The Effect of a Targeted Cash Transfer on Cognitive Function in Later Life: Evidence from a Gene-by-Environment Interaction

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Abstract

We examined whether the Winter Fuel Payment - an unconditional targeted cash transfer - improves cognitive function among older people in England; and whether this effect varied by genetic makeup. Data came from the English Longitudinal Study of Ageing (ELSA, 2002-10, *N*=13,663). To overcome the limitations of previous gene-by environment studies, we assessed the effect of receiving the cash transfer on cognition using individual fixed effects to minimize confounding. Receipt of the transfer was interacted with polygenic risk scores for Alzheimer's disease and general cognition to examine whether the effect varied by genetic predisposition. Receiving the cash transfer was associated with an 0.024 increase (95% confidence interval [CI]: 0.001 to 0.046) in the total cognitive function z-score, driven primarily by improvements in executive function. Respondents in the highest quartile of polygenic risk for Alzheimer's experienced larger increases in total cognition (β=0.076, 95% CI: 0.01 to 0.142) compared to those in the lowest quartile. Genetic predisposition for general cognition did not modify the effect of the cash transfer on cognition. These results support the potential for social policies to improve cognition in later life and highlight the ability of the social environment to mitigate genetic risk factors.

INTRODUCTION

In the wake of the mapping of the human genome, hopes were high that genetic causes for major cognitive diseases including dementia would be identified and their mechanisms targeted for clinical intervention. Recent genome-wide-association-studies have however showed that genetic variants explained much less variation than initially expected.[1,2] Part of this 'missing heritability'[3] in cognitive function and dementia risk may reflect social and environmental circumstances: social environments may amplify or reduce the effect of innate genetic vulnerabilities. Studies have for example outlined differences in the effect of the ε4 allele of the apolipoprotein E (APOE) gene on cognition and dementia as a function of neighborhood environment,[4,5] prolonged exposure to stress[6] or educational attainment.[7,8]

The initial enthusiasm for gene-by-environment interactions (GXE) studies was however tempered by concerns around replicability.[9,10] An important drawback of most studies of genetic interaction with social environments to date is the potential for gene-environment correlations, whereby "environments" are partly selected by the individual and/or their biological parents (or elicited by others response to genes) and thus might be a function of the genes themselves.[11,12] Apart from a number of notable exceptions,[13-16] most existing GXE studies suffer from potentially endogenous measures of the environment. As a consequence, the extent to which social interventions in later life can support cognitive function in particular among those predisposed to cognitive decline or dementia due to their genetic makeup is not yet fully understood.

We overcome these empirical challenges by combining quasi-experimental variation in the social environment with polygenic scores (PGSs) for general cognition and Alzheimer's.[17,18] Specifically, we leverage the exogenous variation in income introduced by the Winter Fuel Payment (WFP), a universal unconditional cash transfer introduced in England in 1997 to support older households with the costs of heating their homes during cold months. The available evidence indicates that the policy had a positive effect on excess winter mortality[19] and biomarkers of stress[20] but physical health effects are mixed.[20,21] We extend this literature by looking at the effect of receiving the WFP on cognition. There is ample evidence that higher income is associated with better cognition;[22,23] but these associations may be biased by unmeasured confounders correlated with both income and cognition or by reverse

causality. The quasi-experimental evidence is more limited and it remains unclear whether *changes* in income induced by a policy can improve cognitive function in later life.

In this study, we assess the effect of receiving the WFP on cognitive function using a quasi-experimental design and we test the hypothesis that the cash transfer has stronger effects among respondents who carry a genetic liability for cognitive decline or Alzheimer's.

METHODS

Study population

We used longitudinal data from the English Longitudinal Study of Ageing (ELSA), a nationally representative cohort of individuals aged 50 and older residing in England and their spouses. The ELSA sample was drawn from respondents to the Health Survey for England (HSE) who were in the eligible age bracket. Details of the study are provided elsewhere.[24] Enrollment started in 2002-2003 and biennial interviews have been conducted through 2016, with wave-to-wave retention rates of approximately 70%. Our dataset was comprised of five waves starting in 2002 and ending in 2010, the last year when both our exposure (receipt of the WFP) and outcomes (cognitive scores) of interest were available. Ethical approval was granted by the London Multicentre Research Ethics Committee (MREC/01/2/91) and informed consent was obtained from all participants.

We restricted our sample to participants who had at least two waves of data available in our time period. This led to the exclusion of 3,094 individuals and a final sample of 13,663 respondents. Genetic data was collected in 2012 and available for 7,081 respondents. **Appendix Table 1** confirms that our analytical samples have similar baseline characteristics to the overall sample. Less than 1% of the observations had missing data for the WFP variable, and 3 to 8% had data missing for the cognitive scores.

Receipt of the Winter Fuel Payment

Our policy exposure of interest was the receipt of the WFP. The cash transfer is provided every year to households containing an individual aged 60 or over. The cash transfer is automatic for individuals

who receive the state pension or another social security benefit, while individuals who do not receive these benefits are eligible but have to submit a claim. Its value ranges between £200 per year for households where the oldest person is aged between 60 and 79 and £300 since 2003 for households where the oldest person is 80 or over. Although the transfer is unconditional (there is no obligation to spend the cash transfer on household fuel), households spend almost half of the transfer they receive on fuel.[25] Eligibility for the WFP is aligned with the female state pension age and started to increase in 2012 in line with the pension reform.[26] However, these changes take place after our study period.

ELSA respondents aged 60 and over or living with a partner aged 60 and over were asked at each wave of the survey about their receipt of the WFP. Respondents could answer yes or no. Our exposure was a binary variable which took the value of 1 if the respondent had received the WFP in the past year or 0 if he/she had not or was not eligible.

Eligibility to receive the WFP is closely linked to age. Only capturing receipt of the WFP through age would risk biasing our estimate, which would measure the cognitive effects of becoming older rather than that of receiving the cash transfer. We consequently rely on the variable measuring the receipt of the WFP described above. As shown in **Figure 1**, there is a sharp increase in the proportion of the respondents who receive the cash benefit at the age cut-off for eligibility. We exploit this exogenous increase in receipt in our individual fixed-effects models as described below. We also adjust all models for age and age squared. Another potential threat to our approach is that the female state pension age coincides with WFP eligibility for the duration of our study sample. To avoid the confounding effect of the receipt of state pension age on WFP and cognition, we employ two strategies. First, in all models, we adjust for respondents' employment and retirement status. Second, in sensitivity analyses, we follow previous research[20,25] and restrict our sample to single men and households in which the man is the oldest, because those households do not qualify simultaneously for the WFP and the female state pension.

Assessment of cognitive function

Cognitive function was assessed in ELSA using standard tests covering three major cognitive domains: memory, processing speed and executive function. Memory was measured using a word-recall test. A

list of ten words was presented orally to participants who were then asked to recall as many as possible immediately and after a five-minute delay. An overall memory score was computed (ranging from 0 to 20) by adding the scores of both the immediate and delayed recall. Processing speed was measured using a letter cancellation test. The respondent was given a piece of paper with random letters and asked to cross out as many of the 65 target letters (Ps and Ws) as possible in one minute by working across and down the page. The score is the total number of letters searched, ranging from 0 to 65. Executive function was measured using a test of how many different animals the respondent could name in one minute (ranging from 0 to 60). All these scores are robust to floor, ceiling and practice effects.[27,28] To facilitate comparisons, we transformed each test into z-scores. These scores were then combined to build a total cognitive function z-score, as recommended in previous studies.[29] Higher scores indicate better cognitive function.

