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The longitudinal relationships between the built and natural environment, air pollution, noise and dementia: results from two UK-based cohort studies

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ABSTRACT

Objective: Recent epidemiological studies have investigated a variety of environmental risk factors for dementia. However, most existing studies have focused on single environmental factors and reported mixed results. The aim of this study is to examine the interrelationships between multiple environment factors and their joint associations with cognitive health in later life.

Methods: This study was based on the Cognitive Function and Ageing Study II and Wales, two population-based cohort studies of 11,055 people aged ≥65 across five urban and rural areas in the UK. Using geospatial data, a wide range of environmental variables were generated for the participants and integrated into five domains through a latent approach, including the built environment, natural environment, noise, air pollution and deprivation. Multistate modelling was used to investigate their longitudinal associations with dementia and death adjusting for individual sociodemographic factors.

Results: The effect sizes of joint associations between the built environment (HR: 1.00; 95 %CI: 0.66, 1.52), natural environment (HR: 0.95; 95 %CI: 0.66, 1.36), air pollution (HR: 0.91; 95 %CI: 0.78, 1.07), deprivation (HR: 1.02; 95 %CI: 0.96, 1.09) and incident dementia were generally small. The strongest association was found in noise, where a high level of exposure was associated with an increased risk of incident dementia (HR: 1.22; 95 %CI: 0.97, 1.54). However, the confidence intervals were wide.

Conclusions: The joint associations between multiple environmental factors and incident dementia were found to be modest. Given mixed results in this field, future research should address methodological challenges and enhance evidence for population-level interventions on dementia risk factors.

1. Introduction

Cognitive health, the ability to think, learn and remember clearly, has been recognised as an important topic in older age (*NIH National Institute on Aging (NIA). Cognitive Health and Older Adults*, 2024). A large body of research has identified risk and protective factors related to cognitive decline and dementia, including environmental determinants beyond the individual level (Leshner et al., 2017; Livingston et al.,

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2020). Several environmental factors, such as characteristics of the built environment, air pollution exposure, have been linked to individual lifestyle (e.g., physical inactivity) (Kärmeniemi et al., 2018) and chronic conditions (e.g., cardiovascular diseases) (Cerin et al., 2024) and can have subsequent impacts on cognitive health in later life.

Several cohort studies have investigated the associations between different environmental factors, cognitive and brain health (Song et al., 2024; Besser et al., 2017; Cerin et al., 2017; Michael et al., 2024). A recent systematic review identified 40 longitudinal studies focusing on the relationships between neighbourhood characteristics and brain health, including outcome measures for cognitive function, dementia, Alzheimer's disease and cortical thickness (Michael et al., 2024). The review summarised 15 types of exposure measures for environmental hazards (e.g., noise), physical (e.g., green spaces, retail food environment, public transport) and social environment (e.g., neighbourhood cohesion) and neighbourhood socioeconomic status. Evidence on most environmental factors was mixed and dependent on assessment methods for exposure and outcome measures. For example, exposure to green spaces has been investigated in 10 studies but only three (30 %) suggested an association (Michael et al., 2024). Another example is air pollution, which has been suggested as a key modifiable risk factor for dementia, accounting for 2.3 % of worldwide cases (Livingston et al., 2020). However, mixed evidence has been reported in recent systematic reviews and longitudinal studies (Wilker et al., 2023; Abolhasani et al., 2023; Wu et al., 2024; Wood et al., 2022).

One possible explanation for the inconsistent findings might be related to variation in exposure measures and the interrelationships between different environmental factors. Most existing studies focused on a single aspect of the environment but these measures might include unknown measurement errors and the complex relationships with multiple environmental factors (Cerin, 2019). For example, areas with high levels of air pollution are likely to have lower availability of green spaces, higher density, and more issues related to poverty and social deprivation (Pearce et al., 2011). While all of these factors could have negative impacts on cognitive and brain health in older age, it is not possible to investigate which factors are more important and/or have stronger effect when including only one aspect of environmental measures in the analyses. To enhance research evidence in this field, it is essential to incorporate multiple domains of environmental measures and investigate their complicated relationships with cognitive health in later life.

Building on our previous work (Wu et al., 2024), the aim of this study is to investigate the longitudinal associations between multiple environmental factors and dementia in older people across five areas in the UK. Environmental data on deprivation, characteristics of the built environment, availability of the natural environment, air pollution and noise exposure were integrated into two population-based cohort studies. Their joint associations with incident dementia were examined incorporating the competing risk outcome of death.

2. Methods

2.1. Study population

This study was based on the Cognitive Function and Ageing Study (CFAS) II and Wales, two multicentre cohort studies of people aged ≥65 in England and Wales, UK (Matthews et al., 2016; Macleod, 2011). CFAS II included two urban (Newcastle upon Tyne, Nottingham) and one rural areas (Cambridgeshire) in England. CFAS Wales (cfaswales.bangor.ac.uk) had one rural (Gwynedd/Ynys Môn) and one urban (Neath Port Talbot) area in Wales. Informed consent was obtained from all the participants. CFAS II was approved by Cambridgeshire 4 Research Ethics Committee (reference 07/MRE05/48). CFAS Wales was approved by the North Wales Research Ethics Committee (West) (reference (Wilker et al., 2023)/WNo01/37).

The same study design was used in the two studies. The study populations were sampled from primary care registrations with equal numbers of people aged 65–74 and ≥ 75 years for each centre. An introductory letter was sent by general practitioners. The participants were visited by trained interviewers, who used standardised computerised questionnaires to collect data on sociodemographic factors, lifestyle, health and in-depth assessments of cognitive function and psychiatric symptoms. More detailed information is provided in Supplement S1. The baseline study population included 7762 people in CFAS II (2008–2011) and 3593 in CFAS Wales (2011−2013). A two-year follow-up was carried out for CFAS II (2011–2013) and Wales (2013–2016). This study excluded 285 participants in care homes at baseline and 15 participants who had unknown dementia diagnosis at the baseline. This left 11,055 (7562 in CFAS II and 3493 in CFAS Wales) for analysis.

