Public Transportation Use and Cognitive Function in Older Age: A Quasiexperimental Evaluation of the Free Bus Pass Policy in the United Kingdom

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In this quasiexperimental study, we examined whether the introduction of an age-friendly transportation policy—free bus passes for older adults—increased public transport use and in turn affected cognitive function among older people in England. Data came from 7 waves (2002–2014) of the English Longitudinal Study of Ageing (n = 17,953), which measured total cognitive function, memory, executive function, and processing speed before and after the bus pass was introduced in 2006. The analytical strategy was an instrumental-variable approach with fixed effects, which made use of the age-eligibility criteria for free bus passes and addressed bias due to reverse causality, measurement error, and time-invariant confounding. Eligibility for the bus pass was associated with a 7% increase in public transport use. The increase in public transportation use was associated with a 0.346 (95% confidence interval: 0.017, 0.674) increase in the total cognitive function z score and with a 0.546 (95% confidence interval: 0.111, 0.982) increase in memory z score. Free bus passes were associated with an increase in public transport use and, in turn, benefits to cognitive function in older age. Public transport use might promote cognitive health through encouraging intellectually, socially, and physically active lifestyles. Transport policies could serve as public health tools to promote cognitive health in aging populations.

aging; cognition; cognitive aging; policy; transportation

Abbreviations: CI, confidence interval; ELSA, English Longitudinal Study of Ageing; FE, fixed effects; IV-FE, instrumental variable with fixed effects.

Aging is associated with declines in cognitive function, particularly fluid intelligence, which includes memory, executive function, and processing speed (1). However, there is considerable variation in levels of cognitive function and rates of cognitive decline, partly as a result of exposures over the life course (1). Maintaining cognitive health is critical for autonomy and well-being, given that cognitive impairment is a key predictor of disability and death in older age (1). With approximately one-fifth of the UK population currently aged 65 years or older (2), and similar trends projected in the United States by 2030 (3) and worldwide by 2050 (4), rapid population aging makes the promotion of cognitive health an urgent target for public health policy.

Evidence suggests that physically, socially, and intellectually active lifestyles protect against cognitive decline (1). The ability of aging individuals to maintain an active lifestyle might depend on the levels of mobility enabled by the built environment (4, 5). In particular, public transportation plays an increasingly important role in promoting mobility, physical activity, social engagement, leisure activities, and physical and mental health among older people (6–11). While these benefits might also extend to cognitive health, there is limited evidence on how policies that encourage public transportation use impact cognitive function in older people.

Research suggests that making public transportation more affordable increases transport use and engagement among older people (6, 7, 9). In the United Kingdom, the older person's free bus pass, introduced in 2006, allows older adults to travel for free on public buses throughout the country (12). This scheme provides a natural experiment to examine how a policy that encourages older people to use public transportation affects cognitive function. Previous evaluations show that the policy led to increases in public transport use among older people, as well as higher levels of physical activity and social engagement and lower levels of obesity, depressive symptoms, and loneliness (6–8). There is reason to expect that by encouraging social, intellectual, and physical activity, increased public transport use due to the free bus pass might also benefit cognitive health among older people. For example, social interaction and intellectually stimulating activities require use of cognitive faculties, which according to the "use it or lose it" hypothesis, has direct impacts on brain structure and function that protect against cognitive decline (1, 13, 14). Additionally, physical activity bolsters cognitive health through cardiovascular, cerebrovascular, and neurotrophic pathways (15).

In this study, we examined the impact of increased public transportation use on measures of cognitive function among older people in England. Because older people with higher cognitive function might be more likely to use public transport from the outset, this study exploits the introduction of the free bus pass policy, longitudinal data, and a quasiexperimental design to address reverse causality and time-invariant confounding.

METHODS

Data and measures

We used longitudinal data from waves 1–7 of the English Longitudinal Study of Ageing (ELSA), a representative cohort of individuals aged 50 years or older residing in England ($n = 18{,}489$) that has been described elsewhere (16). We excluded individuals who were younger than 50 years ($n = 498$), who resided outside of England ($n = 1$), and whose actual age-based eligibility for the bus pass could not be determined due to increases in the eligibility age ($n = 35$). Previous work indicates that including these individuals under various assumptions about their bus pass eligibility does not affect results (6). This provided an eligible sample of 17,953 individuals. The study period included years before (waves 1 and 2, collected in 2002 and 2004) and after (waves 3–7, collected every 2 years between 2006 and 2014) the introduction of the free bus pass.

