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Abstract

It is known that people feel less happy in areas with higher levels of nitrogen dioxide NO2 (MacKerron and Mourato, 2009). What else might air pollution do to human wellbeing? This paper uses data on a standardized word-recall test that was done in the year 2011 by 34,000 randomly sampled English citizens across 318 geographical areas. We find that human memory is worse in areas where NO2 and PM10 levels are greater. The paper provides both (i) OLS results and (ii) instrumental-variable estimates that exploit the direction of the prevailing westerly wind and levels of population density. Although caution is always advisable on causal interpretation, these results are concerning and are consistent with laboratory studies of rats and other non-human animals. Our estimates suggest that the difference in memory quality between England's cleanest and most-polluted areas is equivalent to the loss of memory from 10 extra years of ageing.

KEY MESSAGES

- The paper provides evidence that NO2 and PM10 in the air may impair human memory.
- This result is consistent with laboratory animal studies' finding of harm to the animal brain from air pollution.
- It may contribute to an understanding of a potential transmission mechanism from air quality to risk of dementia.

Is There a Link Between Air Pollution and Impaired Memory? Evidence on 34,000 English Citizens

INTRODUCTION

People feel less happy when there are high levels of nitrogen dioxide (NO2) in the region in which they live. One of the most important demonstrations of this was provided by MacKerron and Mourato (2009) using data on geographical districts across London. Related prior evidence comes from Welsch (2006) and Rehdanz and Maddison (2008). However, might there be other ways in which wellbeing and the human mind are affected by air pollutants? This paper studies the possibility of a link between air quality and memory. We focus on NO2 levels and PM10 air particulates. This paper, more generally, is one of the first to pursue the little-studied microeconometrics of human memory.

Methodologically, we have been influenced by Luechinger (2009, 2014) and Bilger and Carrieri (2013), and more broadly by Marcus (2017). The paper may also relate to the scientific foundations of dementia, which is now one of the modern world's most fundamental health problems. Its consequences are known to be profound (Aguero-Torres et al. 1998). Yet, partly because the topic is difficult to study, the causal mechanisms are poorly understood.

The background is familiar to epidemiologists and health economists. It is known that air pollution is injurious to breathing and cardiovascular health (Bell, Zanobetti and Dominici 2013). New research has documented other possible outcomes. There is evidence of potential damage to the structure of the adult human brain, and of adverse effects, under controlled laboratory conditions, upon non-human animals (Calderon-Garciduenas et al. 2008; Killin et al. 2016). Salvi et al. (2017) recently showed evidence of memory impairment in laboratory rats that were exposed to air pollution.

However, there remain two fundamental gaps in scientific knowledge about air pollution and its possible effects on the human brain.

1. *First, are normal people, across the whole age-spectrum, at risk of memory impairment?*
2. *Second, is there causal evidence?*

The answer to the first question is currently not known. Almost all research has been on populations of elderly men and women or in some rare instances on children (Weuve et al. 2012; Ailshire and Crimmins 2014). Moreover, almost all research in human studies on this

topic has been based on simple associations in the data. So far, therefore, it has not been possible, as a technical matter, for causal conclusions to be drawn, even though there is some cross-sectional support in the epidemiology literature for the hypothesis of a link between air pollution and dementia (Killin et al 2016).

The current paper attempts to address these two lacunae -- (i) the issue of population representativeness and (ii) issues of cause-and-effect. It goes on, below, to document new evidence, for the country of England, consistent with a causal connection between air quality (as measured particularly by nitrogen dioxide NO2 levels and PM10 particulates) and a measure of the average person's ability to remember words in a standard form of word-recall test. The analysis draws upon a nationally representative data set. It also adjusts for people's characteristics, adopts a statistical method, instrumental-variable estimation, that can in principle allow identification, and probes the robustness of the relationship. The reason to use IV estimation is the usual one that a correlation between a regressor and the error term may arise due to (i) omitted variables, (ii) measurement error, or (iii) reverse causation. Since it is unlikely that impaired memory influences the pollution load, it seems that (i) and (ii) are possibly relevant concerns in the present case.

METHODS

The data set used is the so-called 'Understanding Society' UKHLS (the annual United Kingdom Household Longitudinal Survey), which is explained at, and is downloadable from, site https://www.understandingsociety.ac.uk. In one particular year, 2011, the survey participants completed a memory test. The full sample-size exceeds 34,000 randomly sampled individuals. Ten words had to be remembered (a similar measure is used in Bonsang, Adam, and Perelman 2012). People's answers were scored on an eleven-point scale from zero to ten. Two forms of test were administered -- an immediate-recall test and a delayed-recall test. For the latter, the individual had to answer a number of other questions before being asked to recall the list of words. We have examined evidence on both forms of test but concentrate on the latter (the more challenging) delayed test.

Interviewers were given the following instructions: For this task, the computer reads a list of 10 words to standardize the presentation and speed of the word list. The interviewer checks if the respondent can hear the computer playing a short test message. If the voice cannot be heard, the interviewer checks again following adjustment of the volume. If the respondent still cannot hear the computer's voice, the interviewer reads the words at a slow

steady rate of about one word every two seconds. The list of words is not repeated. No aids are allowed for the test. Interviewer's script: *The computer will now read a set of 10 words. I would like you to remember as many as you can. We have purposely made the list long so it will be difficult for anyone to remember all the words. Most people remember just a few. Please listen carefully to the set of words as they cannot be repeated. When it has finished, I will ask you to recall aloud as many of the words as you can, in any order. Is this clear? Now please tell me the words you can remember.*

For the delayed-word recall test, respondents are asked, after being given another task, to try to remember the words from the list. On average, people in the delayed-recall test can remember 5 words. The interviewer codes each correct response.

More generally, the UKHLS survey collects annual information from members of UK households who are at least 15 years of age. It provides information on demographic and socio-economic information, and measures of health and lifestyle choices. The individuals within England live in 318 local-authority districts. Information on air quality was collected for each of those districts. Data on both NO2 and PM10 were available from formal government sources at the United Kingdom's Department for Environment Food & Rural Affairs (DEFRA) official website: https://uk-air.defra.gov.uk/data/laqm-background-maps?year=2011. Clustered standard errors were applied in the regression analysis (an equivalent correction would be through multi-level modelling).

The main analysis in this study uses instrumental variable (IV) estimation. The instruments for air quality are twofold. They are: (i) population density, because factors like vehicles and home heating lead to air pollutants; and (ii) being a coastal district immediately on the west or south coast of England, because England has a prevailing south-westerly wind that means that particularly clean air comes in from the Atlantic Ocean. As is known to economists, although it seems less commonly used by epidemiologists, regression with instrumental variables is appropriate when the error term is believed to be correlated with the right-hand-side regressors in the equation. For an IV approach (that is, 2-stage least squares) to be valid, a rank and order condition have to be satisfied; sufficiently strong instruments are also required. An instrument is a variable that is correlated with the regressor in question but unrelated with the dependent variable other than through that regressor.

Tables S1 and S2 give the means and standard deviations for the key variables in the data set, and the distribution of memory scores across the sampled population.