Polygenic Scores for general cognition and Alzheimer's

Multiple analyses of genetic effects on cognitive function and Alzheimer's have indicated that both phenotypes are likely to be highly polygenic, resulting from the combined effect of many risk variants, each with relatively small effect sizes.[30] PGSs can be used to overcome this limitation and test the predictive power of multiple genetic variants simultaneously.[31] PGSs have been shown to be suitable for the analysis of GxE.[32] The methods employed in ELSA to create these scores are modelled after the Health and Retirement Study to enhance comparability across ageing surveys.[33] The genome-wide genotyping was performed in 2013-14 on 7,597 participants of European ancestry in two batches (batch one n=5,652; batch two n=1,945) using the Ilumina HumanOmni 2.5-8 BeadChips. A sample of 7,081 participants remained after quality control procedures (including removal of SNPs based on call rate, minor allele frequency, deviations from Hardy-Weinberg equilibrium; and removal of individuals based on call rate, relatedness, gender mismatch and non-European ancestry).

Data were available on over 2.5 million genetic locations for each individual. Polygenic scores for general cognition and Alzheimer's were then built by weighting each nucleotide by their estimated contribution from large Genome Wide Association Studies (GWAS) of general cognition and Alzheimer's.[34,35] These GWAS did not include the ELSA data. The PGS for Alzheimer's contains 1,191,420 SNPs overlapping between the ELSA genetic database and the GWAS (mean 25896.2, standard error 0.64). As PGSs are based on linear models from single SNPs, the Alzheimer's PGS

does not include the two variants that contribute to APOE status. The PGS for general cognition covers 795,327 SNPs overlapping with the ELSA genetic database (mean 5861.4, standard error 0.19). We derived quartiles based on the continuous PGSs, with the top quartile coded as "high risk" for both Alzheimer's and lower overall cognitive ability. In supplementary analyses, we investigated the potential role of APOE genotype. Genotypes were based on imputed data for 6,151 participants on the two SNPs for APOE, rs429358 and rs7412 that comprise the ε2, ε3 and ε4 alleles. Participant APOE carrier status was determined based on the presence (APOE ε2/4, ε3/4 and ε4/4) or absence (APOE ε2/2, ε2/3 and ε3/3) of APOE ε4 alleles. In our sample, 69% of respondents carried two ε3 alleles; 27% a combination of alleles ε3 and 4; 2.6% two ε4 alleles; 0.7% two ε2 alleles.

Controls

Time-varying characteristics measured at each wave include: age, age squared, study wave, at least one limitation in the activities of daily living [ADLs], at least one limitation in the instrumental activities of daily living [IADLs], the natural log of net total non-housing household wealth, the natural log of equivalised household income, marital (married, cohabitating, single/never married, widowed, divorced, separated) and employment status (employed, unemployed, retired, out of the labour force).

Statistical analysis

The Hausman specification test[36] indicated that the assumption of no-correlation between explanatory variables and unobserved effects was violated in random-effects models (**Appendix Table 2**). Individual fixed effect models were consequently used to assess the relationship between receipt of WFP and cognitive function. These models leverage within-individual changes in both exposure and outcome, thereby adjusting for measured and unmeasured time-invariant confounders that differ across individuals.[37] Our approach fulfills the two conditions of fixed-effects models: our outcome variables are measured in the same way for each respondent for at least two time points and exposure to the WFP varies over time for at least part the respondents.[38,39] Specifically, we compared the cognitive scores of a respondent before receiving the WFP to that same respondent's cognitive function after he/she started receiving the cash transfer. Our basic model is as follows:

$$Cog_{it} = \mu_t^1 + \beta^2 WFP_{it} + \beta^3 X_{it} + \beta^4 X_{it} + \alpha_i^5 + \varepsilon_{it} \quad (1)$$

Where Cog_{it} represents the total cognitive function z-score for individual i at time t; WFP_{it} is the WFP indicator, which takes the value of 1 if the household receives the cash transfer and 0 otherwise; X_{it} is a vector of time-varying controls; μ_t^1 is a fixed effect for time that accounts for time trends constant across individuals; α_i^5 controls for time-invariant individual characteristics; and ε_{it} is the error term. We then extended these models to examine the interaction between PGSs for general cognition and Alzheimer's and time-varying receipt of WFP:

$$Cog_{it} = \mu_t^1 + \beta^2 WFP_{it} \times PGS_i + \beta^3 WFP_{it} \times PC_i + \beta^4 X_{it} + \alpha_i^5 + \varepsilon_{it} \quad (2)$$

Where $WFP_{it} \times PGS_i$ is the interaction between time-varying receipt of WFP and PGSs for cognitive function or Alzheimer's; PC_i is a vector of the principal components (PCs) of the genotypic data significantly associated with the outcome of interest. We included $WFP_{it} \times PC_i$ to adjust for population stratification.[40,41]

We calculated individual clustered standard errors for all estimates. All analyses were conducted in Stata version 15.

RESULTS

Table 1 summarizes the baseline characteristics of the sample. Over half of the sample was receiving the WFP at baseline (52.85%, with a further 4.43% eligible based on their partner's age). The majority of respondents eligible for the WFP receive it (92.02%). Those who are eligible but do not claim it are younger and more likely to still be in employment (**Appendix Table 3**). Average age at baseline was 61.85 (SD: 10.27); 68.40% of respondents were married or in civil partnership. 42.19% of respondents were employed at baseline, while 40.61% were retired. The vast majority of the sample was in good functional health, reporting no limitations with activities of daily living (ADLs, 83.14%) or instrumental activities of daily living (IADL, 82.79%). At baseline, respondents recalled on average 10.07 words (SD: 3.51), correctly identified 19.35 target letters (SD: 5.89) and named 19.62 animals (7.47).

During the study period, 3,448 respondents started receiving the WFP. Results from fully adjusted fixed-effects models are presented in **Table 2**. Receiving the cash transfer predicted an increase in the total cognitive function z-score in the same year (β=0.024, 95% confidence interval [CI]: 0.001 to 0.046). This is driven primarily by improvements in the executive function domain (β=0.031, 95% CI: 0.004 to 0.058). Full results by cognitive scores are presented in **Appendix Table 4**.

Figure 2 displays the effect of receiving the WFP on total cognitive z-scores across quartiles of Alzheimer's (panel A) and general cognition PGSs (panel B). Estimates are from a model incorporating an interaction term between receipt of the WFP and PGSs, controlling for the same covariates as in the main model as well as the interaction between the exposure and PCs. In the genetic sample, 2,116 respondents started receiving the WFP. Full results are presented in **Appendix Table 5.** The effect of receiving the cash transfer on the total cognitive function z-score was concentrated among respondents in the top quartile (highest risk) of Alzheimer's PGSs (β=0.076, 95% CI: 0.01 to 0.142). This effect was not driven by specific cognitive domains (**Appendix Table 6**). There was no interaction between receiving the WFP and the general cognition PGSs, suggesting that genetic predisposition for overall cognition did not modify the effect of the cash transfer on changes in cognitive function (**Appendix Table 7**). Similarly, we found no interaction effect between receipt of the WFP and APOE status (**Appendix Table 8**)

We conducted several sensitivity analyses to assess the robustness of our findings. First, coding our exposure of interest as eligibility for the cash transfer (respondent turning 60 or living in a household where the older member turns 60) rather than receipt of the cash transfer led to essentially the same results (β=0.024, 95% CI: 0.001 to 0.048, **Appendix Table 9**). Second, a potential concern is that eligibility for the WFP and female state pension coincide during our study period. Our results were robust to restricting our sample to single men and households in which the man is the oldest (β=0.035, 95% CI: 0.006 to 0.064), households which do not qualify simultaneously for the cash transfer and female state pension (**Appendix Table 10**). The effect of the WFP on cognition did not vary by individual baseline characteristics such as educational attainment or income levels (results available upon request).

DISCUSSION

Our findings suggest that receipt of a small universal unconditional cash transfer in older age was associated with modest cognitive benefits; and that these benefits were stronger among respondents who carried a higher genetic risk for Alzheimer's. These results provide novel evidence of the interaction between the social environment and genetic susceptibility and the potential role of social policies in improving cognition in later life.