2.2. Dementia and death

Dementia cases were identified using the Geriatric Mental State examination (GMS), which was embedded in the CFAS standardised questionnaires and informant interviews, and its algorithmic diagnosis programme, Automated Geriatric Examination for Computer Assisted Taxonomy (AGECAT) (Copeland et al., 1986). The GMS-AGECAT diagnosis is validated against the clinical criteria, the Diagnostic and Statistical Manual of Mental Disorders, revised third edition (DSM-III-R) (Copeland et al., 1986; American Psychiatric Association, 1987). Death information (months and years) was obtained through data linkage to national death certification until the end of 2015 for CFAS II and February 2019 for CFAS Wales. A censored date was set at 31st December 2015 for CFAS II and 1st March 2019 for CFAS Wales.

2.3. Environmental factors

Several environmental measures were integrated into CFAS II and Wales (Table S1, Supplement S2). Geographic information system (GIS) datasets were used to generate measures related to the built and natural environment. For each participant, their residential postcode at baseline was geocoded and a 300-m street network buffer (Frank et al., 2017) was created to indicate an accessible area by 5-min walk. Ten variables related to the built environment were generated including four distance measures to local services and amenities (the nearest general practitioner surgery, food shop, social facility and bus station); four types of density: population, point of interest (commercial services, education and health, sport and entertainment, accommodation, eating and drinking, and attractions), bus stops and street intersections within the buffers; two measures for street network accessibility: choice (betweenness centrality) and integration (closeness centrality) (van Nes and Yamu, 2021). These measures focused on how likely a street segment can be passed (i.e., choice) and reached (i.e., integration) in the network and their mean values were calculated within the buffers. Three variables related to the natural environment were generated to indicate the proportion of green spaces within the buffers, distance to centroids of green spaces and blue spaces (i.e., water bodies). More detailed information is provided in the figshare depository (doi.org/10.25405/data.ncl.26927530.v1).

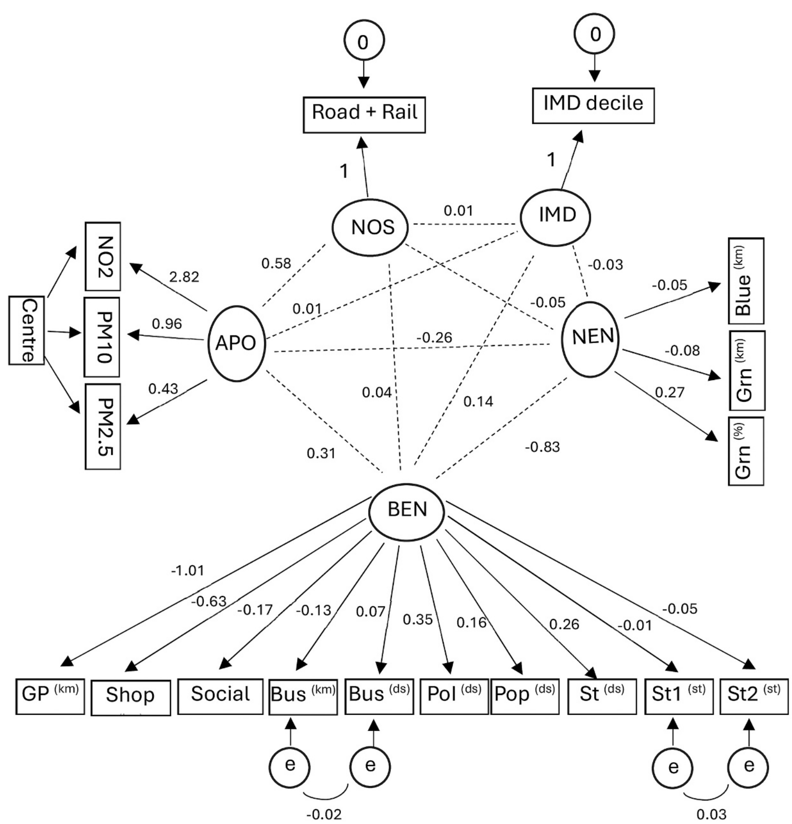
For ambient air pollution, exposure to nitrogen dioxide (NO_2), and particulate matter with a diameter ≤ 10 μm (PM_{10}) and ≤ 2.5 μm ($PM_{2.5}$), were modelled for the study areas. The Community Multiscale Air Quality Urban model was used to estimate concentration levels for the year 2012 at a resolution of 20 × 20 m (Beevers et al., 2012). The measures were linked to the participants' postcode centroids. More detailed information is reported in the previous study (Wu et al., 2024). The noise data were obtained from the strategic noise mapping 2012 (UK government. Department for Environment, Food, and Rural Affairs, 2015) for CFAS II and Environmental Noise Mapping 2012 (Welsh government, 2015) for CFAS Wales. The 'Lden' datasets for road and rail noise were used to indicate a 24-h annual average noise level with separate weightings for the evening and night periods. Exposure to road and rail noise was linked to the participants' residential locations and categorised into six ordinal levels (<55.0 (dB), 55.0–59.9, 60.0–64.9, 65.0–69.9, 70.0–74.9, ≥75.0).

The English Index of Multiple Deprivation 2010 (UK government, 2010) and Welsh Index of Multiple Deprivation 2011 (Welsh government, 2011) at the Lower Layer Super Output Area level was linked to participants using postcode information. The measure summarises different domains of area characteristics related to poverty and socio-economic disadvantage. The deciles were used to indicate relative deprivation within England or Wales.