RAW PATTERNS

At the spatial level, if the mean values across the 318 geographical districts are calculated, there is a mild correlation between poor air and poor memory. Without regression adjustment, the simple Pearson's correlation coefficient between NO2 in an area and memory-quality in the area (measured by the mean number of words recalled out of a possible maximum of ten) is -0.14. The equivalent correlation for memory and PM10 is -0.01. For completeness, it should be recorded that the Pearson's correlation coefficient between NO2 and PM10 is 0.80. The current paper will not attempt, in correlational analysis, to distinguish in any fine-grained way between their relative importance (thus it will not enter both NO2 and PM10 as independent variables within the same equation).
Maps of air quality are provided in Figures 1 and 2. These give visual data for the entire UK, although the main regression analysis uses only English areas, because only England has complete data on air pollution that could be matched here to people's characteristics.

Particularly high-pollution areas are districts such as Kensington and Chelsea or Islington. Both of these are in London. Particularly low-pollution areas are districts such as Devon or West Somerset. Both of these are close to the coastline in the far west of England.

Table S1 in the supplementary appendix describes the frequency distribution of memory in England. Approximately 1.4 % of the population manage to obtain a perfect memory score of ten out of ten. At the lower end of the memory distribution, approximately 6.6% of the population can remember no words or at most just a single word out of the ten words. Later in the paper we will examine this group and view them as individuals with a 'severe' memory problem. Table S2 gives descriptive statistics on the sample.

RESULTS

The main statistical findings are reported in Tables 1-4. We begin, each time, with ordinary least squares results and then give instrumental-variable ones.

In Model 1 of Table 1, the level of NO2 in the geographical district enters with a coefficient of -0.020 [95% confidence interval of -0.027 to -0.012]. Men have poorer memory than women, with a coefficient of -0.282 [95% C.I. of -0.325 to -0.239], which means that males typically remember approximately one third of a word less than females. There is a strong age gradient in memory; it is monotonic. Those older than 80 remember,

on average, three and a half fewer words than those who are aged under 21.

Models 2 and 3 in Table 1 gradually add extra covariates. When the full set of those are included, the broad patterns remain the same, and the estimated coefficient on NO2 is -0.011 [C.I. -0.017 to -0.005]. The null of zero can thus be rejected at the 95% confidence level. The mean value of NO2 is M = 17.258, SD = 7.421, and the size of the relationship is substantial. Levels of NO2 pollution vary dramatically across England from a low of approximately 5 close to the west coast of England to a high of approximately 45 in central London. These units are in micrograms per cubic metre of air. In all estimates, the regression equations include the controls for personal characteristics -- income, education, etc -- that are listed in Table 1, as well as controls for the mean income levels in the local-authority districts, the mean deprivation levels in the local-authority districts, and a set of large-region dummy variables (there are 9 standard administrative regions in England).

It can be seen from Table 1 that the estimates imply a negative association between memory and the level of nitrogen dioxide in the air of a local-authority district. Consider a comparison between the area with the cleanest air and the area with the most polluted air. The estimates imply a predicted difference in human memory of approximately 0.5 of a word, on the zero to ten scale used in the memory test. Using the estimates on age in Table 1, that would be equivalent to approximately the difference between being 61-70 years old rather than being 51-60 years old. At lower age-levels, it would be bigger than a 10 year age-equivalent difference.

We wish to caution that our analysis does not mean that if a person moved from Devon to central London they would immediately suffer a drop in their ability to remember words. Our econometric work is unable to say anything about the dynamics of biological processes that might be at work (it seems possible, for instance, that memory perhaps erodes rather slowly with decades of exposure to polluted air). We are not alone: to our knowledge, no researchers have produced evidence of a straightforward kind on such dynamics. This seems an important scientific issue for future work.

Table 2, again for NO2 air pollution, reveals similar evidence. It gives the instrumental-variable estimates.

Table 3 presents equivalent kinds of results for PM10 air particulates. In the full specification, in the right-hand corner of Table 3, the coefficient on local-district PM10 is -0.031, with a confidence interval of [-0.05, -0.012]. Table 4 gives the equivalent instrumental-variable findings.

Next, for completeness, Table 5 reports the so-called first-stage equations for the

application of instrumental variables. As explained, instruments for air quality are (i) population density and (ii) being a coastal district immediately on the west or south coast of England. The latter choice was inspired particularly by the seminal paper of Luechinger (2009); he uses wind direction and power-plant location, whereas we use wind direction and the fact that air from the Atlantic Ocean is clean. In the current sample, approximately 12.6% of English citizens reside in a south-west coastal area.

Consistent with intuition, Table 5 reveals that air pollutants are strongly related to both of our instrumental variables (ie., positively with population density; negatively with being somewhere on the south-west coastline). As a check, we tested whether coastal areas on the east coast were also disproportionately ones with clean air. That was approximately true; the estimated coefficient, however, was smaller. Diagnostic statistics on the instrumenting (at the foot of Table 5), including one for a J test, indicate that the instruments are valid.

Table 6 moves to a dependent variable closer to the concept of extreme memory loss. Here we report probit equations. The dependent variable takes the value of unity if the person can remember either none of the ten words that were read to him or her, or only one of the ten words. Although this measure cannot, of course, do justice to every physician's idea of 'near-dementia', it is our hope that Table 6's results might be of value to future researchers. The equivalent table for PM10, with similar implications, is available on request.

The possible consequences of air pollution for different age-groups might be considered (see also Menz and Welsch 2012). Table 7 summarizes some of our results. In each age-group, air pollution enters negatively in the memory equation. Detrimental effects cannot in a statistically significant sense be established for young people (though there is recent published evidence by colleagues showing that exam performance may be impaired by poor air, Ebenstein, Lavy and Roth 2016). It can be seen, however, that at somewhat older ages the coefficients on NO2 and PM10 in the Instrumental Variable IV estimates seem to be becoming somewhat more negative. This may be because air pollution has a gradual cumulative effect, or for biological reasons (see also Menz and Welsch 2012), or for some other currently unknown reason. This area warrants future research.

Finally, on the suggestion of referees, Table 8 briefly explores the relationship between memory and the average level of air pollutant measured in the earlier years of 2009 and 2010. While it is possible to obtain general air-pollution data from 2001 onwards, we only have information, in this data set, on each respondent's local authority district from

2009. When the average air-pollution measures is used, it can be seen that the results are very similar and the coefficients on average NO2 and average PM10 are negative and statistically robust at the 1% level. The Pearson's correlation coefficient between NO2 in 2011 and the average NO2 measured in 2009 and 2010 is 0.99 (and equivalently for data on PM10), so, for collinearity reasons, it is not possible to try to enter pollution for different years within a single equation.

Lastly, a previous version of the paper also provided all these kinds of calculations for immediate-recall data. The results, which are similar in character to the paper's delayed-recall findings, are available on request.

CONCLUSION

This study probes the possible links between the quality of human memory and the quality of air that people breathe. We do so in an admittedly simple way -- by examining word-recall data for a nationally representative random sample of 34,000 English men and women who live in 318 different geographical areas. The paper does not focus on the extreme loss of memory that is a characteristic of dementia-like conditions. Instead, the paper's contribution is to inquire into the statistical determinants of human memory in more typical human beings. Kawas et al. (2003) has, however, shown that the quality of current memory is a predictor of the later risk of Alzheimer's disease.