Cognitive function

The outcomes included memory, executive function, processing speed, and total cognitive function, based on tests conducted during ELSA interviews at multiple waves (17). We used scores from the word recall test, the animal naming test, and the letter cancellation test, because these tests were found to be robust to floor, ceiling, and practice effects in previous studies using ELSA (18, 19).

Memory was measured using the word recall test, conducted at every wave. The respondent is asked to remember 10 common nouns, which are presented aurally using a taped voice. The respondent is asked to recall the words immediately and after a short delay, during which they complete other cognitive tests. The total word recall score, ranging from 0 to 20, is the sum of the words correctly remembered during the immediate and delayed recall. Executive function was measured using the animal names test, conducted in waves 1–5 and wave 7. The respondent is asked to name as many different animals as possible in one minute. The score is the total number of animals named, which ranged from 0 to 50 at baseline. Processing speed was measured using the letter cancellation test, conducted in waves 1–5. The respondent is 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 1 minute by working across and down the page. The score is the total number of letters searched, ranging from 0 to 65.

The total scores from the 3 tests were transformed into z scores, standardized across all waves, and then averaged for a total cognitive function score, as has been done in previous studies (20). The total cognitive function score was available for waves 1–5. For every measure, a higher score indicates better function.

Public transportation use

In the first 2 waves, participants were asked: "Do you use public transport . . . a lot, quite often, sometimes, rarely, or never." In the third wave, the question changed to: "How often do you use public transport . . . every day or nearly every day, 2 or 3 times a week, once a week, 2 or 3 times a month, once a month or less, or never." Because never is the only consistent response category, we created a binary variable that assigns 1 to public transport users and 0 to non- or never-users at each wave. Previous studies show that this measure is robust to the change in questionnaire and different classifications of transport use frequency (6–8).

Control variables

We controlled for the following time-varying characteristics: age, age squared, ≥1 limitation in the activities of daily living, ≥1 limitation in the instrumental activities of daily living, car ownership, any chronic illnesses/disabilities/diseases, the natural log of net total nonpension household wealth, the natural log of equivalized household income, marital status (married, cohabiting, single/never married, widowed, divorced, separated), and household region.

The instrument: free bus pass eligibility

We used eligibility for free bus passes as an exogenous source of variation in public transportation use. We use a binary variable to indicate whether individuals were eligible for free bus travel at each wave, based on government criteria for eligibility age. Specifically, those who were at least 60 years old between April 2006 and March 2010 were classified as eligible. In April 2010, the bus pass eligibility age began increasing in monthly increments corresponding to increases in women's state pension age (12). Because birth month is not publicly available in ELSA, we rounded up the eligibility age to 61 years between April 2012 and 2012, to 62 between 2012 and 2013, and to 63 in 2014. The interaction between the eligibility age and the timing of the bus pass legislation was the basis for causal identification, because eligibility varied due to both age and year of measurement in the study.

Statistical analysis

We first implemented linear fixed-effects (FE) models without the instrument because Hausman specification tests (21) rejected the null hypothesis that random-effects models are consistent (Web Table 1, available at https://academic.oup.com/aje). The FE model estimated whether a change in public transport use was associated with a change in cognitive function, controlling for measured time-varying confounders. FE models essentially rule out confounding by time-invariant characteristics, such as early-life intelligence and education, by treating each individual as their own control (22).

Because the FE estimates might be biased due to reverse causality (i.e., cognitive function determines transport use), omitted variables (i.e., unmeasured confounders), and measurement error, we implemented a 2-stage least squares instrumental-variable approach with fixed effects (IV-FE) as the main model (23, 24). The IV-FE model enhances causal inference by using fixed effects to control for time-invariant confounding and by using the instrument to address reverse causality and unmeasured or erroneously measured confounders (24).

Three assumptions must be met to yield unbiased estimates of the relationship between transport use and cognitive function using the instrument. First, the instrument (free bus pass eligibility) must be predictive of the endogenous treatment variable (public transport use). We established whether eligibility is strongly associated with public transport use with the first-stage F statistic (25).