Our study contributes several new insights. First, we find that receipt of a small cash transfer - corresponding to roughly the weekly median income in our sample - is associated with modest improvements in cognition in older age, and in particular in executive function. This effect is similar in size to the increase in total cognitive function z-score associated with becoming a public transport user (β=0.014, 95% CI: 0.001 to 0.028).[42] Cash transfers in different forms have been shown to reduce financial hardship.[43] Previous research has linked poverty-associated stress to losses in executive function[44-48] but this damage to neural pathways is believed to be reversible.[44-49] The positive effect of the WFP on executive function supports the idea that income support may alleviate stressors that impact this cognitive domain. This result may have added importance given that impaired executive function is often an early indicator of Alzheimer's disease.[50] These findings add to a small literature documenting the causal impact of income on cognition in later life.[51,52] They also have implications for policy-making. The age of eligibility for the WFP has been rising in recent years along with female state pension age to equal the male state pension age of 65 in 2018. Our findings suggest that reducing eligibility for the cash transfer might have unforeseen consequences for cognitive function in this ageing population.

Second, our findings suggest that the effect of genes on phenotypes such as cognition might be modified by even small changes in the social environment. Indeed, respondents who have a higher genetic susceptibility to Alzheimer's as defined by the top quartile of the PGS benefitted the most from the cash transfer in terms of cognition. These results indicate that small average treatment effects may conceal larger effects for individuals with particular genotypes. They are consistent with the differential susceptibility model which posits that individuals carrying certain genetic susceptibilities will be more sensitive to the social environment, whether positive or negative.[53] In this model, a positive income shock such as the WFP would be associated with greater improvements in cognitive function among individuals carrying higher genetic predisposition for cognitive decline, potentially by

delaying the onset of symptoms. It is worth noting that we did not find a significant interaction effect with the PGS for general cognition, likely reflecting different sets of risks and mechanisms. Previous studies had documented that higher educational attainment and participation in leisure activities may lower the risk of dementia associated with carrying the APOE ε4 allele.[8] We do not replicate these findings in relation to income in our sample. We may not have enough power to detect the differential effect of the WFP on cognition by APOE status: the confidence intervals for this estimate are wide and include benefits as well as harms as plausible effects.

Third, most existing GxE studies to date have been limited by their reliance on endogenous measures of the environment.[11,12] As receipt of the WFP is not correlated with innate individual characteristics or characteristics of the respondents' parents, the risk of gene-environment correlations – whereby measured environments are correlated with unmeasured genetic variation – is considerably reduced. To our knowledge, only a handful of studies have used quasi-experimental approaches to investigate GXE interactions.[12,13,16] For example, Fletcher *et al* found that individuals who were genetically *less* responsive to nicotine responded more strongly to state-level tobacco taxation policies in the United States.[16] Using changes in the compulsory schooling law in the U.K, Barcellos *et al* found that additional education was associated with greater reductions in BMI for those most genetically susceptible to obesity, consistent with our results here for a positive change in the social environment.[13] To our knowledge, ours is the first study to test a quasi-experimental social exposure together with genetic susceptibility for cognitive function.

This study has several strengths. First, our analyses are based on a large, representative, longitudinal sample of older adults in England, with validated measures of socioeconomic status, health, cognition and PGSs. Second, the fixed-effects models control for time-invariant characteristics that differ across individuals and might confound the association between receipt of the cash transfer and cognition. We also leverage the sharp discontinuity in age eligibility for WFP receipt to improve causal inference. However, a number of limitations should also be considered. First, we cannot completely rule out reverse causality based on our fixed-effects models: a deterioration in cognitive function might compromise an individual's ability to claim the cash transfer. However, most eligible respondents in our sample receive the WFP automatically as they receive the state pension or another old-age benefit. 92.02% of eligible respondents receive the transfer in our sample. Third, although our fixed-effects models controlled for a large number of time-varying confounders, unmeasured time-varying

confounding remains a possible source of bias. Fourth, PGSs aggregate many SNPs but not all SNPs may respond uniformly to the environment, and aggregation may obscure the exact nature of the biological pathways. Effect sizes are small but the fact that a modest income intervention still produces cognitive effects that vary by genetic risk is noteworthy. Finally, attrition is a potential concern in longitudinal studies. Retention rates are high in ELSA[24] and previous research has indicated that attrition is not linked to health outcomes.[54]

In conclusion, we find that an unconditional universal cash transfer not only improved cognitive function in an older population but also compensated genetic risk for cognitive decline: the association between genetic susceptibility and cognition was reduced among respondents who started receiving the WFP, thus reducing the gap in cognitive function between those in the top and bottom quartile of genetic risk for cognitive decline. These findings highlight the potential role of social policies across the life course in protecting against health risks, including those arising from genetic characteristics. Considering the interplay of genes and environment in late adulthood may improve our understanding of cognitive ageing and lay the ground for the development of interventions promoting successful ageing.

REFERENCES

1. Ridge PG, Mukherjee S, Crane PK, Kauwe JSK, Alzheimer's Disease Genetics C. Alzheimer's disease: analyzing the missing heritability. *PloS one.* 2013;8(11):e79771-e79771.
2. Levine M, Harrati A, Crimmins E. Predictors and implications of accelerated cognitive aging. *Biodemography and Social Biology.* 2018;64(2):83-101.
3. Ridge PG, Mukherjee S, Crane PK, Kauwe JSK, Alzheimer's Disease Genetics C. Alzheimer's Disease: Analyzing the Missing Heritability. *PLOS ONE.* 2013;8(11):e79771.
4. Boardman JD, Barnes LL, Wilson RS, Evans DA, de Leon CFM. Social disorder, APOE-E4 genotype, and change in cognitive function among older adults living in Chicago. *Social Science & Medicine.* 2012;74(10):1584-1590.
5. Lee BK, Glass TA, James BD, Bandeen-Roche K, Schwartz BS. Neighborhood psychosocial environment, apolipoprotein E genotype, and cognitive function in older adults. *Archives of General Psychiatry.* 2011;68(2011):314-321.
6. Peavy GM, Lange KL, Salmon DP, et al. The Effects of Prolonged Stress and APOE Genotype on Memory and Cortisol in Older Adults. *Biol Psychiatry.* 2007;62(5):472-478.
7. McArdle JJ, Prescott CA. Contemporary Modeling of Gene × Environment Effects in Randomized Multivariate Longitudinal Studies. *Perspectives on Psychological Science.* 2010;5(5):606-621.
8. Ferrari C, Xu W-L, Wang H-X, et al. How can elderly apolipoprotein E ε4 carriers remain free from dementia? *Neurobiology of Aging.* 2013;34(1):13-21.
9. Duncan LE, Keller MC. A critical review of the first 10 years of candidate gene0by-environment interaction research in psychiatry. *Am J Psychiatry.* 2011;168(1):1041-1049.
10. Hewitt JK. Editorial policy on candiate gene association and candidate gene-by-environment interaction studies of complex traits. *Behav Genet.* 2012;42(1):1-2.
11. Fletcher JM, Conley D. The Challenge of Causal Inference in Gene–Environment Interaction Research: Leveraging Research Designs From the Social Sciences. *American Journal of Public Health.* 2013;103(S1):S42-S45.
12. Schmitz L, Conley D. Modeling Gene-Environment Interactions With Quasi-Natural Experiments. *Journal of Personality.* 2017;85(1):10-21.
13. Barcellos S, Carvalho L, Turley P. Education can reduce health differences related to genetic risk of obesity. *PNAS.* 2018;115(42):9765-9772.
14. Schmitz L, Conley D. The effect of Vietnam-era conscription and genetic potential for educational attainment on schooling outcomes. *Econ Educ Rev.* 2017;61(1):85-97.
15. Boardman JD, Roettger ME, Domingue BW, McQueen MB, Haberstick BC, Harris KM. Gene-environment interactions related to body mass: School policies and social context as environmental moderators. *J Theor Polit.* 2012;24(3):370-388.
16. Fletcher JM. Why have tobacco control policies stalled? Using genetic moderation to examine policy impacts. *PloS one.* 2012;7(12):e50576-e50576.
17. Domingue BW, Liu H, Okbay A, Belsky DW. Genetic Heterogeneity in Depressive Symptoms Following the Death of a Spouse: Polygenic Score Analysis of the U.S. Health and Retirement Study. *Am J Psychiatry.* 2017;174(10):963-970.
18. Belsky DW, Israel S. Integrating genetics and social science: genetic risk scores. *Biodemography and social biology.* 2014;60(2):137-155.
19. Iparraguirre J. Have winter fuel payments reduced excess winter mortality in England and Wales? *Journal of Public Health.* 2014;37(1):26-33.
20. Crossley TF, Zilio F. The health benefits of a targeted cash transfer: The UK Winter Fuel Payment. *Health Economics.* 2018;27(9):1354-1365.