2.4. Analytical strategy

Descriptive analyses were carried out to investigate the distributions of individual and environmental factors in the two cohort studies. To include multiple environmental factors and estimate their associations with incident dementia, a process of variable selection and/or dimension reduction was needed to account for interrelationships between the environmental variables. While these variables could be included in the models individually to select variables (often based on statistical significance) and estimate their joint associations, multiple testing could be a concern for a large number of models with individual environmental factors. Unknown measurement errors could vary across environmental factors and influence the observed associations (regression dilution bias). Although estimating the association of a specific environment factor with incident dementia might be considered to be etiologically relevant, the estimates could be prone to measurement and analytical issues. Instead of focusing on specific variables, this study considered domains of the environment. A latent approach was employed to incorporate multiple aspects of environmental factors and reduce dimensionality of the data. Based on the recent systematic review (Michael et al., 2024) and available environmental data in CFAS II and Wales, structural equation modelling (SEM) was used to create five latent factors: built environment (BEN), natural environment (NEN), air pollution (APO), noise (NOS) and deprivation (IMD). To generate the same exposure measures, the measurement models were built based on all the participants so therefore the latent scores and their associations with health outcomes were comparable across the two cohort studies.

The measurement models were generated for individual latent factors before incorporating all five latent factors. The environmental variables were rescaled (e.g., metre to kilometre) so the ranges were similar across different measures. This allowed improved convergence of complex modelling while retaining meaningful units in real life, so the latent factors and changes in the predicted scores could be more easily interpreted. More detailed information is provided in Supplement S3. A joint model was fitted to incorporate all the five latent factors with variance fixed at 1 (Fig. 1) and estimate the latent scores simultaneously



[BEN]: Built environment; [GPkm]: Distance to general practitioner surgery; [Shopkm]: Distance to shop; [Socialkm]: Distance to social facility; [Buskm]: Distance to bus station; [Busds]: Density of bus stops; [PoIds]: Density of point of interest; [Popds]: Density of population; [Stds]: Density of street intersection; [St1]: Street network: choice; [St2]: Street network: integration; **[NEN]:** Natural environment; [Grn%]: Proportion of green space; [Grnkm]: Distance to green space; [Bluekm]: Distance to blue space; **[NOS]**: Noise; [Road + Rail]: road and rail noise; **[APO]:** Air pollution; [NO2]: nitrogen dioxide [PM10]: particulate matter with a diameter ≤10 microns; [PM2.5]: particulate matter with a diameter ≤2.5 microns; **[IMD]:** Deprivation.

Fig. 1. The loading and covariance coefficients of measurement model incorporating all the five latent factors among the Cognitive Function and Ageing Study II and Wales participants aged 65 or above in England (2008–2011) and Wales (2011–2013), UK.

for all the participants. A higher score of BEN indicated an environment with higher density of population, public transport, and points of interest and shorter distance to local facilities and amenities. A higher score of NEN indicated a higher availability of local green and blue spaces. Higher latent scores of APO and NOS indicated higher levels of air pollution and noise exposure. A higher IMD score indicated a higher level of area deprivation. The latent scores were exported to investigate the longitudinal associations between environmental factors, dementia and death.

Based on the analytical framework developed in our previous work on air pollution and dementia (Wu et al., 2024), multistate hidden Markov modelling with continuous time (Jackson, 2011) was used to examine the longitudinal associations between the five environmental latent factors and risk of three transition states: from no dementia to dementia, from no dementia to death and from dementia to death (Fig. 2). The five latent factors were fitted in the models to examine their individual and joint associations with incident dementia and death. The hazard ratios (HRs) were calculated as the exponential of the estimated coefficients on the log-transition intensities. The models were adjusted for two basic demographic factors of age and sex, and cohort study (CFAS II or Wales) to account for any differences between these two studies (e.g., years of investigation). Further adjustment included education, a key indicator of individual socioeconomic status.

Inverse probability weighting was applied in the multistate modelling to account for sampling design and longitudinal attrition (Bennett et al., 2022). To examine the issue of overadjustment of deprivation/neighbourhood socioeconomic status (Chaix et al., 2010), sensitivity analyses were carried out to estimate a four-latent model excluding deprivation. To fully account for baseline variation in environmental variables across study centres (e.g., proportion of local green spaces in urban and rural sites), multigroup SEM was estimated to allow variation in constants across the five study centres but invariant loadings, errors and covariances. The latent scores from this model were calibrated within each centre (i.e., the mean score was 0 for each centre). In this case, per unit increase in latent scores (and their associations with incident dementia and death) was based on comparison of participants in the same centres. All the analyses were carried out in Stata 18.0 (SEM) and R 4.0.4 (multistate modelling).

3. Results

Table 1 shows descriptive information on the 11,055 participants. Both cohort studies had higher proportions of the 65–69 age group (>25 %), women (54 %) and people with 10–11 years of education (>50 %). For environmental factors, the CFAS II participants generally had better access to local services and amenities (e.g., shorter distance and higher density of point of interests), lower availability of natural environment (e.g., lower percentage of local green spaces) and higher levels of ambient air pollution than those in CFAS Wales. Yet the road noise level was higher in CFAS Wales.

Fig. 1 shows the structure of the five latent factors, estimated loadings and covariances of latent factors and errors. The full results of measurement models for individual and joint latent factors are reported in Table S7, Supplement S3.

There were 464 (4.2 %) participants with dementia at baseline. At the two-year follow-up wave (67.5 % interviewed), 220 developed dementia and 2228 died over the follow-up period (mean = 61 months, SD = 17). More detailed information on transition states and descriptive analysis is reported in the data.ncl depository (https://figshare.com/s/5f0097a9f1860e13e952).