The related second and third assumptions are that the instrument must affect the outcome (cognitive function) only through its impact on the endogenous treatment variable (transport use), and the instrument must not be associated with unmeasured confounders. Other variables, such as depressive symptoms, might lie on the pathway between public transport use and cognitive function. However, if the impact of bus pass eligibility on these other variables is also through the impact on transport use, this would not invalidate the second assumption. Another potential concern is that bus pass eligibility age overlaps with women's state pension age. To address this, we controlled for employment status and for state and private pension receipt in our models and implemented sensitivity analyses, detailed below.

In the first stage of the IV-FE model, public transportation use was regressed on bus pass eligibility and all control variables. In the second stage, the cognitive function score was regressed on the predicted values of public transportation use from the first stage and all control variables. Using IV-FE, we can assess whether becoming eligible for the bus pass leads to changes in public transport use in the first stage and whether this increase in transport use leads to changes in the level of cognitive function in the second stage. A directed acyclic graph (Web Figure 1) and the equations for the FE model and the 2 stages of the IV-FE model are provided in Web Appendix 1. The models were fitted using the command xtivreg2 (26), a wrapper for ivreg2 (27), in Stata, version 15 (StataCorp LLC, College Station, Texas) (28).

Sensitivity and subgroup analyses

Testing the IV-FE results, we implemented a sensitivity analysis excluding controls for activities of daily living, instrumental activities of daily living, and chronic health conditions, because these might be mediators of the impact of public transport use on cognitive function or partially capture the outcome. Because those with missing scores for the cognitive function tests might be systematically different, we conducted a sensitivity analysis using multiple imputation with chained equations. Missing values are detailed in Web Table 2. Additionally, we tested whether using a balanced panel affects results, by limiting the sample to individuals who participated in every wave with complete cognitive function measures. Because education is a key predictor of later-life cognitive function (1), we performed subgroup analyses according to educational level (low, medium, high).

We also implemented several models to address potential bias from the overlap between women's state pension age and bus pass eligibility age. First, the 2 waves of ELSA data before the bus pass was introduced serve as a placebo, during which women turning 60 years old would become eligible for state pensions but not for bus passes. We fitted an IV-FE model on the first 2 waves of data using age 60 as placebo instrument for public transport use. Additionally, men's state pension age was higher than the bus pass eligibility age throughout the study period, which enabled us to isolate the impact of bus pass eligibility age from that of pension eligibility age. We therefore present subgroup analyses according to sex.

RESULTS

Table 1 suggests that users and nonusers of public transportation differ along all covariates at baseline, based on χ^2 tests. Public transport users were more likely to be female, to be retired, and to live in London, and they were less likely to have a car, any chronic health conditions, or limitations in activities or instrumental activities of daily living than nonusers. Additionally, the ratio of transport users to nonusers increased around the bus pass eligibility age (Web Figure 2).

Figure 1 shows locally weighted regression-smoothed curves of total cognitive function (Figure 1A), memory (Figure 1B), executive function (Figure 1C), and processing speed scores (Figure 1D). For all domains of cognitive function, average scores declined among both transport users and nonusers as age increased. However, the average score for transport users was higher than the score for nonusers at all ages. While this might suggest that public transport use is associated with better cognitive function, it could also reflect confounding or reverse causality. In order to address this, we move to the results of the regression models.

Web Table 3 presents the results from the first stage of the IV-FE model. The first stage of the IV-FE model indicated that becoming eligible for the free bus pass was associated with a 7% increase in the probability of public transport use. The F statistic was greater than 10, meeting the criteria for a strong first stage (25), and additional tests for weak identification and underidentification indicated that the first stage was strongly identified in all models (Web Table 4).

Table 1. Characteristics of Public Transport Users and Nonusers at Baseline, English Longitudinal Study of Ageing, 2002–2014