21. Angelini V, Daly M, Moro M, et al. The effect of the Winter Fuel Payment on household temperature and health: A regression discontinuity design study. *Public Health Research.* 2019;7(1).
22. Lee S, Buring JE, Cook NR, Grodstein F. The relation of education and income to cognitive function among professional women. *Neuroepidemiology.* 2006;26(2):93-101.
23. Cagney KA, Lauderdale DS. Education, Wealth, and Cognitive Function in Later Life. *The Journals of Gerontology: Series B.* 2002;57(2):P163-P172.
24. Steptoe A, Breeze E, Banks J, Nazroo J. Cohort profile: the English longitudinal study of ageing. *Int J Epidemiol.* 2013;42(6):1640-1648.
25. Beatty TKM, Blow L, Crossley TF, O'Dea C. Cash by any other name? Evidence on labeling from the UK Winter Fuel Payment. *Journal of Public Economics.* 2014;118:86-96.
26. Thurley D, Kennedy S. *Winter Fuel Payments update.* London: House of Commons Library, Briefing Paper CBP-6019;2018.
27. Batty GD, Deary IJ, Zaninotto P. Association of cognitive function with cause-specific mortality in middle and older age: follow-up of participants in the english longitudinal study of ageing. *American journal of epidemiology.* 2016;183(3):183-190.
28. Zaninotto P, Batty GD, Allerhand M, Deary IJ. Cognitive function trajectories and their determinants in older people: 8 years of follow-up in the English Longitudinal Study of Ageing. *J Epidemiol Community Health.* 2018:jech-2017-210116.
29. Llewellyn DJ, Lang IA, Langa KM, Huppert FA. Cognitive function and psychological well-being: findings from a population-based cohort. *Age and Ageing.* 2008;37(6):685-689.
30. Okuizumi K, Tsuji S. Alzheimer's disease as a polygenic disease. *Neuropathology.* 1998;18(1):111-115.
31. Sugrue LP, Desikan RS. What Are Polygenic Scores and Why Are They Important? *JAMA.* 2019;online first.
32. Mullins N, Power RA, Fisher HL, et al. Polygenic interactions with environmental adversity in the aetiology of major depressive disorder. *Psychological medicine.* 2016;46(4):759-770.
33. Ware E, Schmitz L, Faul J, et al. Method of Construction Affects Polygenic Score Prediction of Common Human Trait. *BiorXiv.* 2017:1-13.
34. Lambert J-C, Ibrahim-Verbaas CA, Harold D, et al. Meta-analysis of 74,046 individuals identifies 11 new susceptibility loci for Alzheimer's disease. *Nature Genetics.* 2013;45:1452.
35. Davies G, Armstrong N, Bis JC, et al. Genetic contributions to variation in general cognitive function: a meta-analysis of genome-wide association studies in the CHARGE consortium (N=53 949). *Molecular Psychiatry.* 2015;20:183.
36. Hausman JA. Specification tests in econometrics. *Econometrica.* 1978;46(6):1251-1271.
37. Bell A, Jones K. Explaining fixed effects: random effects modeling on time-series cross-sectional and panel data. *Plot Sci Res Methods.* 2015;3(1):133-153.
38. Firebaugh G, Warner C, Massoglia M. Fixed effects, random effects, and hybrid models for causal analysis. In: Morgan SL, ed. *Handbook of Causal Analysis for Social Research.* Dordrecht, the Netherlands: Springer; 2013:113-132.
39. Gunasekara FI, Richardson K, Carter K, Blakely T. Fixed effects analysis of repeated measures data. *International Journal of Epidemiology.* 2013;43(1):264-269.
40. Price AL, Patterson NJ, Plenge RM, Weinblatt ME, Shadick NA, Reich D. Principal components analysis corrects for stratification in genome-wide association studies. *Nature Genetics.* 2006;38(8):904-909.

41. Keller MC. Gene × environment interaction studies have not properly controlled for potential confounders: the problem and the (simple) solution. *Biol Psychiatry*. 2014;75(1):18-24.
42. Reinhard E, Carrino L, Courtin E, van Lenthe FJ, Avendano M. Public Transportation Use and Cognitive Function in Older Age: A Quasiexperimental Evaluation of the Free Bus Pass Policy in the United Kingdom. *American journal of epidemiology*. 2019;188(10):1774-1783.
43. Akee RKQ, Copeland WE, Keeler G, Angold A, Costello EJ. Parents' Incomes and Children's Outcomes: A Quasi-experiment Using Transfer Payments from Casino Profits. *American Economic Journal: Applied Economics*. 2010;2(1):86-115.
44. Hackman DA, Gallop R, Evans GW, Farah MJ. Socioeconomic status and executive function: Developmental trajectories and mediation. *Developmental Science*. 2015;18(5):686-702.
45. Raver CC, Blair C, Willoughby M. Poverty as a predictor of 4-year-olds' executive function: New perspectives on models of differential susceptibility. *Developmental psychology*. 2013;49(2):292.
46. Blair C, Granger DA, Willoughby M, et al. Salivary cortisol mediates effects of poverty and parenting on executive functions in early childhood. *Child development*. 2011;82(6):1970-1984.
47. Blair C, Granger D, Peters Razza R. Cortisol reactivity is positively related to executive function in preschool children attending Head Start. *Child development*. 2005;76(3):554-567.
48. Farah MJ, Shera DM, Savage JH, et al. Childhood poverty: Specific associations with neurocognitive development. *Brain research*. 2006;1110(1):166-174.
49. Wolf TJ. Participation in work: The necessity of addressing executive function deficits. *Work*. 2010;36(4):459-463.
50. Guarino A, Favieri F, Boncompagni I, Agostini F, Cantone M, Casagrande M. Executive Functions in Alzheimer Disease: A Systematic Review. *Frontiers in Aging Neuroscience*. 2019;10(437).
51. Aguila E, Kapteyn A, Smith J. Effects of income supplementation on health of the poor elderly: the case of Mexico. *Proceedings of the National Academy of Sciences*. 2015;112(1):70-75.
52. Ayyagari P, Frisvold D. The impact of social security income on congitive function at older ages. *American Journal of Health Economics*. 2016;2(4):463-488.
53. Belsky J, Pluess M. Beyond diathesis stress: Differential susceptibility to environmental influences. *Psychological Bulletin*. 2009;135(1):885-908.
54. Banks J, Muriel A, Smith J. Attrition and health in aging studies: Evidence from ELSA and HRS. *Longit Life Course Stud*. 2011;2(2).