To our knowledge, the analysis here is the first to be able to exploit a large, nationally representative sample of English citizens who complete a memory test. It is also apparently the first to use instrumental-variable estimation to try to tackle the problem that otherwise observational data can provide only associations between air pollution and cognitive outcomes. It may be one of the first studies of what might be termed the microeconometrics of human memory.

The paper's findings are consistent with the hypothesis that polluted air is dangerous for the human brain. Our conclusions seem complementary to the result demonstrated in laboratory studies such as Salvi et al. (2017) that rats' memories, for example, are impaired by air pollution. The potential strengths of the current study are its large sample, the national representativeness of the sample, and the use of instrumental-variable methods. The persuasiveness of an IV approach necessarily depends on the validity of the instruments used in the first-stage regression. Our chosen instruments are closeness to the south-westerly coastline and population density. As would be expected intuitively (and as we test

more formally, with a J test among others, in the paper), these two are independently predictive of worse local air-quality, and better local air-quality, respectively. In principle, by correcting an air-quality independent variable in the regression equation, instrumental-variable methods allows consistent estimates of the size of causal effects of air pollutants to be obtained.

Nevertheless, a degree of caution is advisable and is particularly sensible in interpreting IV results in applied research. The limitations of this study are that it is not a formal RCT randomized trial; that some kind of subtle confounding can never entirely be ruled out; and that only one particular verbal kind of memory test is examined in this paper.

One other potentially valuable aspect of our study's results should perhaps be noted. We find that areas like Kensington and Chelsea or Islington have the worst levels of air pollution. Yet these districts, which are in London, contain many of the wealthiest and most privileged people in England. If, as seems likely, such individuals have unobservable cognitive advantages, it appears that the paper's empirical results are sufficiently strong that they are able to outweigh any possible biases produced by those unobservables.

Finally, it should be noted that in this data set we do not have information on how long an individual has lived in their particular geographical area. This means that some people in high-pollution areas were potentially previously living in low-pollution ones, and vice versa. However, this dark cloud has one silver lining. Measurement error created in this way will -- for standard reasons of attenuation bias -- tend to lead to an underestimate of the true coefficient on air pollution.

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Author Contributions

Author contributions: NP and AJO had the idea for the study; NP and AJO designed the research; AJO wrote the first draft; NP analyzed the data; both authors revised the draft. AJO wishes to record that NP found the key data and should be assigned the majority of the credit for this work.

Declaration of Conflicting Interests

The authors declare no conflict of interest.

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Table 1: **Memory Quality and the Level of Nitrogen Dioxide in the Local Area: OLS Regressions, UKHLS data for 2011**

(The dependent variable in these regression equations is the delayed number of words remembered, scored from zero to ten. Sample size here is 34,000 approx. people in 2011)

	Model 1		Model 2		Model 3	
Number of words remembered	Coef.	95% C.I.	Coef.	95% C.I.	Coef.	95% C.I.
NO2 level in the district	-0.020***	[-0.027,-0.012]	-0.011**	[-0.018,-0.003]	-0.011***	[-0.017,-0.005]
Male	-0.282***	[-0.326,-0.239]	-0.283***	[-0.326,-0.240]	-0.324***	[-0.363,-0.285]
Age 21-30	0.08	[-0.017,0.176]	0.076	[-0.019,0.172]	-0.038	[-0.155,0.078]
Age 31-40	-0.037	[-0.126,0.052]	-0.047	[-0.137,0.042]	-0.170**	[-0.293,-0.047]
Age 41-50	-0.418***	[-0.518,-0.317]	-0.430***	[-0.530,-0.330]	-0.471***	[-0.592,-0.350]
Age 51-60	-0.777***	[-0.870,-0.684]	-0.786***	[-0.879,-0.693]	-0.727***	[-0.854,-0.600]
Age 61-70	-1.302***	[-1.403,-1.201]	-1.310***	[-1.411,-1.209]	-1.162***	[-1.309,-1.015]
Age 71-80	-2.321***	[-2.434,-2.208]	-2.326***	[-2.438,-2.213]	-2.036***	[-2.196,-1.875]
Age 81 and older	-3.384***	[-3.520,-3.248]	-3.383***	[-3.520,-3.247]	-2.971***	[-3.156,-2.786]
Mixed ethnicity	-0.239**	[-0.412,-0.066]	-0.213*	[-0.387,-0.040]	-0.172	[-0.344,0.000]
Indian/Pakistani/Bangladeshi	-0.837***	[-1.020,-0.654]	-0.755***	[-0.927,-0.584]	-0.678***	[-0.806,-0.550]
Chinese/other Asians	-0.482***	[-0.721,-0.242]	-0.465***	[-0.711,-0.219]	-0.576***	[-0.780,-0.371]
Black Caribbean/Africans	-0.894***	[-1.021,-0.766]	-0.846***	[-0.967,-0.724]	-0.804***	[-0.916,-0.692]
Other ethnicities	-0.282	[-0.718,0.153]	-0.284	[-0.719,0.152]	-0.274	[-0.657,0.109]
Missing ethnicity dummy	-0.130***	[-0.207,-0.053]	-0.127***	[-0.203,-0.052]	0.109**	[0.034,0.185]
Average income by Local Authority District (LAD)			0.681***	[0.417,0.946]	0.219	[-0.006,0.444]
Relative deprivation rank index by LAD in 2010			0.000	[-0.001,0.001]	0.000	[-0.000,0.001]
Log of equivalent household income					0.162***	[0.126,0.197]
Highest qualification: A-level					0.531***	[0.446,0.616]
Highest qualification: First degree					0.638***	[0.581,0.696]
Highest qualification: Higher degree					0.887***	[0.797,0.978]
Self employed					0.066	[-0.014,0.145]
Unemployed					-0.298***	[-0.395,-0.200]
Retired					-0.109*	[-0.203,-0.015]
On maternity leave					-0.197	[-0.446,0.051]
Family care or home					-0.281***	[-0.384,-0.178]
Full-time student					0.219***	[0.117,0.322]
Long-term sick or disabled					-0.790***	[-0.937,-0.643]
Government training scheme					-0.33	[-1.123,0.463]
Unpaid, family business					0.787	[-0.056,1.631]
On apprenticeship					-0.229	[-0.819,0.361]
Doing something else					-0.228	[-0.499,0.043]
Married					0.02	[-0.047,0.087]
Civil partner (legal)					0.433*	[0.015,0.851]

Separated, legally married					-0.002	[-0.142,0.138]
Divorced					0.076	[-0.008,0.160]
Widowed					-0.045	[-0.157,0.066]
Separated from civil partner					0.266	[-0.293,0.825]
Health: Very good					-0.064*	[-0.124,-0.005]
Health: Good					-0.183***	[-0.243,-0.122]
Health: Fair					-0.408***	[-0.488,-0.328]
Health: Poor					-0.607***	[-0.713,-0.502]
Number of children < 16					-0.004	[-0.035,0.028]
Constant	6.196***	[5.974,6.418]	-0.514	[-2.972,1.944]	2.375*	[0.271,4.479]
R-squared	0.175		0.178		0.232	
N. of cases	33966		33966		33858	

Note: *<0.05; **<0.01, ***<0.001. Dependent variable = Delayed no. of words recalled (M = 5.136, SD = 2.132). Nitrogen dioxide (M = 17.211, SD = 7.397). Other control variables include regional dummies (9), marital status dummies (7), and self-assessed health dummies (5). 318 districts. Standard errors, here and in later tables, are corrected for clustering.