Characteristic	Users (n = 12,217)[a]		Nonusers (n = 5,471)[a]		χ^2 P Value	Total (n = 17,688)[b]	
	No.	%	No.	%		No.	%
Age, years					<0.001		
<60	6,042	49.5	2,806	51.3		8,848	50.0
60–74	4,602	37.7	1,797	32.8		6,399	36.2
≥75	1,573	12.9	868	15.9		2,441	13.8
Sex					<0.001		
Male	5,181	42.4	2,943	53.8		8,124	45.9
Female	7,036	57.6	2,528	46.2		9,564	54.1
ADLs[c]					<0.001		
0	10,432	85.4	4,116	75.2		14,548	82.3
≥1	1,782	14.6	1,355	24.8		3,137	17.7
IADLs[c]					<0.001		
0	10,385	85.0	4,041	73.9		14,426	81.6
≥1	1,829	15.0	1,430	26.1		3,259	18.4
Illness[c]					<0.001		
No illness	5,922	48.5	2,317	42.4		8,239	46.6
Any illness	6,291	51.5	3,153	57.6		9,444	53.4
Access to car[c]					<0.001		
Yes	9,975	81.7	5,027	91.9		15,002	84.8
No	2,240	18.3	442	8.1		2,682	15.2
Employment status					<0.001		
Employed	5,262	43.1	2,425	44.3		7,687	43.5
Unemployed	179	1.5	72	1.3		251	1.4
Retired	4,998	40.9	1,959	35.8		6,957	39.3
Out of labor force	1,778	14.6	1,015	18.6		2,793	15.8
Marital status[d]					<0.001		
Married/civil partnership	8,104	66.3	3,914	71.5		12,018	67.9
Cohabiting	671	5.5	321	5.9		992	5.6
Single, never married	697	5.7	227	4.1		924	5.2
Widowed	1,524	12.5	605	11.1		2,129	12.0
Divorced	992	8.1	325	5.9		1,317	7.4
Separated	229	1.9	79	1.4		308	1.7
Region[c,d]					<0.001		
North East	809	6.6	331	6.1		1,140	6.4
North West	1,587	13.0	744	13.6		2,331	13.2
Yorkshire and the Humber	1,289	10.6	599	11.0		1,888	10.7
East Midlands	1,095	9.0	649	11.9		1,744	9.9
West Midlands	1,230	10.1	711	13.0		1,941	11.0
East of England	1,421	11.6	661	12.1		2,082	11.8
London	1,468	12.0	209	3.8		1,677	9.5
South East	2,082	17.1	840	15.4		2,922	16.5
South West	1,229	10.1	726	13.3		1,955	11.1
Nonpension wealth, £[e]	271,385 (619,467)		238,277 (565,842)			260,134 (599,970)	
Equivalized income, £[e]	306 (251)		287 (256)			301 (270)	
Private pension					<0.001		
Receives private pension	8,318	68.1	3,894	71.2		12,212	69.0
No private pension	3,899	31.9	1,577	28.8		5,476	31.0

Table continues

Table 1. Continued

Characteristic	Users (n = 12,217)[a]		Nonusers (n = 5,471)[a]		χ^2 P Value	Total (n = 17,688)[b]	
	No.	%	No.	%		No.	%
State pension[c]					<0.001		
Receives State pension	6,971	57.5	3,343	61.6		10,314	58.8
No State pension	5,152	42.5	2,088	38.4		7,240	41.2

Abbreviations: ADLs, activities of daily living; IADLs, instrumental activities of daily living.
[a] Values are numbers (column %) unless otherwise indicated.
[b] Difference in table total and total eligible sample is due to 265 participants with missing data on transport use at baseline.
[c] Numbers do not sum to total due to missing data on baseline characteristics.
[d] Percentages do not sum to 100 due to rounding.
[e] Values are expressed as mean (standard deviation). £1 = US$1.24.

