-0.001	0.173**	-0.002
Poor Childhood Health			-0.161	0.001	-0.083	0.001	-0.063	0.003	-0.059	0.003
Southern Born			-0.133**	0.005	-0.095	0.006	-0.093	0.006	-0.080	0.007
Intercept	0.273***		0.342***		-0.392***		-0.607***		-0.599***	
Variance components										
Variance of random intercept	0.380**		0.375***		0.299***		0.289***		0.284***	
Variance of random slope	0.001***		0.001***		0.001***		0.001***		0.001***	
Residual variance	0.313***		0.313***		0.313***		0.312***		0.312***	
Goodness-of-fit										
AIC	15255.84		15259.75		15070.02		15022.39		15005.05	
BIC	15401.02		15474.07		15325.82		15305.84		15329.99	

Table S7. Growth curve modeling predicting cognitive function by childhood lead exposure, adult education and health outcomes without imputed cognitive values, Health and Retirement study, 1998-2016 (N=6,218 person-wave observations). AIC = Akaike information criterion; BIC = Bayesian information criterion; ref. = reference; *p < .05. **p < .01. ***p < .001.

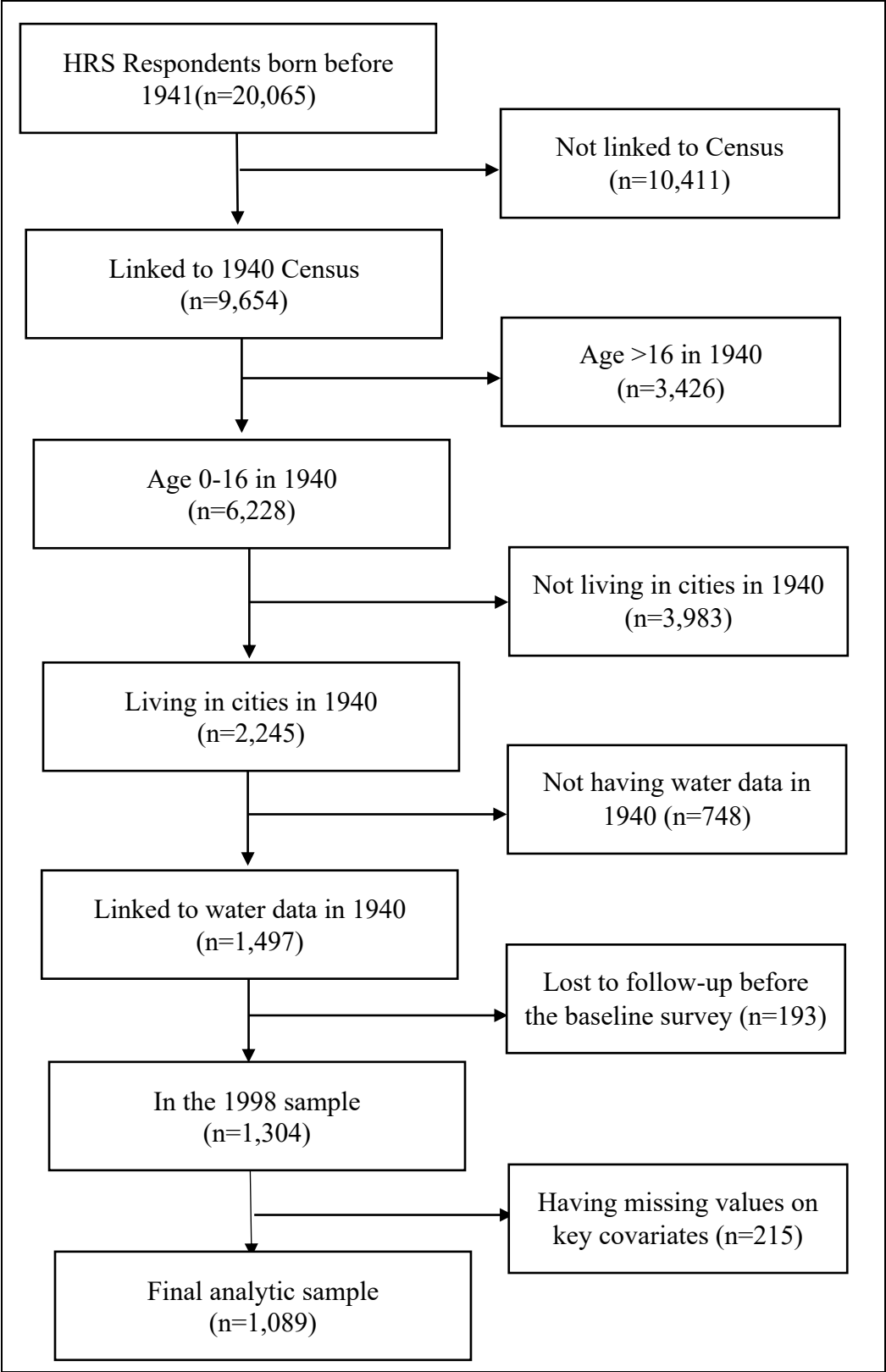|	Model 0		Model 1		Model 2		Model 3		Model 4	
	Intercept	Slope	Intercept	Slope	Intercept	Slope	Intercept	Slope	Intercept	Slope
Fixed Effects										
Age (centered)	-0.052***		-0.056***		-0.050***		-0.065***		-0.073***	
Age-squared	-0.001***		-0.001***		-0.001***		-0.001***		-0.001***	
Lead	0.093	0.001	0.106*	0.001	0.075	0.001	0.088	0.002	0.084	0.000
Acidic/Alkaline Water	0.097	0.012	0.127	0.011	0.131	0.013	0.137	0.013	0.149	0.014
Lead X Acidic/Alkaline Water	**-0.406****	-0.008	**-0.515****	-0.007	**-0.394****	-0.010	**-0.388****	-0.008	**-0.400****	-0.008
Educational Attainment (ref.= <High School)										
High School					0.441***	-0.010	0.392***	-0.012	0.400***	-0.010
Some College					0.667***	-0.008	0.591***	-0.011	0.599***	-0.009
College +					0.919***	-0.003	0.783***	-0.011	0.788***	-0.009
Income							0.022***	0.001	0.022***	0.001
Wealth							0.025***	0.002*	0.024***	0.002*