Table 2: **Memory Quality and the Level of Nitrogen Dioxide in the Local Area: Instrumental-Variable Regressions, UKHLS data for 2011**

	Model 1		Model 2		Model 3	
Number of words remembered	Coef.	95% C.I.	Coef.	95% C.I.	Coef.	95% C.I.
NO2 level in the district	-0.023***	[-0.035,-0.012]	-0.010	[-0.023,0.002]	-0.012*	[-0.022,-0.002]
Male	-0.282***	[-0.325,-0.239]	-0.283***	[-0.326,-0.240]	-0.324***	[-0.363,-0.285]
Age 21-30	0.082	[-0.015,0.179]	0.076	[-0.019,0.172]	-0.037	[-0.153,0.079]
Age 31-40	-0.037	[-0.125,0.052]	-0.048	[-0.136,0.041]	-0.169**	[-0.291,-0.046]
Age 41-50	-0.418***	[-0.518,-0.318]	-0.430***	[-0.529,-0.331]	-0.470***	[-0.590,-0.350]
Age 51-60	-0.777***	[-0.870,-0.685]	-0.786***	[-0.879,-0.693]	-0.726***	[-0.853,-0.600]
Age 61-70	-1.304***	[-1.404,-1.203]	-1.310***	[-1.410,-1.209]	-1.161***	[-1.307,-1.015]
Age 71-80	-2.322***	[-2.435,-2.209]	-2.326***	[-2.438,-2.213]	-2.035***	[-2.193,-1.876]
Age 81 and older	-3.386***	[-3.522,-3.251]	-3.383***	[-3.519,-3.247]	-2.970***	[-3.154,-2.787]
Mixed ethnicity	-0.230*	[-0.408,-0.053]	-0.214*	[-0.390,-0.037]	-0.17	[-0.344,0.004]
Indian/Pakistani/Bangladeshi	-0.822***	[-0.988,-0.657]	-0.756***	[-0.919,-0.593]	-0.675***	[-0.796,-0.555]
Chinese/other Asians	-0.474***	[-0.716,-0.231]	-0.465***	[-0.713,-0.218]	-0.574***	[-0.779,-0.369]
Black Caribbean/Africans	-0.882***	[-1.015,-0.750]	-0.846***	[-0.970,-0.722]	-0.802***	[-0.915,-0.689]
Other ethnicities	-0.262	[-0.688,0.163]	-0.285	[-0.713,0.142]	-0.268	[-0.643,0.108]
Missing ethnicity dummy	-0.131***	[-0.207,-0.054]	-0.127***	[-0.202,-0.052]	0.109**	[0.034,0.185]
Average income by Local Authority District (LAD)			0.684***	[0.425,0.942]	0.208	[-0.013,0.429]
Relative deprivation rank index by LAD in 2010			0.000	[-0.001,0.001]	0.000	[-0.001,0.001]
Log of equivalent household income					0.162***	[0.127,0.197]
Highest qualification: A-level					0.531***	[0.447,0.616]
Highest qualification: First degree					0.638***	[0.581,0.696]
Highest qualification: Higher degree					0.888***	[0.797,0.979]
Self employed					0.065	[-0.014,0.144]
Unemployed					-0.297***	[-0.393,-0.201]
Retired					-0.109*	[-0.203,-0.016]
On maternity leave					-0.198	[-0.445,0.049]
Family care or home					-0.281***	[-0.383,-0.179]
Full-time student					0.220***	[0.118,0.321]
Long-term sick or disabled					-0.789***	[-0.935,-0.643]
Government training scheme					-0.329	[-1.117,0.459]
Unpaid, family business					0.787	[-0.051,1.625]
On apprenticeship					-0.23	[-0.818,0.358]
Doing something else					-0.228	[-0.497,0.041]
Married					0.02	[-0.047,0.086]
Civil partner (legal)					0.433*	[0.017,0.849]

Separated, legally married					-0.002	[-0.142,0.137]
Divorced					0.076	[-0.008,0.159]
Widowed					-0.045	[-0.156,0.065]
Separated from civil partner					0.268	[-0.288,0.824]
Health: Very good					-0.064*	[-0.123,-0.006]
Health: Good					-0.183***	[-0.243,-0.122]
Health: Fair					-0.408***	[-0.488,-0.328]
Health: Poor					-0.607***	[-0.712,-0.502]
Number of children < 16					-0.004	[-0.035,0.028]
Constant	6.247***	[5.988,6.506]	-0.545	[-2.984,1.893]	2.509*	[0.418,4.601]
R-squared	0.175		0.178		0.232	
N. of cases	33966		33966		33858	

Note: *<0.05; **<0.01, ***<0.001. Robust standard errors are in parentheses. UKHLS Data 2011. Dependent variable = Delayed number of words recalled out of a possible maximum of ten (M = 5.13, SD = 2.14). NO2 (M = 17.905, SD = 7.689). Other control variables include regional dummies (9), marital status dummies (7), and self-assessed health dummies (5). The instrumental variables (IV) are population density by LAD district measured in 2011 and south-west coastal dummies.

Table 3: **Memory Quality and the Level of PM10 Air Particulates in the Local Area: OLS Regressions, UKHLS data for 2011**