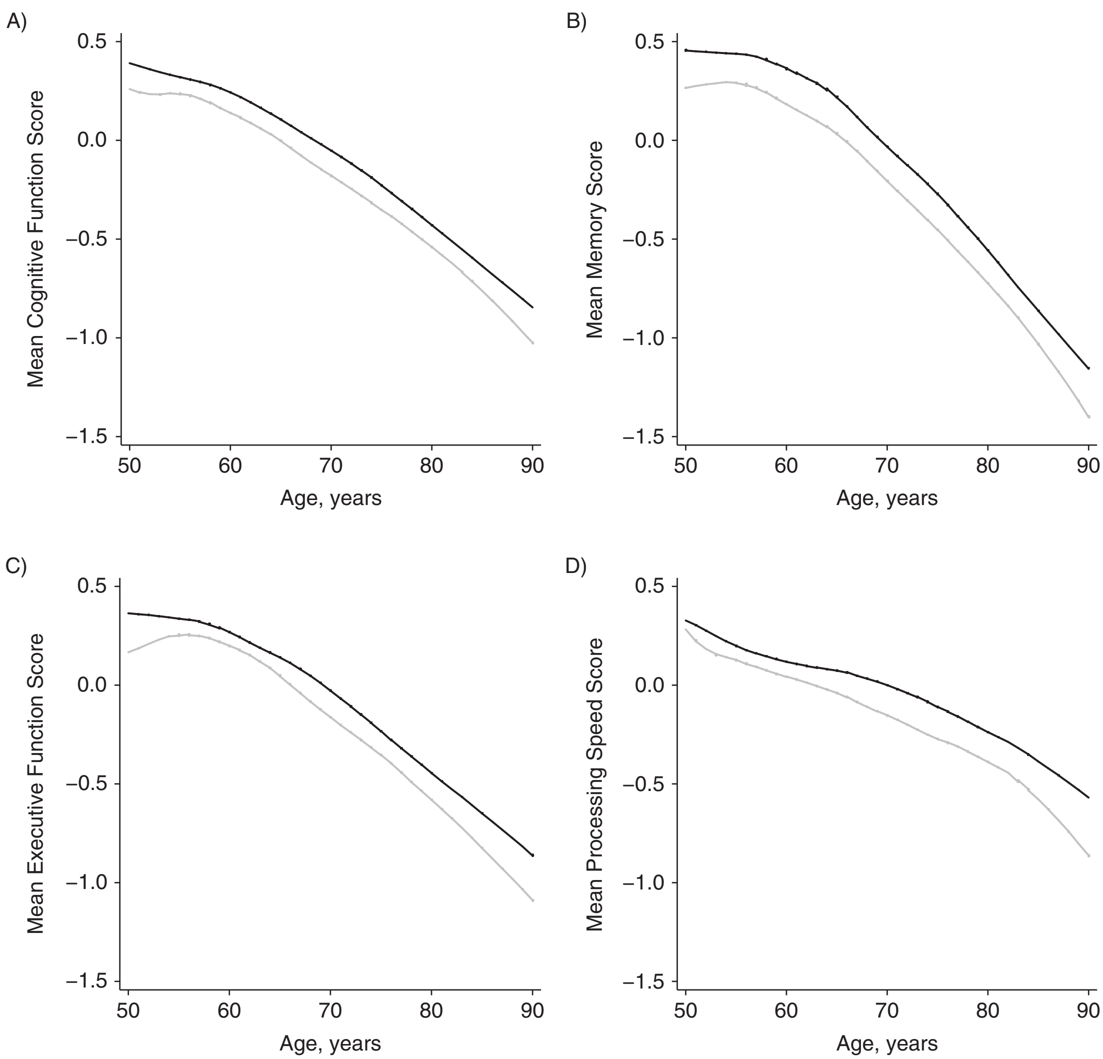

Figure 1. Locally weighted regression curves showing mean cognitive *z* scores according to age for public transport users and nonusers, English Longitudinal Study of Ageing, 2002–2014. Scores are for total cognitive function (A), memory (B), executive function (C), and processing speed (D). Public transport users shown in black; nonusers shown in gray. *Y*-axis represents mean *z* score.

Table 2 presents the results from models that estimated the association between public transport use and cognitive function. In the FE models without the instrument (model 1), becoming a public transport user was associated with a 0.014 (95% confidence interval (CI): 0.000, 0.028) increase in total cognitive function z score, a 0.028 (95% CI: 0.010, 0.046) increase in memory z score, and a 0.031 (95% CI: 0.011, 0.051) increase in executive function z score. In the second stage of the IV-FE models (model 2), increased public transport use due to the free bus pass was associated with a 0.346 (95% CI: 0.017, 0.674) increase in total cognitive function z score and a 0.546 (95% CI: 0.111, 0.982) increase in memory z score.

Results were robust to different sensitivity analyses, presented in Figure 2 for total cognitive function (Figure 2A), memory (Figure 2B), executive function (Figure 2C), and processing speed (Figure 2D) scores (full estimates in Web Table 5). Results were consistent when excluding variables that might be mediators or partially capture cognitive function (activities of daily living, instrumental activities of daily living, and chronic illness), using a balanced panel and using multiple imputation for missing values. Analyses stratified by sex produced estimates for total cognitive function and memory scores that were larger and more consistent for men than for women, suggesting that our main results are unlikely to reflect confounding by state pension eligibility. Results were also in the same direction as the main models for the low-, medium-, and high-education groups. However, results for total cognitive function score were weaker for the low-education group, while results for memory score were stronger for the high-education group.