FIGURES

Figure 1. Share of the sample receiving the Winter Fuel Payment by age, English Longitudinal Study of Ageing, 2002-10 (*N*=13,663)

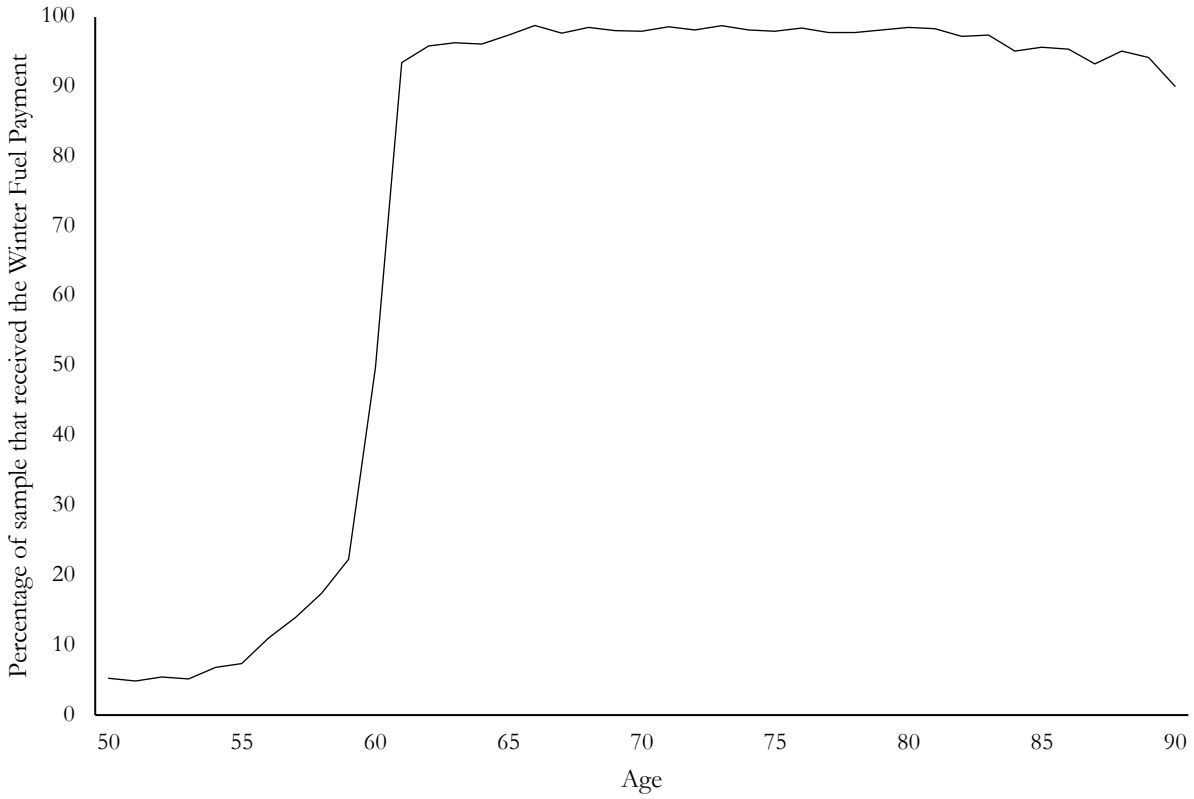
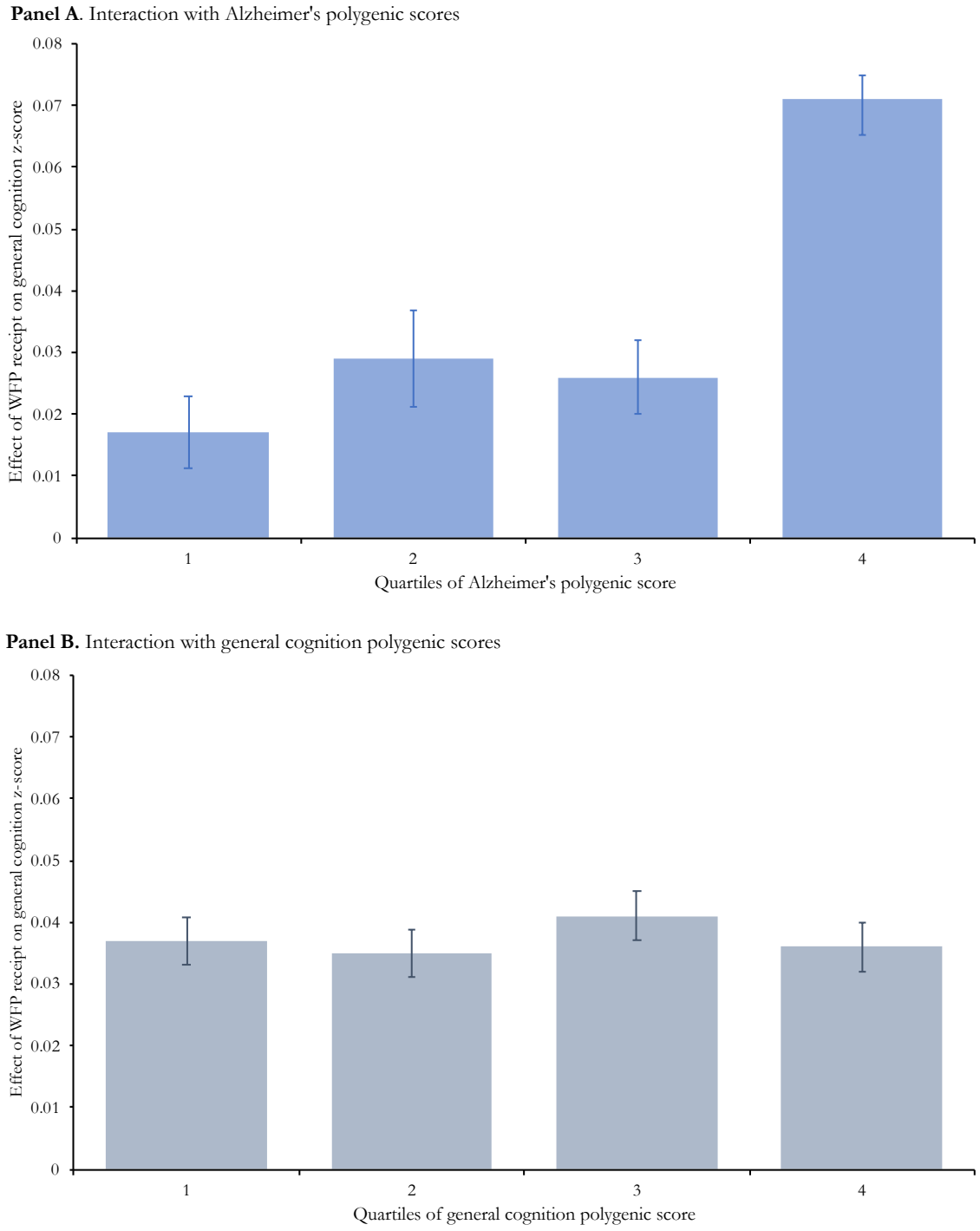


Figure 2. Predicted increase in cognitive scores after receipt of the Winter Fuel Payment by quartiles of polygenic scores, English Longitudinal Study of Ageing, 2002-10 (*N*=7,081)



Abbreviations: WFP, Winter Fuel Payment.
Notes: Higher values indicate higher cognitive function. Models include interview year fixed effects. Estimates are from models that include an interaction between receipt of the WFP and quartiles of polygenic scores for Alzheimer's and general cognition, and controls for sociodemographics, wealth, income, physical health and population stratification.