The associations individual latent factors between incident dementia and death are provided in Fig. 2 and their joint associations are reported in Table 2. In the unadjusted model, higher scores of NOS (HR: 1.21; 95 % CI: 0.98, 1.50) and IMD (HR: 1.05; 95 % CI: 1.00, 1.11) was associated with higher risk of dementia but the associations did not achieve statistical significance. A higher score of APO was associated with lower

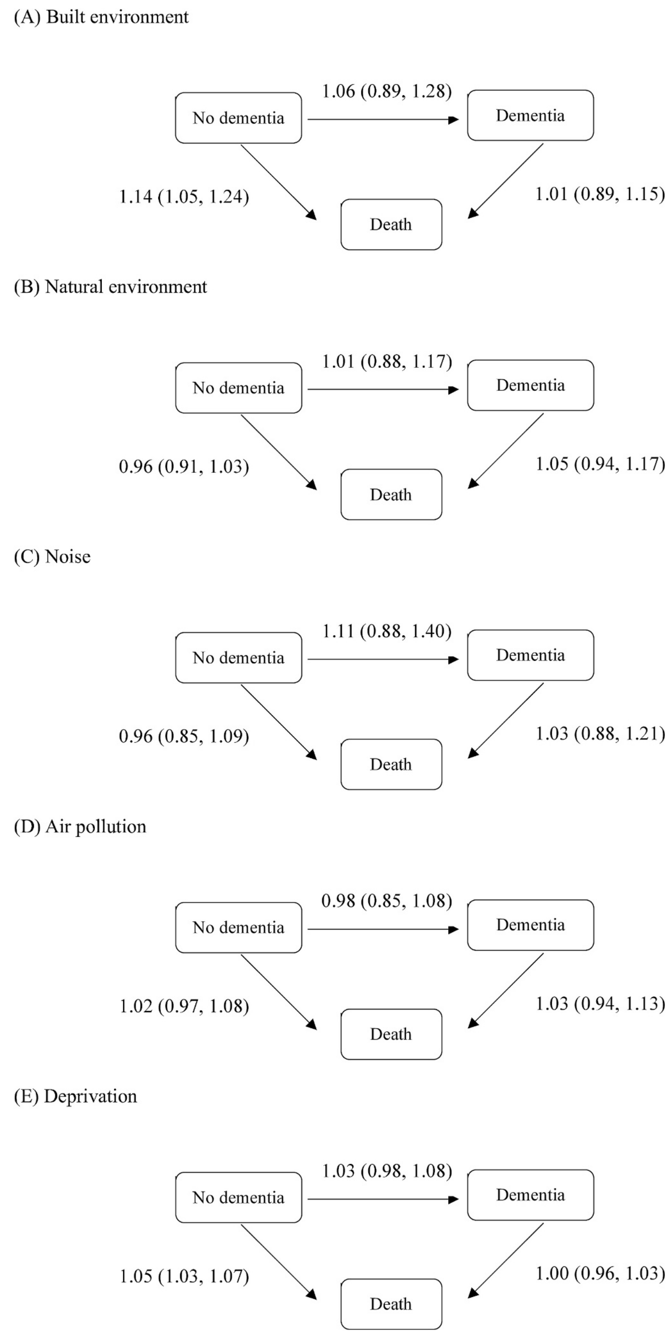


Fig. 2. The individual associations between five environmental latent factors (per 1 unit increase) and transition states of dementia and death among the Cognitive Function and Ageing Study II and Wales participants aged 65 or above in England (2008–2015) and Wales (2011–2019), UK (adjusted for age, sex and cohort study; hazard ratios (95 % confidence intervals)).
(A) Built environment: the higher latent score indicated an environment with higher density of population, public transport, and points of interest and shorter distance to local facilities and amenities; (B) Natural environment: the higher latent score indicated a higher availability of local green and blue spaces; (C) Noise: the higher latent scores higher levels of noise exposure; (D) Air pollution: the higher latent scores higher levels of air pollution exposure; (E) Deprivation: the higher score indicated a higher level of poverty and socioeconomic disadvantage in local areas. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

risk of dementia (0.80; 95 % CI: 0.70, 0.93). In the fully adjusted model, the effect size of noise remained similar (HR: 1.22; 95 % CI: 0.97, 1.54) but the other associations were attenuated. For transitioning from no

Table 1
Descriptive statistics of the study population and environmental factors among people aged 65 or above in England (CFAS II; 2008–2011) and Wales (CFAS Wales; 2011–2013), UK.

		CFAS II ($N = 7562$)	CFAS Wales ($N = 3493$)	Total ($N = 11,055$)
		N (%)	N (%)	N (%)
Age	65–69	1928 (25.5)	1038 (29.7)	2966 (26.8)
	70–74	1866 (24.7)	909 (26.0)	2775 (25.1)
	75–79	1596 (21.1)	656 (18.8)	2252 (20.4)
	80–84	1240 (16.4)	485 (13.9)	1725 (15.6)
	85+	932 (12.3)	405 (11.8)	1337 (12.1)
Sex	Men	3477 (46.0)	1590 (45.5)	5067 (45.8)
	Women	4085 (54.0)	1903 (54.5)	5988 (54.2)
Education	≤9 years	1956 (26.2)	409 (11.9)	2365 (21.6)
	10–11 years	3876 (51.8)	1763 (50.9)	5639 (51.6)
	≥12 years	1641 (22.0)	1289 (37.2)	2930 (26.8)
	Missing	89	32	121
		Mean (SD)	Mean (SD)	Mean (SD)
Built Environment	Distance to general practitioner surgery (km)	1.2 (1.2)	2.2 (2.1)	1.5 (1.6)
	Distance to shops (km)	0.6 (0.7)	1.1 (1.3)	0.8 (1.0)
	Distance to social facility (km)	0.5 (0.3)	0.5 (0.4)	0.5 (0.4)
	Distance to bus station (km)	0.3 (0.2)	0.3 (0.4)	0.3 (0.3)
	Density of bus stops (per 100 stops/km^2)	0.2 (0.2)	0.2 (0.2)	0.2 (0.2)
	Density of point of interest (per 100 points/km^2)	0.7 (0.8)	0.3 (0.3)	0.6 (0.7)
	Density of population (per 10,000 people/km^2)	0.3 (0.3)	0.1 (0.1)	0.3 (0.3)
	Density of street intersection (per 10,000 intersections/km^2)	0.7 (0.4)	0.5 (0.3)	0.6 (0.4)
	Street network: Choice	0.9 (0.1)	0.9 (0.1)	0.9 (0.1)
	Street network: Integration	1.5 (0.6)	1.2 (0.4)	1.4 (0.6)
Natural Environment	Proportion of green spaces	0.2 (0.2)	0.4 (0.3)	0.3 (0.3)
	Distance to green space (km)	0.2 (0.2)	0.2 (0.1)	0.2 (0.2)
	Distance to blue space (km)	1.7 (1.0)	1.2 (0.8)	1.5 (1.0)
Air Pollution	NO_2 (1 μg/m^3)	23.0 (7.2)	11.0 (5.3)	19.2 (8.7)
	PM_{10} (1 μg/m^3)	16.5 (2.0)	15.3 (1.8)	16.1 (2.0)
	$PM_{2.5}$ (1 μg/m^3)	11.7 (1.6)	7.4 (2.3)	10.3 (2.7)
Noise	Road	0.1 (0.4)	0.2 (0.6)	0.1 (0.5)
	Rail	0.0 (0.1)	0.0 (0.1)	0.0 (0.1)
Deprivation	Indices of multiple deprivation	5.1 (2.9)	5.5 (2.4)	5.3 (2.8)