Stroke									-0.129*	-0.011
Hypertension									0.020	0.012**
Heart diseases									0.009	0.004
Covariates										
Female	0.156**	-0.002	0.154**	-0.002	0.220***	-0.002	0.240***	0.000	0.237***	0.001
Race/Ethnicity (ref.=NH-White)										
Non-Hispanic, Black	-0.617***	-0.016*	-0.512***	-0.018*	-0.420***	-0.016*	-0.334***	-0.012	-0.348***	-0.014
Hispanic	-0.147	-0.017	-0.161	-0.017	-0.061	-0.017	-0.030	-0.015	-0.039	-0.017
Other	-0.662*	-0.015	-0.638*	-0.015	-0.311	0.014	-0.242	-0.008	-0.244	-0.001
Childhood SES (ref.=0)										
1			-0.017	0.004	0.071	0.004	0.067	0.004	0.069	0.004
2			-0.043	0.009	0.121	0.011	0.120	0.011	0.118	0.011*
3+			-0.014	0.003	0.151**	0.002	0.155*	0.002	0.148*	0.001
Poor Childhood Health			-0.126	0.005	-0.018	0.006	-0.002	0.008	0.002	0.008
Southern Born			-0.210**	0.003	-0.164*	0.003	-0.168**	0.003	-0.158*	0.004
Intercept	0.211***		0.253***		-0.448***		-0.687***		-0.689***	
Variance components										
Variance of random intercept	0.393***		0.387***		0.315***		0.304***		0.301***	
Variance of random slope	0.001***		0.001***		0.001***		0.001***		0.001***	
Residual variance	0.359***		0.359***		0.359***		0.358***		0.357***	
Goodness-of-fit										
AIC	13539.73		13540.48		13399.29		13358.90		13348.66	
BIC	13681.17		13749.27		13648.49		13635.05		13665.22	

Table S8. Growth curve modeling predicting learning task, working memory, and attention and processing speed tests by childhood lead exposure, adult education and health outcomes, Health and Retirement study, 1998-2016 (N=6,218 person-wave observations). Model 1 regresses trajectories of cognitive functioning on childhood lead exposure net of age, sex, race/ethnicity, childhood SES, childhood health, and region of birth. Model 2 adds educational attainment to Model 1. Model 3 adds income and wealth to Model 2. Model 4 adds stroke, hypertension, and heart diseases to Model 3. *p < .05. **p < .01. ***p < .001.