TABLES

Table 1. Baseline characteristics of the study sample, English Longitudinal Study of Ageing

	Baseline
Received the WFP in the past year (%)	52.85
Demographic characteristics	
Male (%)	44.62
Female (%)	55.38
Age: mean (SD)	61.85 10.27)
Married/civil partnership (%)	68.40
Cohabiting (%)	5.42
Single, never married (%)	4.82
Widowed (%)	12.30
Divorced (%)	7.42
Separated (%)	1.64
Socioeconomic characteristics	
Employed (%)	42.19
Unemployed (%)	1.09
Retired (%)	40.61
Out of labour force (%)	16.11
Household non-housing wealth in £: median (IQR)	21,500 (83,400)
Household total equivalised weekly income in £: median (IQR)	233.85 (209.15)
Health status	
No ADL limitation (%)	83.14
At least 1 ADL limitation (%)	16.86
No IADL limitation (%)	82.79
At least 1 IADL limitation (%)	17.21
Memory score: mean (SD)	10.07 (3.51)
Processing speed: mean (SD)	19.35 (5.89)
Executive function: mean (SD)	19.62 (7.47)

Abbreviations: WFP, Winter Fuel Payment, SD, standard deviation; IQR, Inter-quartile range; ADL, activities of daily living; IADL, instrumental activities of daily living.
Notes: Baseline is defined as the first wave in which data on receipt of Winter Fuel Payment is available for each participant.

Table 2. Associations between changes in Winter Fuel Payment receipt and changes in total cognitive function (*N*=13,663), English Longitudinal Study of Ageing, 2002-10

	β	95% CI
Exposure of interest		
Received the WFP in the past year	0.024	0.001 to 0.046
Demographic characteristics		
Age	0.169	0.146 to 0.192
Age^2	-0.001	-0.001 to -0.001
Cohabiting (ref: married or in a civil partnership)	-0.064	-0.133 to 0.005
Single, never married	-0.063	-0.188 to 0.063
Widowed	-0.013	-0.058 to 0.032
Divorced	0.000	-0.074 to 0.074
Separated	0.029	-0.053 to 0.111
Socioeconomic characteristics		
Unemployed (ref: employed)	0.004	-0.064 to 0.072
Retired	0.004	-0.023 to 0.030
Out of labour force	0.002	-0.028 to 0.031
Log of household non-housing wealth	-0.003	-0.008 to 0.002
Log of household total equivalised income	-0.003	-0.014 to 0.009
Health status		
At least 1 limitation with ADLs (ref: none)	-0.008	-0.030 to 0.013
At least 1 limitation with IADLs (ref: none)	-0.046	-0.067 to -0.025

Abbreviations: CI, confidence interval; WFP, winter fuel payment; ADL, activities of daily living; IADL, instrumental activities of daily living.
Notes: The model includes survey-year fixed effects. Standard errors are clustered at the individual level.

APPENDIX

Appendix 1. Baseline characteristics of the overall and analytical samples, English Longitudinal Study of Ageing

	Overall sample	**After exclusion to those with 2 waves of data**	**Participants with genetic data**
Received the WFP in the past year: frequency (%)	8,969 (53.56)	7,221 (52.85)	3,968 (56.04)
Demographic characteristics			
Male (%)	7,588 (45.28)	6,096 (44.62)	3,252 (45.93)
Female (%)	9,169 (54.72)	7,567 (55.38)	3,829 (54.07)
Age: mean (SD)	62.31 (10.66)	61.85 (10.27)	62.64 (9.41)
Married/civil partnership (%)	11,420 (68.15)	9,345 (68.40)	4,881 (68.93)
Cohabiting (%)	916 (5.47)	741 (5.42)	327 (4.62)
Single, never married (%)	820 (4.89)	659 (4.82)	323 (4.56)
Widowed (%)	2,141 (12.78)	1,680 (12.30)	914 (12.91)
Divorced (%)	1,188 (7.09)	1,014 (7.42)	523 (7.39)
Separated (%)	272 (1.62)	224 (1.64)	113 (1.60)
Socioeconomic characteristics			
Employed (%)	6,859 (40.93)	5,764 (42.19)	2,857 (40.35)
Unemployed (%)	192 (1.15)	149 (1.09)	66 (0.93)
Retired (%)	6,918 (41.28)	5,549 (40.61)	3,128 (44.17)
Out of labour force (%)	2,788 (16.64)	2,201 (16.11)	1,030 (14.55)
Household non-housing wealth in £: median (IQR)	19,515 (79,721)	21,500 (83,400)	26,000 (89,700)
Household total equivalised weekly income in £: median (IQR)	227.58 (206.69)	233.85 (209.15)	234.29 (195.31)
Health status			
No ADL limitation (%)	13,557 (81.88)	11,271 (83.14)	5,933 (83.95)
At least 1 ADL limitation (%)	3,000 (18.12)	2,286 (16.86)	1,134 (16.05)
No IADL limitation (%)	13,424 (81.08)	11,224 (82.79)	5,997 (84.86)
At least 1 IADL limitation (%)	3,133 (18.92)	2,333 (17.21)	1,070 (15.14)
Memory score: mean (SD)	9.86 (3.61)	10.07 (3.51)	10.17 (3.38)
Processing speed: mean (SD)	19.12 (5.94)	19.35 (5.89)	19.43 (5.83)
Executive function: mean (SD)	19.32 (7.91)	19.62 (7.47)	20.39 (6.62)

Appendix Table 2. Random effects regression model of the impact of Winter Fuel Payment receipt on total cognitive function and Hausman test, ELSA waves 1-5, 2002-10 (*N*=13,663)

	β	95% CI
Exposure of interest		
Received the WFP in the past year	0.023	0.003 to 0.044
Demographic characteristics		
Age	0.073	0.062 to 0.0834
Age^2	-0.001	-0.001 to -0.001
Cohabiting (ref: married or in a civil partnership)	-0.032	-0.07 to 0.016
Single, never married	-0.106	-0.161 to -0.050
Widowed	0.027	-0.004 to 0.058
Divorced	0.022	-0.019 to 0.063
Separated	0.050	-0.016 to 0.116
Socioeconomic characteristics		
Unemployed (ref: employed)	-0.012	-0.073 to 0.050
Retired	-0.003	-0.026 to 0.019
Out of labour force	-0.026	-0.051 to -0.001
Log of household non-housing wealth	0.031	0.027 to 0.034
Log of household total equivalised income	0.046	0.036 to 0.055
Health status		
At least 1 limitation with ADLs (ref: none)	-0.047	-0.067 to -0.027
At least 1 limitation with IADLs (ref: none)	-0.107	-0.127 to -0.088

Abbreviations: CI, confidence interval; WFP, winter fuel payment; ADL, activities of daily living; IADL, instrumental activities of daily living.
Notes: The model includes survey-year fixed effects. Standard errors are clustered at the individual level.

Hausman test: χ^2=1345.36 (P<0.0001)

Appendix Table 3. Descriptive statistics of study sample who are eligible for Winter Fuel Payment, by receipt status, ELSA waves 1-5, 2002-10 (*N*=13,663)

	Receiving WFP	**Not receiving WFP**
Male, frequency (%)	13,925 (43.10)	1,204 (42.98)
Female, frequency (%)	18,382 (56.90)	1,597 (57.02)
Age group		
<50, frequency (%)	145 (0.45)	99 (3.53)
50-54, frequency (%)	331 (1.02)	205 (7.32)
55-59, frequency (%)	1,287 (3.98)	691 (24.67)
60-64, frequency (%)	7,329 (22.69)	1,244 (44.41)
65-69, frequency (%)	7,010 (21.70)	138 (4.93)
70-74, frequency (%)	6,317 (19.55)	107 (3.82)
75-79, frequency (%)	4,682 (14.49)	94 (3.36)
80-84, frequency (%)	3,113 (9.64)	80 (2.86)
85+, frequency (%)	2,093 (6.48)	143 (5.11)
Any ADL limitations		
None, frequency (%)	25,008 (77.59)	2,279 (81.66)
At least 1, frequency (%)	7,224 (22.41)	512 (18.34)
Any IADL limitations		
None, frequency (%)	24,510 (76.04)	2,257 (80.87)
At least 1, frequency (%)	7,722 (23.96)	534 (19.13)
Employment status		
Employed, frequency (%)	4,924 (15.24)	1,399 (49.95)
Unemployed, frequency (%)	138 (0.43)	40 (1.43)
Retired, frequency (%)	23,076 (71.43)	878 (31.35)
Out of labour force, frequency (%)	4,168 (12.90)	484 (17.28)
Marital status		
Married/civil partnership, frequency (%)	20,665 (63.96)	2,006 (71.62)
Cohabiting, frequency (%)	874 (2.71)	239 (8.53)
Single, never married, frequency (%)	1,357 (4.20)	103 (3.68)
Widowed, frequency (%)	6,917 (21.41)	257 (9.18)
Divorced, frequency (%)	2,114 (6.54)	153 (5.46)
Separated, frequency (%)	380 (1.18)	43 (1.54)
Education		
No educational qualification, frequency (%)	12,599 (43.16)	812 (31.45)
Secondary, frequency (%)	8,611 (29.50)	906 (35.09)
Tertiary, frequency (%)	7,983 (27.35)	864 (33.46)
Household non-housing wealth, median (IQR)	23,401 (83,333)	38,000 (128,100)
Household total equivalised income, median (IQR)	227.38 (179.94)	294.50 (246.36)

Abbreviations: WFP, winter fuel payment; ADL, activities of daily living; IADL, instrumental activities of daily living.