CFAS II: Cognitive Function and Ageing Study II; CFAS Wales: Cognitive Function and Ageing Study Wales; SD: standard deviation; NO_2: nitrogen dioxide; PM_{10}: particulate matter with a diameter ≤ 10 μm; $PM_{2.5}$: particulate matter with a diameter ≤ 2.5 μm; km: kilometre; km^2: square kilometre; μg/m^3: micrograms per cubic metre; Density of point of interest: numbers of commercial services, education and health, sport and entertainment, accommodation, eating and drinking, and attractions within 300 m areas of the participants' residences; Street network: measures indicating how likely a street segment can be passed (Street network: choice) and reached (Street network: integration) in the network and higher values indicated better accessibility of street network; Distance to blue space: the nearest distance (km) to water bodies from the participants' residences; Indices of Multiple Deprivation: the deciles of the English Index of Multiple Deprivation 2010 and Welsh Index of Multiple Deprivation 2011, which summarise multiple domains of area characteristics related to poverty and socioeconomic disadvantage.

dementia to death, only the association with deprivation remained similar after adjustment (HR: 1.03; 95 % CI: 1.00, 1.07). For transitioning from dementia to death, BEN (HR: 1.30; 95 % CI: 0.99, 1.69) had positive associations while IMD had a negative association (HR: 0.94; 95 % CI: 0.90, 0.98). However, these associations became closer to null in the fully adjusted model.

The associations between the four latent factors (BEN, NEN, NOS, APO) and incident dementia were not altered when excluding deprivation. The results of the multigroup measurement model remained similar to the main results. The full results of sensitivity analyses are reported in the data.ncl depository (https://figshare.com/s/5f0097a9f1860e13e952).

4. Discussion

Using two population-based cohort studies and integrated environmental data, this study incorporated multiple variables into five domains of environmental latent factors, including the built environment, natural environment, noise, air pollution and deprivation, and investigated their longitudinal associations with dementia and death in older people across England and Wales. Among the five environmental factors, the strongest association was found for noise. A high level of noise exposure was associated with a 20 % increased risk of dementia after accounting for sociodemographic and other environmental factors. However, the confidence interval was wide, indicating a high level of uncertainty. The effect sizes of the other four environmental factors were generally small (<10 % increase or decrease in risk).

4.1. Strengths and limitations

This study included over 11,000 older people with diverse socioeconomic backgrounds across urban and rural areas in the UK and integrated a variety of environment data to characterise the participants' residential environments. The algorithmic diagnosis of dementia was applied to the participants across regions. Multistate modelling was used to examine the joint associations between different environmental factors and transition states of dementia and death, a competing risk outcome in older age.

There are some limitations. The follow-up period of CFAS II and Wales were two years and a relatively small number of participants ($N = 220$) developed dementia over the short time period. This leads to wide confidence intervals and limited statistical power to detect modest associations. The environmental variables were generated based on certain assumptions. Some of the built and natural environmental variables focused on areas within 300 m of the participants' postcode centroids, which was assumed to be relevant to the daily life of older people. Exposure to environmental hazards was estimated based on geolocations and did not consider potential differences between indoor and housing conditions (e.g., soundproofing). The environmental variables were created for years of the baseline interview and assumed to

Table 2
The joint associations between five environmental latent factors (per 1 unit increase) and transition states of dementia and death among people aged 65 or above in England (CFAS II; 2008–2015) and Wales (CFAS Wales; 2011–2019), UK.

	Built environment	Natural environment	Noise	Air pollution	Deprivation
	HR (95 % CI)	HR (95 % CI)	HR (95 % CI)	HR (95 % CI)	HR (95 % CI)
Model 1					
No to dementia	0.95 (0.68, 1.34)	0.84 (0.61, 1.15)	1.21 (0.98, 1.50)	0.80 (0.70, 0.93)	1.05 (1.00, 1.11)
No to death	1.18 (0.97, 1.43)	1.12 (0.94, 1.34)	0.89 (0.98, 1.05)	1.08 (0.99, 1.18)	1.03 (1.00, 1.06)
Dementia to death	1.30 (0.99, 1.69)	1.18 (0.92, 1.49)	1.04 (0.89, 1.21)	1.02 (0.92, 1.14)	0.94 (0.90, 0.98)
Model 2					
No to dementia	1.00 (0.66, 1.52)	0.95 (0.66, 1.36)	1.22 (0.97, 1.54)	0.91 (0.78, 1.07)	1.02 (0.96, 1.09)
No to death	1.16 (0.95, 1.42)	1.12 (0.94, 1.33)	0.88 (0.74, 1.04)	1.06 (0.98, 1.15)	1.03 (1.00, 1.07)
Dementia to death	1.07 (0.80, 1.41)	1.06 (0.83, 1.36)	1.05 (0.90, 1.23)	1.00 (0.89, 1.11)	1.00 (0.96, 1.05)