	Model 1		Model 2		Model 3	
Number of words remembered	Coef.	95% C.I.	Coef.	95% C.I.	Coef.	95% C.I.
Particle matter (PM10) level in the district	-0.055***	[-0.080,-0.029]	-0.035**	[-0.058,-0.012]	-0.031**	[-0.050,-0.012]
Male	-0.283***	[-0.326,-0.240]	-0.283***	[-0.326,-0.240]	-0.324***	[-0.364,-0.285]
Age 21-30	0.074	[-0.023,0.171]	0.075	[-0.021,0.171]	-0.041	[-0.157,0.076]
Age 31-40	-0.04	[-0.129,0.049]	-0.049	[-0.138,0.040]	-0.173**	[-0.296,-0.050]
Age 41-50	-0.417***	[-0.517,-0.316]	-0.431***	[-0.531,-0.331]	-0.472***	[-0.593,-0.351]
Age 51-60	-0.776***	[-0.868,-0.683]	-0.786***	[-0.879,-0.693]	-0.728***	[-0.855,-0.600]
Age 61-70	-1.301***	[-1.402,-1.200]	-1.311***	[-1.412,-1.210]	-1.164***	[-1.311,-1.017]
Age 71-80	-2.319***	[-2.432,-2.206]	-2.326***	[-2.439,-2.213]	-2.037***	[-2.197,-1.877]
Age 81 and older	-3.384***	[-3.520,-3.248]	-3.384***	[-3.521,-3.248]	-2.971***	[-3.156,-2.786]
Mixed ethnicity	-0.260**	[-0.435,-0.086]	-0.216*	[-0.389,-0.042]	-0.176*	[-0.348,-0.003]
Indian/Pakistani/Bangladeshi	-0.871***	[-1.057,-0.686]	-0.760***	[-0.931,-0.589]	-0.685***	[-0.813,-0.557]
Chinese/other Asians	-0.504***	[-0.739,-0.269]	-0.469***	[-0.715,-0.223]	-0.581***	[-0.786,-0.377]
Black Caribbean/Africans	-0.913***	[-1.039,-0.786]	-0.844***	[-0.966,-0.722]	-0.804***	[-0.916,-0.693]
Other ethnicities	-0.319	[-0.758,0.121]	-0.289	[-0.725,0.147]	-0.284	[-0.668,0.100]
Missing ethnicity dummy	-0.130**	[-0.208,-0.052]	-0.127**	[-0.203,-0.052]	0.109**	[0.033,0.185]
Average income by Local Authority District (LAD)			0.671***	[0.408,0.934]	0.221	[-0.002,0.444]
Relative deprivation rank index by LAD in 2010			0.000	[-0.000,0.001]	0.000	[-0.000,0.001]
Log of equivalent household income					0.162***	[0.126,0.197]
Highest qualification: A-level					0.531***	[0.446,0.615]
Highest qualification: First degree					0.637***	[0.579,0.694]
Highest qualification: Higher degree					0.886***	[0.795,0.976]
Self employed					0.067	[-0.013,0.147]
Unemployed					-0.298***	[-0.395,-0.200]
Retired					-0.108*	[-0.202,-0.014]
On maternity leave					-0.192	[-0.441,0.056]
Family care or home					-0.280***	[-0.383,-0.177]
Full-time student					0.219***	[0.116,0.321]
Long-term sick or disabled					-0.789***	[-0.935,-0.642]
Government training scheme					-0.33	[-1.125,0.465]
Unpaid, family business					0.788	[-0.058,1.633]
On apprenticeship					-0.227	[-0.815,0.360]
Doing something else					-0.228	[-0.499,0.043]
Married					0.021	[-0.046,0.088]
Civil partner (legal)					0.431*	[0.012,0.850]
Separated, legally married					-0.002	[-0.142,0.138]
Divorced					0.077	[-0.007,0.160]

Widowed					-0.047	[-0.158,0.064]
Separated from civil partner					0.259	[-0.304,0.821]
Health: Very good					-0.064*	[-0.123,-0.005]
Health: Good					-0.183***	[-0.243,-0.122]
Health: Fair					-0.408***	[-0.489,-0.328]
Health: Poor					-0.607***	[-0.713,-0.501]
Number of children < 16					-0.003	[-0.035,0.028]
Constant	6.689***	[6.273,7.105]	-0.137	[-2.615,2.341]	2.584*	[0.457,4.711]
R-squared	0.175		0.178		0.232	
N. of cases	33966		33966		33858	

Note: *<0.05; **<0.01, ***<0.001. Dependent variable = Delayed no. of words recalled (M = 5.136, SD = 2.132). Particle Matter 10 (M = 17.389, SD = 2.730). Other control variables include regional dummies (9), marital status dummies (7), and self-assessed health dummies (5). Other control variables include regional dummies (9), marital status dummies (7), and self-assessed health dummies (5).

Table 4: **Memory Quality and the Level of PM10 Air Particulates in the Local Area: Instrumental-Variable Regressions, UKHLS data for 2011**

	Model 1		Model 2		Model 3	
Number of words remembered	Coef.	95% C.I.	Coef.	95% C.I.	Coef.	95% C.I.
Particle matter (PM10) level in the district	-0.095***	[-0.141,-0.048]	-0.038	[-0.082,0.006]	-0.044*	[-0.079,-0.010]
Male	-0.283***	[-0.326,-0.240]	-0.283***	[-0.326,-0.240]	-0.324***	[-0.363,-0.285]
Age 21-30	0.079	[-0.018,0.176]	0.075	[-0.020,0.171]	-0.038	[-0.154,0.078]
Age 31-40	-0.039	[-0.128,0.049]	-0.049	[-0.138,0.040]	-0.169**	[-0.292,-0.047]
Age 41-50	-0.418***	[-0.519,-0.318]	-0.431***	[-0.530,-0.331]	-0.470***	[-0.590,-0.349]
Age 51-60	-0.777***	[-0.870,-0.685]	-0.786***	[-0.879,-0.693]	-0.726***	[-0.852,-0.599]
Age 61-70	-1.308***	[-1.409,-1.207]	-1.312***	[-1.412,-1.211]	-1.163***	[-1.309,-1.016]
Age 71-80	-2.322***	[-2.436,-2.209]	-2.327***	[-2.439,-2.214]	-2.035***	[-2.193,-1.876]
Age 81 and older	-3.392***	[-3.528,-3.256]	-3.385***	[-3.521,-3.248]	-2.971***	[-3.155,-2.787]
Mixed ethnicity	-0.240**	[-0.416,-0.065]	-0.215*	[-0.390,-0.040]	-0.171	[-0.344,0.002]
Indian/Pakistani/Bangladeshi	-0.837***	[-1.002,-0.672]	-0.759***	[-0.922,-0.595]	-0.679***	[-0.800,-0.558]
Chinese/other Asians	-0.488***	[-0.728,-0.248]	-0.469***	[-0.715,-0.222]	-0.577***	[-0.782,-0.373]
Black Caribbean/Africans	-0.882***	[-1.013,-0.751]	-0.842***	[-0.967,-0.718]	-0.798***	[-0.911,-0.685]
Other ethnicities	-0.266	[-0.689,0.158]	-0.286	[-0.712,0.140]	-0.268	[-0.643,0.106]
Missing ethnicity dummy	-0.133***	[-0.210,-0.055]	-0.128***	[-0.203,-0.052]	0.109**	[0.033,0.184]
Average income by Local Authority District (LAD)			0.662***	[0.404,0.921]	0.184	[-0.038,0.407]
Relative deprivation rank index by LAD in 2010			0.000	[-0.000,0.001]	0.000	[-0.000,0.001]
Log of equivalent household income					0.162***	[0.127,0.197]
Highest qualification: A-level					0.531***	[0.447,0.616]
Highest qualification: First degree					0.637***	[0.580,0.694]
Highest qualification: Higher degree					0.886***	[0.796,0.977]
Self employed					0.066	[-0.013,0.145]
Unemployed					-0.296***	[-0.392,-0.200]
Retired					-0.108*	[-0.202,-0.015]
On maternity leave					-0.192	[-0.439,0.054]
Family care or home					-0.280***	[-0.382,-0.178]
Full-time student					0.220***	[0.119,0.321]
Long-term sick or disabled					-0.787***	[-0.933,-0.642]
Government training scheme					-0.326	[-1.117,0.465]
Unpaid, family business					0.787	[-0.053,1.627]
On apprenticeship					-0.232	[-0.817,0.354]
Doing something else					-0.228	[-0.498,0.042]
Married					0.019	[-0.047,0.086]
Civil partner (legal)					0.430*	[0.012,0.847]
Separated, legally married					-0.003	[-0.142,0.137]