Results were also consistent when excluding individuals above the age of 90 years and restricting the sample to individuals between the ages of 50 and 70 years (Web Table 6). Web Table 7 presents the IV-FE model that uses age 60 years as a placebo instrument before the introduction of the bus pass; the results suggest that there was no impact of reaching women's state pension age on public transport use or cognitive function before the bus pass policy.

DISCUSSION

Our findings suggest that increased public transport use due to the free bus pass is associated with improved cognitive function, particularly memory scores. To our knowledge, this is the first study to show that public transportation use might benefit cognitive function among older adults. The results of this study expand on earlier literature documenting the benefits of the free bus pass for physical activity, obesity (7, 8), social engagement, mental health (6), and quality of life and well-being (9, 10).

Public transport use might promote the maintenance and enhancement of cognitive function among older people by increasing participation in physical, social, and intellectually stimulating activities. First, previous studies have linked the free bus pass and public transportation use to higher levels of physical activity (7, 8). Physical activity protects cognitive health by reducing cardiovascular and cerebrovascular risks and by upregulating molecules involved in healthy brain structure and function (15). Second, research has linked increased public transportation use due to the free bus pass with social engagement, such as volunteering and spending time with children and friends, and with reductions in depressive symptoms and loneliness (6). Studies have also documented how the bus ride itself can be a social activity, by offering opportunities for social interaction and group travel (9). Social engagement is postulated to benefit cognitive health by increasing use of cognitive faculties in social interactions, reducing stress, and promoting mental and physical health (13, 29). Third, the free bus pass might have increased participation in intellectually stimulating activities—for example, in cultural, educational, or civic settings, which might benefit cognitive health according to the "use it or lose it" hypothesis (1). We explored this question with available ELSA data and found that increased public transportation use due to the free bus pass was indeed linked to increased likelihood of at least monthly participation in cultural activities (theater, museums, galleries, cinema), although it was not associated with civic or social group membership (Web Table 8). Finally, it is important to

Table 2. Public Transport Use and z Scores for Cognitive Function, Results of the Fixed-Effects and Instrumental-Variable Fixed-Effects Second-Stage Models, English Longitudinal Study of Ageing, 2002–2014

Outcome	Model 1: FE[a,b]			Model 2: IV-FE Second Stage[a,c]		
	β	95% CI	*P* Value[d]	β	95% CI	*P* Value[d]
Total cognitive function	0.014	0.000, 0.028	0.047	0.346	0.017, 0.674	0.039
Memory	0.028	0.010, 0.046	0.002	0.546	0.111, 0.982	0.014
Executive function	0.031	0.011, 0.051	0.002	0.323	−0.153, 0.800	0.184
Processing speed	0.001	−0.023, 0.025	0.941	0.332	−0.234, 0.898	0.250

Abbreviations: β, β coefficient; CI, confidence interval; FE, fixed effects; IV-FE, instrumental variable with fixed effects.

[a] Models controlled for age, age squared, wave, any limitations in the activities of daily living, any limitations in the instrumental activities of daily living, any chronic illnesses, car ownership, log net total household wealth, log equivalized household income, employment status, marital status, region, private pension receipt, and state pension receipt.

[b] Model 1: cognitive function outcomes regressed on public transport use and all covariates.

[c] Model 2: cognitive function outcomes regressed on the predicted values of public transport use from the first stage of the IV-FE model and all covariates.

[d] Two-sided *P* values.

consider the positive utility or intrinsic value of transport use for cognitive function (30). The bus ride itself might serve as a cognitively stimulating environment or activity that directly benefits cognitive health (31).

The strengths of this study include the use of a quasiexperimental design and IV-FE model, which addresses reverse causality, time-invariant confounders, and unmeasured or poorly measured confounders. Given that later-life cognitive function is strongly determined by early-life cognitive capacity and educational level, and these factors might also be associated with transport use, the instrument allowed us to isolate the impact of public transport use on cognitive function.