Model 1: Unadjusted.
Model 2: Adjusted for age, sex, cohort study and education.
CFAS II: Cognitive Function and Ageing Study II; CFAS Wales: Cognitive Function and Ageing Study Wales; HR: hazard ratio; 95 % CI: 95 % confidence interval.

capture exposure in later life. Although these measurement methods have been commonly used in the literature and the participants were followed up only for two years, these measures might not fully reflect individual differences in environmental exposure and the exposure levels at different life stages. The quality of GIS data may vary across time and areas with potential errors and missingness. This study did not include measures related to the social environment (e.g., neighbourhood cohesion, crime) but crime is one of the deprivation indicators. Over-adjustment of deprivation might have masked the associations of other environmental factors and/or caused spurious associations (Bennett et al., 2022). Yet sensitivity analyses without deprivation showed similar results. The analyses did not include individual lifestyle factors as they might be mediators on the pathways between environmental factors, dementia and death.

5. Interpretation of findings

Several longitudinal studies have investigated environmental factors related to dementia and suggested some risk (air pollution (Chen et al., 2017a; Carey et al., 2018), noise (Meng et al., 2022), neighbourhood socioeconomic disadvantage (Mobley et al., 2023; Vassilaki et al., 2022), low availability of food stores (Tani et al., 2019)) and protective factors (exposure to greenness (Slawsky et al., 2022; Astell-Burt et al., 2020)). This study covered most of these environmental factors and investigated their individual and joint associations with risk of dementia. However, the effect sizes were generally small. Although a wide range of environmental factors have been identified to be associated with cognitive health in cross-sectional studies (Song et al., 2024), our study corresponds to evidence from longitudinal studies, which is mixed and depends on research methods (Michael et al., 2024).

A small number of studies have examined multiple domains of environments and their longitudinal associations with dementia using health insurance databases (Liu et al., 2020; Yuchi et al., 2020). One study was based on over 600,000 people aged 45–84 years old in Vancouver, Canada, examining road proximity (proxy indicator for air pollution) (Chen et al., 2017b), noise and green spaces and their joint associations with Alzheimer's disease and non-Alzheimer's dementia over four years (Yuchi et al., 2020). Proximity to major roads was associated with higher odds of non-Alzheimer's dementia accounting for green spaces and individual level factors. However, these associations were not found for Alzheimer's disease. The other study, using over 52,000 people aged≥65 from National Health Insurance Database in Taiwan, carried out a nested case-control analysis to investigate physical (availability of parks, greeneries, and square area; playgrounds and sport venues; community centres) and social environments (median annual family income; percentage of illiterate; living alone) in 2006 and their associations with dementia in 2010 (Liu et al., 2020). When including the six environmental variables in one model, high availability of playgrounds and sport venues was associated with lower odds of dementia. Although these two large studies accounted for multiple environmental factors, the findings seem to be sparse with potential methodological concerns (e.g., multiple testing, variation in diagnostic methods).

The joint associations between air pollution, noise and dementia have been investigated in longitudinal studies using health administrative and cohort data (Carey et al., 2018; Andersson et al., 2018; Tuffier et al., 2024; Yu et al., 2023). Most of these studies did not identify the associations with noise (Andersson et al., 2018; Tuffier et al., 2024; Yu et al., 2023) or the effect size of noise was largely attenuated after including air pollutants (Carey et al., 2018; Tuffier et al., 2024). These studies also reported mixed results of interactions between air pollution and noise (Andersson et al., 2018; Yu et al., 2023). Compared to the literature (Carey et al., 2018; Andersson et al., 2018; Tuffier et al., 2024; Yu et al., 2023), this study did not find a clear association between air pollution and dementia and the effect size of noise was the strongest among the five environmental domains. Since air pollution and hearing impairment are recognised as key modifiable risk factors for dementia (Livingston et al., 2020), more evidence is needed to clarify the impacts of these environmental hazards.

Compared to previous studies focusing on specific measures (Liu et al., 2020; Yuchi et al., 2020; Chen et al., 2017b; Andersson et al., 2018; Tuffier et al., 2024; Yu et al., 2023), this study used a latent approach to summarise multiple environmental variables into domains. Instead of applying a variable selection approach, factor analysis was used to reduce dimensionality of complex data (Kline, 2015). Interpretation of latent factors and their effect sizes can be a challenging issue as units of latent factors are different from the original measures. The results of this study mainly suggested which domains of the environment were important to cognitive health and did not specify the associations of particular environmental factors. Although fitting specific environmental factors provides effect sizes that can be explained in a straightforward way, care is needed for public health implications. Per unit increase in a specific environmental factor and its association with health outcomes was often based on the condition that other environmental factors remain constant. This may be difficult to achieve in real life as it is unlikely to address isolated environmental factors without affecting other factors (Rehkopf et al., 2016).

6. Future research directions and implications

To identify environmental factors related to cognitive health, recent studies have developed ecological models to illustrate linkages between different domains of neighbourhood environments, health behaviours, individual characteristics and health outcomes (Cerin, 2019; Finlay et al., 2022). Yet more evidence from longitudinal studies is needed to clarify source of mixed results in the existing studies and determine underlying mechanisms. To enhance the quality of evidence in this field, future epidemiological research should address methodological challenges in data (e.g., changes in health and environmental measures over time), measurements (e.g., timing of environmental exposure across different life stages) and longitudinal analysis (e.g., multiple environmental factors and their interactions with individual characteristics) (Besser et al., 2017; Michael et al., 2024). In addition to cohort studies, qualitative research can provide insights into how people interact with the environment, such as their perceptions of green space quality, barriers to accessibility and wellbeing benefits (Reece et al., 2024; Ward et al., 2023). Recent research has combined quantitative and qualitative methods to involve the public and policymakers and investigate behaviours, perceptions and awareness related to neighbourhood and cognitive health (Stevens et al., 2023; Finlay et al., 2021). This may provide a valuable approach to develop population-level interventions tailored for older people living across diverse settings and inform evidence-based policy and practice to support cognitive health over the ageing process.