Divorced					0.075	[-0.008,0.159]
Widowed					-0.048	[-0.159,0.063]
Separated from civil partner					0.262	[-0.299,0.823]
Health: Very good					-0.064*	[-0.123,-0.005]
Health: Good					-0.183***	[-0.243,-0.122]
Health: Fair					-0.408***	[-0.488,-0.328]
Health: Poor					-0.607***	[-0.712,-0.501]
Number of children < 16					-0.004	[-0.035,0.028]
Constant	7.257***	[6.560,7.954]	-0.015	[-2.614,2.584]	3.114**	[0.868,5.360]
R-squared	0.174		0.178		0.232	
N. of cases	33966		33966		33858	

Note: *<0.05; **<0.01, ***<0.001. Dependent variable = Delayed number of words recalled out of a possible maximum of ten (M = 5.13, SD = 2.14). Particle Matter 10 (M = 17.632, SD = 2.856). Other control variables include regional dummies (9), marital status dummies (7), and self-assessed health dummies (5). The instrumental variables (IV) are population density by LAD district measured in 2011 and south-west coastal dummies.

Table 5: The First-Stage NO2 and PM10 Regressions Used in the IV Estimation

	First-stage regression: NO2		First-stage regression: PM10	
	Coef.	**95% C.I.**	**Coef.**	**95% C.I.**
Population density 2011	0.207***	[0.170,0.245]	0.056***	[0.047,0.066]
West/South West coastal district LAD = 1	-1.862**	[-3.123,-0.601]	-0.894***	[-1.342,-0.446]
Male	0.03	[-0.013,0.073]	0.005	[-0.012,0.022]
Age 21-30	0.266**	[0.064,0.468]	0.059	[-0.013,0.131]
Age 31-40	0.361**	[0.110,0.613]	0.082	[-0.004,0.169]
Age 41-50	0.287*	[0.059,0.514]	0.087*	[0.009,0.164]
Age 51-60	0.162	[-0.066,0.391]	0.062	[-0.017,0.141]
Age 61-70	0.152	[-0.127,0.432]	0.011	[-0.080,0.103]
Age 71-80	0.194	[-0.128,0.515]	0.05	[-0.061,0.160]
Age 81 and older	-0.18	[-0.538,0.177]	-0.054	[-0.180,0.072]
Mixed ethnicity	0.567**	[0.159,0.975]	0.108	[-0.023,0.239]
Indian/Pakistani/Bangladeshi	0.634	[-0.111,1.379]	0.077	[-0.154,0.307]
Chinese/other Asians	0.724***	[0.301,1.147]	0.103	[-0.037,0.242]
Black Caribbean/Africans	0.341	[-0.317,1.000]	0.169*	[0.000,0.338]
Other ethnicities	1.425	[-0.236,3.086]	0.374	[-0.031,0.779]
Missing ethnicity dummy	-0.156	[-0.410,0.097]	-0.065	[-0.179,0.050]
Average income by Local Authority District (LAD)	-1.166	[-4.184,1.852]	-0.853	[-1.905,0.198]
Relative deprivation rank index by LAD in 2010	-0.003	[-0.010,0.004]	0.005***	[0.003,0.007]
Log of equivalent household income	0.011	[-0.040,0.063]	0.013	[-0.003,0.030]
Highest qualification: A-level	0.098	[-0.055,0.252]	0.028	[-0.021,0.077]
Highest qualification: First degree	0.022	[-0.124,0.169]	-0.033	[-0.083,0.017]
Highest qualification: Higher degree	0.089	[-0.127,0.306]	-0.008	[-0.081,0.065]
Self employed	-0.335***	[-0.486,-0.184]	-0.074*	[-0.134,-0.015]
Unemployed	0.021	[-0.149,0.192]	0.042	[-0.018,0.103]
Retired	-0.106	[-0.259,0.046]	-0.014	[-0.068,0.041]
On maternity leave	-0.261	[-0.659,0.137]	0.043	[-0.095,0.182]
Family care or home	-0.079	[-0.257,0.099]	0.004	[-0.063,0.071]
Full-time student	0.101	[-0.070,0.272]	0.032	[-0.039,0.103]
Long-term sick or disabled	0.048	[-0.188,0.285]	0.06	[-0.033,0.153]
Government training scheme	-0.134	[-1.105,0.837]	0.04	[-0.369,0.449]
Unpaid, family business	-0.905*	[-1.726,-0.085]	-0.284	[-0.622,0.053]
On apprenticeship	-0.511	[-1.844,0.822]	-0.137	[-0.685,0.411]
Doing something else	-0.379	[-0.853,0.096]	-0.107	[-0.287,0.074]
Number of children < 16	-0.059	[-0.188,0.071]	-0.033	[-0.076,0.011]
Married	0.387	[-0.442,1.215]	-0.004	[-0.333,0.324]
Civil partner (legal)	-0.032	[-0.260,0.197]	-0.013	[-0.103,0.078]
Separated, legally married	-0.159*	[-0.314,-0.003]	-0.045	[-0.097,0.006]

Divorced	0.096	[-0.110,0.303]	-0.04	[-0.112,0.033]
Widowed	0.81	[-0.859,2.480]	0.08	[-0.557,0.717]
Separated from civil partner	0.066	[-0.031,0.163]	0.021	[-0.016,0.058]
Health: Very good	0.155*	[0.027,0.283]	0.038	[-0.008,0.083]
Health: Good	0.257***	[0.128,0.386]	0.068*	[0.016,0.119]
Health: Fair	0.212*	[0.033,0.391]	0.068*	[0.001,0.134]
Health: Poor	-0.028	[-0.082,0.026]	-0.011	[-0.029,0.007]
Constant	23.006	[-5.589,51.601]	20.065***	[9.980,30.150]
F test of excluded instruments	65.23 [0.000]		78.24 [0.000]	
Under-identification test (Kleibergen-Paap LM statistic)	56.33 [0.000]		48.94 [0.000]	
Hansen J Statistic (Overidentification test)	0.447 [0.5038]		0.049 [0.8249]	
N. of cases	33858		26041	

Note: *<0.05; **<0.01, ***<0.001. LAD stands for local authority district.

Table 6: Severe Memory Problems in English Citizens: Probit Equations

The definition of 'severe' memory problem here is being able to remember at most a single word from a list of 10 words.