Panel A	Verbal Memory: Immediate and Delayed Word Recall							
	Model 1		Model 2		Model 3		Model 4	
	Intercept	Slope	Intercept	Slope	Intercept	Slope	Intercept	Slope
Lead	0.076	0.002	0.046	0.002	0.057	0.002	0.052	0.001
Acidic/Alkaline Water	0.064	0.008	0.053	0.010	0.058	0.009	0.073	0.010
Lead X Acidic/Alkaline Water	**-0.342**[*]	-0.007	**-0.221**	-0.009	**-0.218**	-0.007	**-0.231**	-0.007

Panel B	Working Memory: Serial 7s							
	Model 1		Model 2		Model 3		Model 4	
	Intercept	Slope	Intercept	Slope	Intercept	Slope	Intercept	Slope
Lead	0.118[*]	0.001	0.087	0.001	0.098[*]	0.001	0.096[*]	0.001
Acidic/Alkaline Water	0.226	0.012	0.206	0.015	0.209	0.014	0.210	0.014
Lead X Acidic/Alkaline Water	**-0.485**[*]	-0.003	**-0.342**[*]	-0.007	**-0.339**[*]	-0.004	**-0.342**[*]	-0.003

Panel C	Attention and Processing Speed: Counting Backwards							
	Model 1		Model 2		Model 3		Model 4	
	Intercept	Slope	Intercept	Slope	Intercept	Slope	Intercept	Slope
Lead	0.010	0.005	0.007	0.005	0.011	0.005	0.006	0.004
Acidic/Alkaline Water	-0.033	-0.003	+0.057	-0.003	-0.057	-0.004	-0.055	-0.003
Lead X Acidic/Alkaline Water	**0.016**	-0.004	**0.062**	-0.004	**0.063**	-0.003	**0.057**	-0.003

Table S9. Comparison of HRS demographic, socioeconomic, and health variables between participants included in our sample and participants excluded due to census linkage and missing data. Statistical tests of difference: Categorical variables assessed with Pearson Chi-Square Test; Continuous variable means assessed with Two Sample T-Test. Our sample includes HRS participants born 1924-1940 who were successfully linked to the 1940 Census and who had at least one observation in our covariates. We compare our sample with those born 1924-1940 who were excluded due to failed census linkage or missing data. *p<0.05, ** p<0.01, *** p<0.001.

	Participants Excluded due to Census Linkage and Missing Data N=18,976	Participants Linked to the 1940 Census with Valid Data N=1,089	p-value
TICS Score (0-27)	14.86 (4.97)	17.29 (4.02)	***
Age (57-93)	70.47 (9.31)	65.49 (5.01)	***
Female (%)	54.84%	50.69%	**
Race/Ethnicity (%)			***
Non-Hispanic, White	78.93%	88.89%	
Non-Hispanic, Black	15.45%	7.99%	
Hispanic	3.45%	2.30%	
Other	2.18%	0.83%	
Childhood SES (%)			***
0	35.76%	45.55%	
1	21.75%	24.24%	
2	23.34%	17.26%	
3+	19.11%	12.95%	
Poor Childhood Health (%)	6.36%	7.07%	
Southern Born (%)	42.17%	16.53%	***
Educational Attainment (%)			***
< High School	35.61%	12.30%	
High School	33.38%	39.12%	
Some College	16.64%	20.75%	
College +	14.37%	27.82%	
Income (logged)	5.09 (2.75)	6.26 (2.62)	***
Wealth (logged)	5.56 (2.87)	6.43 (2.68)	***
Ever Had Stroke (%)	9.16%	4.41%	***
Ever had hypertension	47.40%	41.05%	***
Ever had heart diseases	24.76%	15.98%	***

Fig. S1. Attrition chart, Health and Retirement Study, 1998-2016 (N=1,089).