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Ethics approval

The Cognitive Function and Ageing Study II was approved by Cambridgeshire 4 Research Ethics Committee (reference 07/MRE05/48) and full information is provided on the CFAS website (www.cfas.ac.uk). The Cognitive Function and Ageing Study Wales was approved by the North Wales Research Ethics Committee (West) (reference 10/WNo01/37). Informed consent was obtained from all individual participants in the Cognitive Function and Ageing Study II and Wales.

CRediT authorship contribution statement

Yu-Tzu Wu: Writing – review & editing, Writing – original draft, Methodology, Investigation, Funding acquisition, Formal analysis, Data curation, Conceptualization. **Sean Beevers:** Writing – review & editing, Resources, Investigation, Funding acquisition. **Benjamin Barratt:** Writing – review & editing, Resources, Investigation, Funding acquisition. **Carol Brayne:** Writing – review & editing, Resources, Data curation. **Ester Cerin:** Writing – review & editing, Funding acquisition, Conceptualization. **Rachel Franklin:** Methodology, Writing – review & editing, Funding acquisition. **Victoria Houlden:** Methodology, Writing – review & editing, Funding acquisition. **Bob Woods:** Writing – review & editing, Resources, Data curation. **Eman Zied Abozied:** Writing – review & editing, Investigation, Data curation. **Matthew Prina:** Writing – review & editing, Funding acquisition, Conceptualization. **Fiona Matthews:** Writing – review & editing, Supervision, Funding acquisition, Conceptualization.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Data availability

Data will be made available on request.

Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.ypmed.2025.108348.

References

Abolhasani, E., Hachinski, V., Ghazaleh, N., Azarpazhooh, M.R., Mokhber, N., Martin, J., 2023. Air pollution and incidence of dementia: a systematic review and meta-analysis. Neurology 100 (2), e242–e254.

American Psychiatric Association, 1987. Diagnostic and Statistical Manual of Mental Disorders (3rd ed., revised).

Andersson, J., Oudin, A., Sundström, A., Forsberg, B., Adolfsson, R., Nordin, M., 2018. Road traffic noise, air pollution, and risk of dementia - results from the Betula project. Environ. Res. 166, 334–339. https://doi.org/10.1016/j.envres.2018.06.008.

Astell-Burt, T., Navakatikyan, M.A., Feng, X., 2020. Urban green space, tree canopy and 11-year risk of dementia in a cohort of 109,688 Australians. Environ. Int. 145, 106102. https://doi.org/10.1016/j.envint.2020.106102.

Beevers, S.D., Kitwiroon, N., Williams, M.L., Carslaw, D.C., 2012. One way coupling of CMAQ and a road source dispersion model for fine scale air pollution predictions. Atmos. Environ. 59, 47–58.

Bennett, H.Q., Kingston, A., Lourida, I., et al., 2022. A comparison over 2 decades of disability-free life expectancy at age 65 years for those with long-term conditions in England: analysis of the 2 longitudinal cognitive function and ageing studies. PLoS Med. 19 (3), e1003936.

Besser, L.M., McDonald, N.C., Song, Y., Kukull, W.A., Rodriguez, D.A., 2017. Neighborhood environment and cognition in older adults: a systematic review. Am. J. Prev. Med. 53 (2), 241–251. https://doi.org/10.1016/j.amepre.2017.02.013.

Carey, I.M., Anderson, H.R., Atkinson, R.W., et al., 2018. Are noise and air pollution related to the incidence of dementia? A cohort study in London, England. BMJ Open 8 (9), e022404.

Cerin, E., 2019. Building the evidence for an ecological model of cognitive health. Health Place 60, 102206. https://doi.org/10.1016/j.healthplace.2019.102206.

Cerin, E., Rainey-Smith, S.R., Ames, D., Lautenschlager, N.T., Macaulay, S.L., Fowler, C., Robertson, J.S., Rowe, C.C., Maruff, P., Martins, R.N., Masters, C.L., Ellis, K.A., 2017. Associations of neighborhood environment with brain imaging outcomes in the Australian imaging, Biomarkers and Lifestyle cohort. Alzheimers Dement. 13 (4), 388–398. https://doi.org/10.1016/j.jalz.2016.06.2364.

Cerin, E., Chan, Y.K., Symmons, M., et al., 2024. Associations of the neighbourhood built and natural environment with cardiometabolic health indicators: a cross-sectional analysis of environmental moderators and behavioural mediators. Environ. Res. 240 (Pt 2), 117524. https://doi.org/10.1016/j.envres.2023.117524.

Chaix, B., Leal, C., Evans, D., 2010. Neighborhood-level confounding in epidemiologic studies: unavoidable challenges, uncertain solutions. Epidemiology 21 (1), 124–127. https://doi.org/10.1097/EDE.0b013e3181c04e70.

Chen, H., Kwong, J.C., Copes, R., et al., 2017a. Exposure to ambient air pollution and the incidence of dementia: a population-based cohort study. Environ. Int. 108, 271–277.

Chen, H., Kwong, J.C., Copes, R., et al., 2017b. Living near major roads and the incidence of dementia, Parkinson's disease, and multiple sclerosis: a population-based cohort study. Lancet 389 (10070), 718–726.

Copeland, J.R., Dewey, M.E., Griffiths-Jones., 1986. HM a computerized psychiatric diagnostic system and case nomenclature for elderly subjects: GMS and AGECAT. Psychol. Med. 16, 89–99.