Appendix Table 4. Fixed effects regression model of the impact of Winter Fuel Payment receipt on individual cognitive domains, ELSA waves 1-5, 2002-10 (*N*=13,663)

	Memory		Processing speed		Executive function	
	β	**95% CI**	**β**	**95% CI**	**β**	**95% CI**
Exposure of interest						
Received the WFP in the past year	0.009	-0.018, 0.036	0.021	-0.007, 0.049	0.031	0.004, 0.058
Demographic characteristics						
Age	0.165	0.140, 0.191	0.093	0.066, 0.119	0.156	0.131, 0.182
Age^2	-0.001	-0.001, -0.001	-0.001	-0.001, -0.001	-0.001	-0.001, -0.001
Cohabiting (ref: married)	-0.065	-0.155, 0.024	-0.058	-0.143, 0.027	-0.014	-0.101, 0.074
Single, never married	0.023	-0.146, 0.193	-0.146	-0.300, 0.009	0.057	-0.089, 0.203
Widowed	0.001	-0.052, 0.054	0.014	-0.046, 0.073	-0.043	-0.095, 0.008
Divorced	-0.017	-0.108, 0.074	0.021	-0.069, 0.111	0.013	-0.067, 0.094
Separated	-0.013	-0.114, 0.088	0.037	-0.075, 0.150	0.003	-0.086, 0.091
Socioeconomic characteristics						
Unemployed (ref: employed)	0.015	-0.060, 0.089	0.020	-0.075, 0.114	-0.011	-0.093, 0.071
Retired	0.025	-0.006, 0.056	0.000	-0.033, 0.033	-0.012	-0.044, 0.019
Out of labour force	0.009	-0.025, 0.044	0.011	-0.025, 0.047	-0.017	-0.053, 0.019
Log of household non-housing wealth	0.002	-0.003, 0.008	-0.005	-0.011, 0.002	0.001	-0.005, 0.006
Log of household total equivalised income	-0.002	-0.015, 0.011	-0.004	-0.018, 0.010	-0.000	-0.015, 0.014
Health status						
At least 1 limitation with ADLs (ref: none)	-0.004	-0.030, 0.022	-0.011	-0.038, 0.017	-0.016	-0.040, 0.008
At least 1 limitation with IADLs (ref: none)	-0.045	-0.070, -0.020	-0.035	-0.062, -0.009	-0.041	-0.066, -0.017

Abbreviations: CI, confidence interval; WFP, winter fuel payment; ADL, activities of daily living; IADL, instrumental activities of daily living.
Notes: The model includes survey-year fixed effects. Standard errors are clustered at the individual level.

Appendix Table 5. Fixed effects regression model of the impact of Winter Fuel Payment receipt total cognitive function with interaction term for genetic predisposition for Alzheimer's, ELSA waves 1-5, 2002-10 (*N*=13,663)

	β	95% CI
Exposure of interest		
Received the WFP in the past year	-0.018	-0.066 to 0.030
Received the WFP in the past year*2nd quartile Alzheimer's PGS (ref: first quartile)	0.025	-0.039 to 0.089
Received the WFP in the past year*3rd quartile Alzheimer's PGS	0.0135	-0.053 to 0.079
Received the WFP in the past year*4th quartile Alzheimer's PGS	0.076	0.01 to 0.142
Principal components		
Received the WFP in the past year*PC 1	1.707	-0.324 to 3.739
Received the WFP in the past year*PC 2	-1.370	-3.258 to 0.517
Received the WFP in the past year*PC 3	0.259	-1.740 to 2.258
Demographic characteristics		
Age	0.180	0.150 to 0.209
Age^2	-0.001	-0.001 to -0.001
Cohabiting (ref: married or in a civil partnership)	-0.105	-0.194 to -0.016
Single, never married	-0.094	-0.270 to 0.081
Widowed	-0.023	-0.079 to 0.033
Divorced	-0.003	-0.104 to 0.098
Separated	-0.010	-0.116 to 0.096
Socioeconomic characteristics		
Unemployed (ref: employed)	0.007	-0.091 to 0.105
Retired	-0.003	-0.035 to 0.028
Out of labour force	-0.005	-0.041 to 0.031
Log of household non-housing wealth	-0.002	-0.008 to 0.005
Log of household total equivalised income	0.003	-0.012 to 0.002
Health status		
At least 1 limitation with ADLs (ref: none)	-0.003	-0.030 to 0.025
At least 1 limitation with IADLs (ref: none)	-0.033	-0.060 to -0.006

Abbreviations: CI, confidence interval; WFP, winter fuel payment; PGS, polygenic score; PC, principal component; ADL, activities of daily living; IADL, instrumental activities of daily living.
Notes: The model includes survey-year fixed effects. Standard errors are clustered at the individual level.

Appendix Table 6. Fixed effects regression model of the impact of Winter Fuel Payment receipt with interaction for genetic predisposition for Alzheimer's on cognitive domains, ELSA waves 1-5, 2002-10 (*N*=13,663)

	Memory		Processing speed		Executive function	
	β	**95% CI**	**β**	**95% CI**	**β**	**95% CI**
Exposure of interest						
Received the WFP in the past year	-0.029	-0.090, 0.031	-0.021	-0.08, 0.039	0.012	-0.045, 0.069
Received the WFP in the past year*2nd quartile PGS (ref: first quartile)	0.004	-0.075, 0.083	0.079	-0.003, 0.162	-0.013	-0.094, 0.067
Received the WFP in the past year*3rd quartile PGS	0.045	-0.037, 0.127	0.023	-0.059, 0.106	-0.028	-0.111, 0.053
Received the WFP in the past year*4th quartile PGS	0.049	-0.033, 0.132	0.063	-0.021, 0.149	0.062	-0.016, 0.141
Principal components						
Received the WFP in the past year*PC 1	0.762	-1.653, 3.177	1.843	-0.624, 4.309	0.028	-2.457, 2.513
Received the WFP in the past year*PC 2	1.285	-1.083, 3.653	-0.935	-3.225, 1.355	0.107	-2.377, 2.591
Received the WFP in the past year*PC 3			-0.243	-2.863, 2.376		
Demographic characteristics						
Age	0.161	0.128, 0.195	0.093	0.066, 0.119	0.156	0.131, 0.182
Age^2	-0.001	-0.001, -0.001	-0.001	-0.001, -0.001	-0.001	-0.001, -0.001
Cohabiting (ref: married)	-0.068	-0.185, 0.021	-0.058	-0.143, 0.027	-0.014	-0.101, 0.074
Single, never married	-0.033	-0.259, 0.193	-0.146	-0.300, 0.009	0.057	-0.089, 0.203
Widowed	0.001	-0.052, 0.054	0.014	-0.046, 0.073	-0.043	-0.095, 0.008
Divorced	-0.017	-0.108, 0.074	0.021	-0.069, 0.111	0.013	-0.067, 0.094
Separated	-0.013	-0.114, 0.088	0.037	-0.075, 0.150	0.003	-0.086, 0.091
Socioeconomic characteristics						
Unemployed (ref: employed)	0.015	-0.060, 0.089	0.020	-0.075, 0.114	-0.011	-0.093, 0.071
Retired	0.025	-0.006, 0.056	0.000	-0.033, 0.033	-0.012	-0.044, 0.019
Out of labour force	0.009	-0.025, 0.044	0.011	-0.025, 0.047	-0.017	-0.053, 0.019
Log of household non-housing wealth	0.004	-0.003, 0.013	-0.005	-0.011, 0.002	0.001	-0.005, 0.006
Log of household total equivalised income	-0.002	-0.015, 0.011	-0.004	-0.018, 0.010	-0.000	-0.015, 0.014
Health status						
At least 1 limitation with ADLs (ref: none)	0.003	-0.030, 0.035	-0.011	-0.038, 0.017	-0.016	-0.040, 0.008
At least 1 limitation with IADLs (ref: none)	-0.024	-0.056, -0.007	-0.035	-0.062, -0.009	-0.041	-0.066, -0.017