	Probit		**IV-Probit**	
Dependent variable: **Has a Severe Memory Problem**	Coef.	95% C.I.	Coef.	95% C.I.
NO2 level in the district	0.010**	[0.003,0.017]	0.008***	[0.004,0.013]
Male	0.079**	[0.032,0.126]	0.079**	[0.032,0.126]
Age 21-30	-0.049	[-0.208,0.111]	-0.042	[-0.201,0.118]
Age 31-40	0.082	[-0.089,0.253]	0.086	[-0.085,0.257]
Age 41-50	0.182*	[0.021,0.344]	0.185*	[0.023,0.348]
Age 51-60	0.190*	[0.017,0.363]	0.191*	[0.018,0.364]
Age 61-70	0.418***	[0.238,0.597]	0.417***	[0.238,0.595]
Age 71-80	0.829***	[0.639,1.019]	0.829***	[0.641,1.016]
Age 81 and older	1.320***	[1.115,1.524]	1.313***	[1.109,1.516]
Mixed ethnicity	0.05	[-0.138,0.239]	0.046	[-0.146,0.237]
Indian/Pakistani/Bangladeshi	0.438***	[0.319,0.556]	0.440***	[0.328,0.552]
Chinese/other Asians	0.452***	[0.263,0.640]	0.434***	[0.246,0.622]
Black Caribbean/Africans	0.307***	[0.200,0.414]	0.295***	[0.196,0.394]
Other ethnicities	0.211	[-0.205,0.627]	0.199	[-0.214,0.613]
Missing ethnicity dummy	0.07	[-0.008,0.147]	0.07	[-0.009,0.149]
Average income by Local Authority District (LAD)	-0.145	[-0.394,0.104]	-0.191	[-0.390,0.009]
Relative deprivation rank index by LAD in 2010	0.000	[-0.000,0.001]	0.000	[-0.000,0.000]
Log of equivalent household income	-0.071***	[-0.098,-0.045]	-0.071***	[-0.098,-0.044]
Highest qualification: A-level	-0.229***	[-0.333,-0.125]	-0.235***	[-0.338,-0.131]
Highest qualification: First degree	-0.273***	[-0.348,-0.198]	-0.278***	[-0.352,-0.204]
Highest qualification: Higher degree	-0.303***	[-0.430,-0.175]	-0.308***	[-0.434,-0.182]
Self employed	-0.084	[-0.202,0.033]	-0.085	[-0.202,0.032]
Unemployed	0.204***	[0.107,0.301]	0.203***	[0.105,0.300]
Retired	0.071	[-0.029,0.171]	0.075	[-0.023,0.174]
On maternity leave	0.371*	[0.047,0.695]	0.365*	[0.041,0.689]
Family care or home	0.240***	[0.136,0.343]	0.234***	[0.131,0.337]
Full-time student	-0.088	[-0.250,0.074]	-0.089	[-0.251,0.073]
Long-term sick or disabled	0.486***	[0.372,0.600]	0.481***	[0.367,0.595]
Government training scheme	0.418	[-0.242,1.078]	0.411	[-0.252,1.074]
Unpaid, family business	-0.071	[-0.937,0.795]	-0.075	[-0.948,0.798]
On apprenticeship	0.124	[-0.684,0.932]	0.116	[-0.717,0.948]
Doing something else	-0.114	[-0.541,0.314]	-0.113	[-0.539,0.313]
Number of children < 16	-0.047	[-0.129,0.035]	-0.044	[-0.126,0.037]
Married	-0.482	[-1.258,0.294]	-0.467	[-1.251,0.317]

Civil partner (legal)	-0.086	[-0.262,0.089]	-0.082	[-0.256,0.092]
Separated, legally married	-0.079	[-0.185,0.027]	-0.079	[-0.184,0.027]
Divorced	0.018	[-0.095,0.130]	0.021	[-0.091,0.132]
Widowed	0.000	[0.000,0.000]	0.000	[0.000,0.000]
Separated from civil partner	0.057	[-0.027,0.140]	0.057	[-0.026,0.140]
Health: Very good	0.112**	[0.028,0.196]	0.113**	[0.029,0.197]
Health: Good	0.236***	[0.144,0.327]	0.235***	[0.143,0.326]
Health: Fair	0.366***	[0.259,0.474]	0.370***	[0.262,0.478]
Health: Poor	-0.034	[-0.074,0.007]	-0.033	[-0.074,0.009]
Constant	-0.18	[-2.573,2.213]	0.354	[-1.607,2.315]
Log likelihood	-7036.94		-94142.62	
N. of cases	33,846		33,846	

Note: *<0.05; **<0.01, ***<0.001. Robust standard errors are in parentheses. UKHLS Data 2011. Dependent variable = Delayed number of words recalled out of a possible maximum of ten = either no words or one just a single word (M = .067, SD = 0.25).

NO2 (M = 17.905, SD = 7.689).

Other control variables include regional dummies (9), marital status dummies (7), and self-assessed health dummies (5). The instrumental variables (IV) are population density by LAD district measured in 2011 and south-west coastal dummies. 318 districts. The first column here has a larger number of observations because to perform the instrumenting it was necessary, due to missing values, to discard some of the observations. Standard errors are corrected for clustering.

Table 7: Ordinary Least Squares (OLS) and Instrumental-Variables (IV) Estimates of Delayed Recall by Age Group

	Age<=18	18<Age<=30	30<Age<=60	Age>60
	Coef.	Coef.	Coef.	Coef.
i) OLS				
Nitrogen dioxide	-0.007	-0.012	-0.012**	-0.007
	[-0.033,0.019]	[-0.024,0.001]	[-0.020,-0.004]	[-0.015,0.001]
N	*1,640*	*5.522*	*17.170*	*8.920*
ii) IV				
Nitrogen dioxide	-0.001	-0.002	-0.015*	-0.014*
	[-0.037,0.035]	[-0.019,0.014]	[-0.029,-0.002]	[-0.025,-0.003]
N	*1,640*	*5.522*	*17.170*	*8.920*
iii) OLS				
Particle matter 10	0.000	-0.033	-0.043***	-0.01
	[-0.082,0.083]	[-0.072,0.006]	[-0.066,-0.020]	[-0.034,0.015]
N	*1,640*	*5,522*	*17,170*	*8.920*
iv) IV				
Particle matter 10	-0.005	-0.008	-0.057*	-0.051*
	[-0.128,0.119]	[-0.066,0.049]	[-0.101,-0.012]	[-0.093,-0.008]
N	*1,640*	*5,522*	*17,170*	*8.920*

Note: *<0.05; **<0.01, ***<0.001.

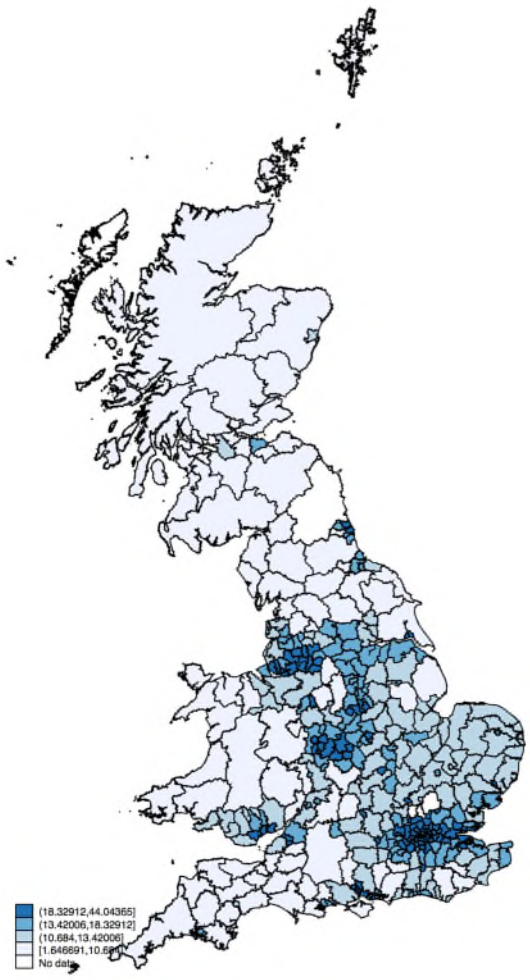
OLS stands for ordinary least squares; IV stands for instrumental-variable estimates.