There are several limitations to this study. First, the measurement of cognitive function was based on a range of standardized tests, which might be subject to measurement error. However, previous studies using ELSA have found that the specific measures used in this study are robust to practice, ceiling, and floor effects (18, 19). There were concerns about the overlap between women's state pension age and bus pass eligibility age; however, the results from the placebo IV-FE model in the period before the free bus pass policy suggest that this overlap is unlikely to explain our main results. Additionally, we found that the impact of increased public transport use due to the free bus pass was stronger for men, whose state pension eligibility age was different from the bus pass eligibility age. If anything, the overlap between women's state pension age and bus pass eligibility age might have led to an underestimation of the impact on women, given that cognitive function tends to decline after retirement (32). Geographic variation in public transportation systems might also affect results. Because London likely has the most extensive transport system, we implemented sensitivity analyses excluding London (Web Table 9). Results were similar to the main results, suggesting that the main estimates were not specific to London's more robust transport system. Additionally, in 2012, London introduced free travel on public transportation for residents age 60 years or older (33). Defining

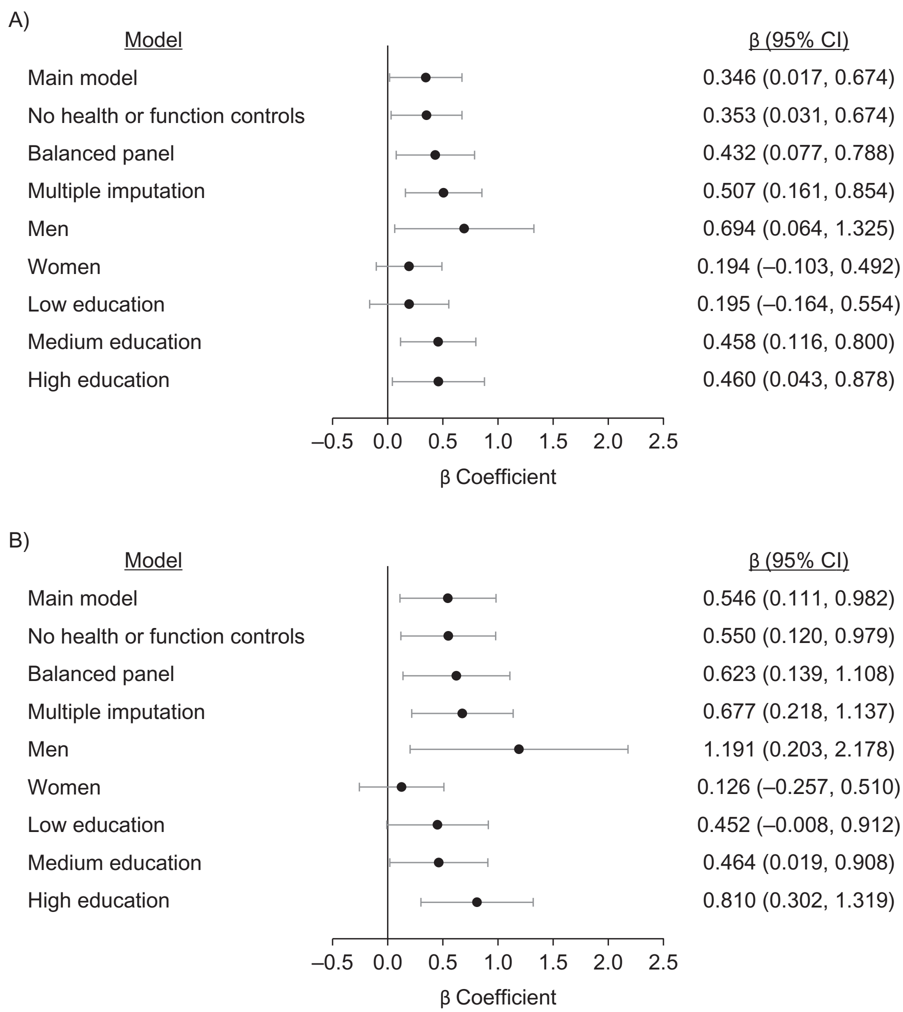

Figure 2 continues

eligibility for London residents based on this expanded scheme yielded similar estimates to the main model (Web Table 10). We note that the second-stage estimates for the IV-FE models are larger than the estimates for FE models that do not use the instrument. This might reflect the fact that the IV-FE model was estimating the local average treatment effect among the "compliers"—those who are induced to become public transport users due to becoming eligible for the free bus pass—while the FE model was estimating the average association between public transport use and cognitive function in the total sample (23). Understanding the impact of public transport use among the "compliers" is of interest from a public health and policy perspective, because it reflects the impact of the bus pass among those who change their behavior in response to the policy. It is likely that this group increases with age. For example, aging is associated with driving cessation, which might increase reliance on public transportation (34). In addition, as income declines after retirement, free bus passes become an increasingly important economic incentive to begin or increase public transport use (35).