Abbreviations: CI, confidence interval; WFP, winter fuel payment; ADL, activities of daily living; IADL, instrumental activities of daily living.
Notes: The model includes survey-year fixed effects. Standard errors are clustered at the individual level.

Appendix Table 7. Fixed effects regression model of the impact of Winter Fuel Payment receipt total cognitive function with interaction term for genetic predisposition for cognitive function, ELSA waves 1-5, 2002-10 (*N*=13,663)

	β	95% CI
Exposure of interest		
Received the WFP in the past year	0.028	-0.021 to 0.076
Received the WFP in the past year*2nd quartile cognitive function PGS (ref: first quartile)	-0.018	-0.085 to 0.048
Received the WFP in the past year*3rd quartile cognitive function PGS	-0.034	-0.098 to 0.029
Received the WFP in the past year*4th quartile cognitive function PGS	-0.013	-0.080 to 0.055
Principal components		
Received the WFP in the past year*PC 1	1.842	-0.217 to 3.901
Received the WFP in the past year*PC 2	-1.535	-3.423 to 0.354
Received the WFP in the past year*PC 3	0.368	-1.620 - 2.356
Demographic characteristics		
Age	0.180	0.150 to 0.209
Age^2	-0.001	-0.001 to -0.001
Cohabiting (ref: married or in a civil partnership)	-0.105	-0.194 to -0.016
Single, never married	-0.094	-0.270 to 0.081
Widowed	-0.023	-0.079 to 0.033
Divorced	-0.003	-0.104 to 0.098
Separated	-0.010	-0.116 to 0.096
Socioeconomic characteristics		
Unemployed (ref: employed)	0.007	-0.091 to 0.105
Retired	-0.003	-0.035 to 0.028
Out of labour force	-0.005	-0.041 to 0.031
Log of household non-housing wealth	-0.002	-0.008 to 0.005
Log of household total equivalised income	0.003	-0.012 to 0.002
Health status		
At least 1 limitation with ADLs (ref: none)	-0.003	-0.030 to 0.025
At least 1 limitation with IADLs (ref: none)	-0.033	-0.060 to -0.006

Abbreviations: CI, confidence interval; WFP, winter fuel payment; PGS, polygenic score; PC, principal component; ADL, activities of daily living; IADL, instrumental activities of daily living.
Notes: The model includes survey-year fixed effects. Standard errors are clustered at the individual level.

Appendix Table 8. Fixed effects regression model of the impact of Winter Fuel Payment receipt on total cognitive function with interaction term for APOE carrier status, ELSA waves 1-5, 2002-10 (*N*=13,663)

	β	95% CI
Exposure of interest		
Received the WFP in the past year	0.013	-0.018, 0.044
Received the WFP in the past year*APOE carrier status	-0.010	-0.064, 0.045
Demographic characteristics		
Age	0.180	0.150, 0.209
Age^2	-0.001	-0.001, -0.001
Cohabiting (ref: married)	-0.104	-0.192, -0.015
Single, never married	-0.096	-0.271, 0.079
Widowed	-0.024	-0.079, 0.032
Divorced	-0.003	-0.104, 0.098
Separated	-0.010	-0.116, 0.096
Socioeconomic characteristics		
Unemployed (ref: employed)	0.010	-0.088, 0.107
Retired	-0.003	-0.035, 0.029
Out of labour force	-0.005	-0.042, 0.031
Log of household non-housing wealth	-0.002	-0.009, 0.005
Log of household total equivalised income	0.003	-0.012, 0.019
Health status		
At least 1 limitation with ADLs (ref: none)	-0.004	-0.032, 0.024
At least 1 limitation with IADLs (ref: none)	-0.033	-0.060, -0.007

*Abbreviation*s: CI, confidence interval; WFP, winter fuel payment; ADLs, activities of daily living; IADLs, instrumental activities of daily living

Notes: The model includes survey-year fixed effects. Standard errors are clustered at the individual level.

Appendix Table 9. Association between changes in eligibility for Winter Fuel Payment and total cognitive function, ELSA waves 1-5, 2002-10 (*N*=13,663)

	β	95% CI
Exposure of interest		
Eligible to WFP	0.024	0.001, 0.048
Demographic characteristics		
Age	0.168	0.144, 0.191
Age^2	-0.001	-0.001, -0.001
Cohabiting (ref: married)	-0.065	-0.134, 0.004
Single, never married	-0.061	-0.187, 0.064
Widowed	-0.012	-0.057, 0.033
Divorced	-0.000	-0.075, 0.074
Separated	0.027	-0.057, 0.111
Socioeconomic characteristics		
Unemployed (ref: employed)	0.000	-0.068, 0.068
Retired	0.005	-0.021, 0.031
Out of labour force	0.003	-0.027, 0.032
Log of household non-housing wealth	-0.002	-0.067, -0.025
Log of household total equivalised income	-0.003	-0.014, 0.008
Health status		
At least 1 limitation with ADL (ref: none)	-0.008	-0.030, 0.013
At least 1 limitation with IADL (ref: none)	-0.046	-0.067, -0.025

Abbreviations: CI, confidence interval; WFP, winter fuel payment; ADL, activities of daily living; IADL, instrumental activities of daily living.
Notes: The model includes survey-year fixed effects. Standard errors are clustered at the individual level.

Appendix Table 10. Association between changes in receipt of Winter Fuel Payment and total cognitive function among single men and households where the male member is the oldest, ELSA waves 1-5, 2002-10 (*N*=8,302)

	β	95% CI
Exposure of interest		
Received the WFP in the last year	0.035	0.006, 0.064
Demographic characteristics		
Age	0.154	0.122, 0.186
Age^2	-0.001	-0.001, -0.001
Cohabiting (ref: married)	-0.050	-0.142, 0.043
Single, never married	-0.053	-0.302, 0.197
Widowed	0.022	-0.074, 0.118
Divorced	-0.015	-0.154, 0.123
Separated	0.105	-0.031, 0.242
Socioeconomic characteristics		
Unemployed (ref: employed)	-0.020	-0.110, 0.071
Retired	-0.003	-0.037, 0.032
Out of labour force	-0.001	-0.039, 0.038
Log of household non-housing wealth	-0.001	-0.008, 0.006
Log of household total equivalised income	-0.003	-0.018, 0.013
Health status		
At least 1ADL limitation (ref: none)	0.003	-0.028, 0.033
At least 1 IADL limitation (ref: none)	-0.036	-0.067, -0.006

Abbreviations: CI, confidence interval; WFP, winter fuel payment; ADL, activities of daily living; IADL, instrumental activities of daily living.

Notes: The model includes survey-year fixed effects. Standard errors are clustered at the individual level.