Table 8: Memory Quality and the Average Past Level of Air Pollutants (averaging 2009 and 2010) in the Local Area

	Model 1	
Number of words remembered	Coef.	95% C.I.
Average NO2 in the district (2009 and 2010)	-0.013***	[-0.021,-0.006]
N	*30,499*	
R-squared	0.237	
Average PM10 in the district (2009 and 2010)	-0.037**	[-0.058,-0.015]
N	*30,499*	
R-squared	0.237	

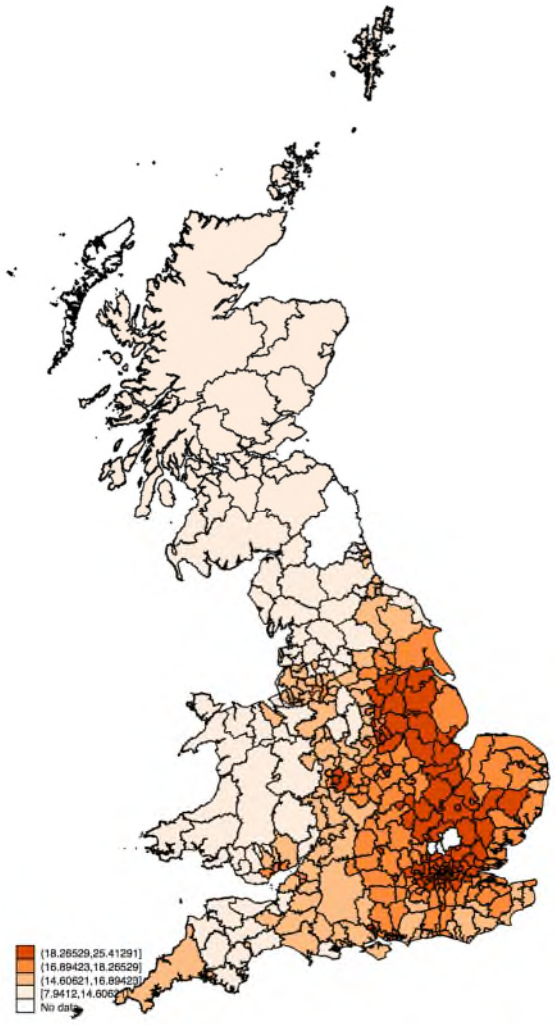
Note: *<0.05; **<0.01, ***<0.001. Dependent variable = Delayed no. of words recalled (M = 5.136, SD = 2.132). All other covariates (not reported) are included in these equations, as in the main equations in the paper. These are OLS results; IV ones are very similar.

Figure 1: Nitrogen Dioxide Levels in the Local Authority Districts of the UK



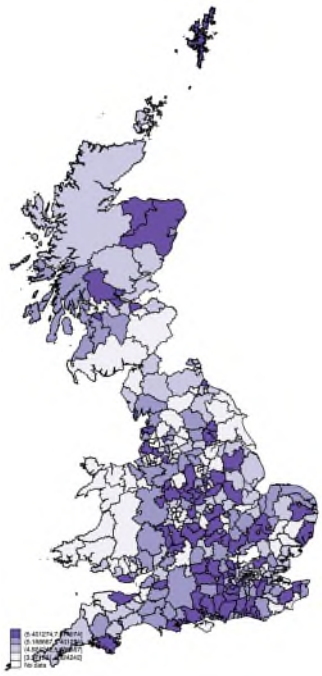
Note: Measured in μg micrograms per cubic metre of air.

Figure 2: PM10 Levels in the Local Authority Districts of the UK



Note: Measured in μg micrograms per cubic metre of air.

Figure 3: Memory Levels in the Local Authority Districts of the UK (measured in number of words remembered)



Note: Delayed words recalled on a memory test scored from zero (no words out of 10 remembered) to ten (10 out of 10 remembered). Darker areas are those where people have better memories.

Figure 4: Map of the 'Standard' Regions of England

Note: This is included as a visual guide to the region-dummies used.

SUPPLEMENTARY APPENDIX

Table S1:
The Frequency Distribution of Memory Scores across Individuals
Number of words remembered out of 10.

Delayed no. of words recalled	zero_one_wrd_recall2 0	1	Total
0	0	1,553	1,553
1	0	701	701
2	1,325	0	1,325
3	2,942	0	2,942
4	5,199	0	5,199
5	6,910	0	6,910
6	6,551	0	6,551
7	4,799	0	4,799
8	2,461	0	2,461
9	1,050	0	1,050
10	477	0	477
Total	31,714	2,254	33,968

Table S2:

Descriptive Statistics on Memory and the English Sample – Means and Standard Deviations for the High-Score and Low-Score Individuals

	Delayed word recalls: 0-5 words recalled		Delayed word recalls: 6-10 words recalled	
	M	SD	M	SD
Nitrogen dioxide level in the individual's district	17.50	7.547	16.97	7.263
Particle matter (PM10) level in the district	17.44	2.794	17.36	2.674
Particle matter (PM2.5) level in the district	11.81	2.071	11.77	1.986
Age	52.01	18.89	41.47	15.59
Male	0.475	0.499	0.405	0.491
Age<=20	0.100	0.300	0.178	0.383
Age 21-30	0.138	0.345	0.221	0.415
Age 31-40	0.176	0.380	0.210	0.408
Age 41-50	0.163	0.369	0.153	0.360
Age 51-60	0.176	0.381	0.104	0.306
Age 66-70	0.130	0.337	0.0287	0.167
Age 71-80	0.0610	0.239	0.00451	0.0670
Age 81 and older	9.831	0.179	9.857	0.178
Relative deprivation rank index by LAD in 2010	136.6	96.66	146.4	98.37
Log of equivalent household income	9.740	0.766	9.966	0.788
Highest qualification: A-level	0.0590	0.236	0.0962	0.295
Highest qualification: First degree	0.163	0.370	0.259	0.438
Highest qualification: Higher degree	0.0543	0.227	0.106	0.308
Self employed	0.0675	0.251	0.0823	0.275
Unemployed	0.0607	0.239	0.0491	0.216
Retired	0.318	0.466	0.115	0.319
On maternity leave	0.00394	0.0626	0.00830	0.0907
Family care or home	0.0651	0.247	0.0619	0.241
Full-time student	0.0456	0.209	0.0899	0.286
Long-term sick or disabled	0.0452	0.208	0.0183	0.134
Government training scheme	0.00102	0.0320	0.000784	0.0280
Unpaid, family business	0.000431	0.0208	0.000784	0.0280
On apprenticeship	0.000539	0.0232	0.000719	0.0268
Doing something else	0.00485	0.0695	0.00405	0.0635
No of children aged under 16	0.460	0.920	0.594	0.959
N	18,630		15,338	

Note: UKHLS data for 2011.