In conclusion, this study provides evidence that a national, age-friendly public transportation policy that enables free bus travel can improve cognitive function among older people. These benefits are likely due to the role of public transportation in promoting physical activity, social engagement, and participation in intellectually stimulating activities, all of which predict better cognitive function (1). Free bus passes address only the affordability dimension of public transportation, and other policies that improve the availability and accessibility of public transportation might also be necessary to fully realize the cognitive health benefits of public transportation use for older people. The findings of this study suggest that public transportation policies might serve as public health tools to promote active lifestyles and cognitive health among older people.

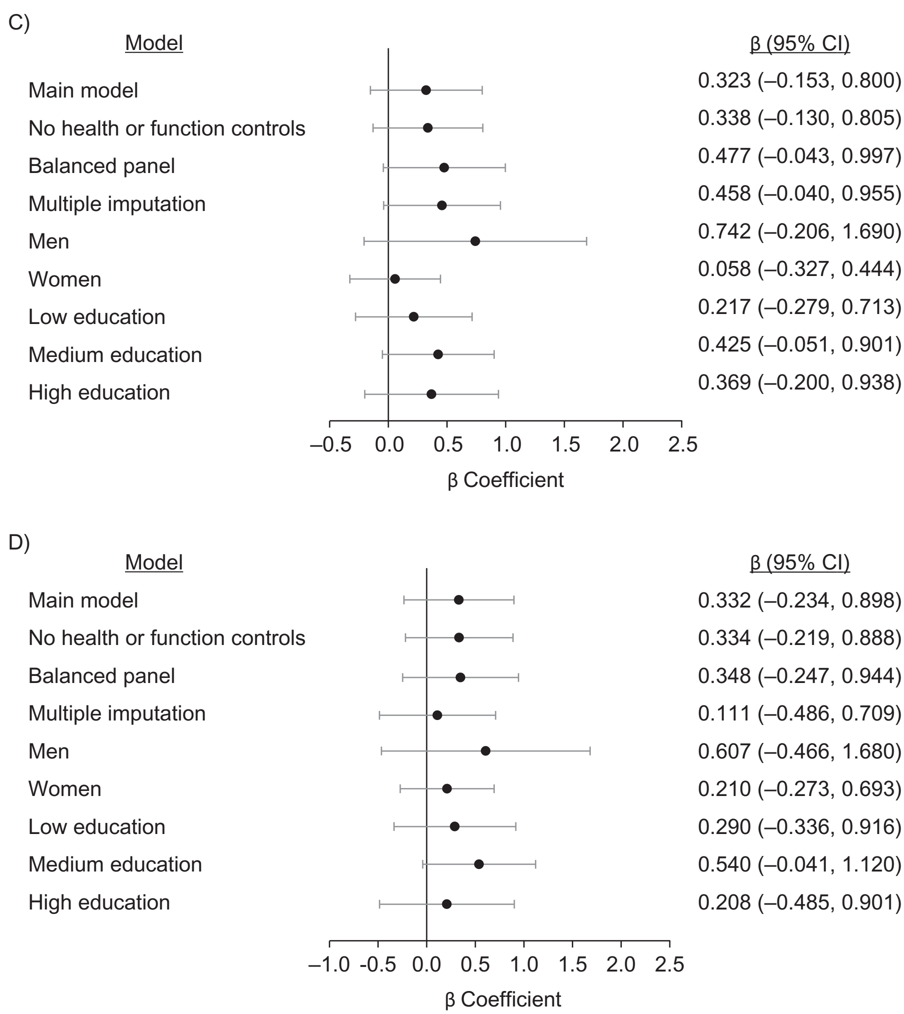

Figure 2. β coefficients and 95% confidence intervals (CIs) from main models, sensitivity analyses, and subgroup analyses for cognitive *z* scores, English Longitudinal Study of Ageing, 2002–2014. Scores are for total cognitive function (A), memory (B), executive function (C), and processing speed (D).

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