Finlay, J., Yu, W., Clarke, P., Lia, M., Judd, S., Esposito, M., 2021. Neighborhood cognitive amenities? A mixed-methods study of intellectually-stimulating places and cognitive function among older Americans. Wellbeing Space Soc. 2, 100040. https://doi.org/10.1016/j.wss.2021.100040.

Finlay, J., Esposito, M., Langa, K.M., Judd, S., Clarke, P., 2022. Cognability: an ecological theory of neighborhoods and cognitive aging. Soc. Sci. Med. 309, 115220. https://doi.org/10.1016/j.socscimed.2022.115220.

Frank, L.D., Fox, E.H., Ulmer, J.M., et al., 2017. International comparison of observation-specific spatial buffers: maximizing the ability to estimate physical activity. Int. J. Health Geogr. 16 (1), 4. https://doi.org/10.1186/s12942-017-0077-9.

Jackson, C.H., 2011. Multi-state models for panel data: the msm package for R. J. Stat. Softw. 38 (8), 1–29.

Kärmeniemi, M., Lankila, T., Ikäheimo, T., Koivumaa-Honkanen, H., Korpelainen, R., 2018. The built environment as a determinant of physical activity: a systematic review of longitudinal studies and natural experiments. Ann. Behav. Med. 52 (3), 239–251. https://doi.org/10.1093/abm/kax043.

Kline, R.B., 2015. Principles and Practice of Structural Equation Modelling. Guilford Publications.

Leshner, A.I., Landis, S., Stroud, C., Downey, A., 2017. Preventing Cognitive Decline and Dementia: A Way Forward. National Academyof Sciences, Washington, DC.

Liu, C.C., Sun, Y., Kung, S.F., et al., 2020. Effects of physical and social environments on the risk of dementia among Taiwanese older adults: a population-based case-control study. BMC Geriatr. 20 (1), 226. https://doi.org/10.1186/s12877-020-01624-6.

Livingston, G., Huntley, J., Sommerlad, A., et al., 2020. Dementia prevention, intervention, and care: 2020 report of the lancet commission. Lancet 396 (10248), 413–446.

Macleod, C.A., 2011. Maintaining function and well-being in later life: a longitudinal cohort study (CFAS Wales). Signpost Journal 16 (1), 23–24.

Matthews, F.E., Stephan, B.C., Robinson, L., et al., 2016. A two decade dementia incidence comparison from the cognitive function and ageing studies I and II. Nat. Commun. 7, 11398. https://doi.org/10.1038/ncomms11398.

Meng, L., Zhang, Y., Zhang, S., et al., 2022. Chronic noise exposure and risk of dementia: a systematic review and dose-response Meta-analysis. Front. Public Health 10, 832881. https://doi.org/10.3389/fpubh.2022.832881.

Michael, Y.L., Senerat, A.M., Buxbaum, C., et al., 2024. Systematic review of longitudinal evidence and methodologies for research on neighborhood characteristics and brain health. Public Health Rev. 45, 1606677. https://doi.org/10.3389/phrs.2024.1606677.

Mobley, T.M., Shaw, C., Hayes-Larson, E., et al., 2023. Neighborhood disadvantage and dementia incidence in a cohort of Asian American and non-Latino white older adults in northern California. Alzheimers Dement. 19 (1), 296–306. https://doi.org/10.1002/alz.12660.

NIH National Institute on Aging (NIA). Cognitive Health and Older Adults. https://www.nia.nih.gov/health/brain-health/cognitive-health-and-older-adults, 2024.

Pearce, J.R., Richardson, E.A., Mitchell, R.J., Shortt, N.K., 2011. Environmental justice and health: a study of multiple environmental deprivation and geographical inequalities in health in New Zealand. Soc. Sci. Med. 73 (3), 410–420. https://doi.org/10.1016/j.socscimed.2011.05.039.

Reece, R., Elliott, L., Bray, I., Bornioli, A., 2024. How properties of urban greenspaces shape well-being across age groups: a qualitative study. Wellbeing, Space and Society. 7, 100206. https://doi.org/10.1016/j.wss.2024.100206.

Rehkopf, D.H., Glymour, M.M., Osypuk, T.L., 2016. The consistency assumption for causal inference in social epidemiology: when a rose is not a rose. Curr. Epidemiol. Rep. 3 (1), 63–71. https://doi.org/10.1007/s40471-016-0069-5.

Slawsky, E.D., Hajat, A., Rhew, I.C., et al., 2022. Neighborhood greenspace exposure as a protective factor in dementia risk among U.S. adults 75 years or older: a cohort study. Environ. Health 21(1):14. https://doi.org/10.1186/s12940-022-00830-6.

Song, Y., Liu, Y., Bai, X., Yu, H., 2024. Effects of neighborhood built environment on cognitive function in older adults: a systematic review. BMC Geriatr. 24 (1), 194. https://doi.org/10.1186/s12877-024-04776-x.

Stevens, M., Matosevic, T., Suarez-Pinilla, M., Pais, S., Rossor, M., Knapp, M., 2023. The link between cognitive health and neighbourhood: perceptions of the public,and of policy-makers, about problems and solutions. BMC Public Health 23 (1), 1694. https://doi.org/10.1186/s12889-023-16592-w.

Tani, Y., Suzuki, N., Fujiwara, T., Hanazato, M., Kondo, K., 2019. Neighborhood food environment and dementia incidence: the Japan Gerontological evaluation study cohort survey. Am. J. Prev. Med. 56 (3), 383–392. https://doi.org/10.1016/j.amepre.2018.10.028.

Tuffier, S., Zhang, J., Bergmann, M., et al., 2024. Long-term exposure to air pollution and road traffic noise and incidence of dementia in the Danish nurse cohort. Alzheimers Dement. 20 (6), 4080–4091. https://doi.org/10.1002/alz.13814.

UK government, 2010. Department for Communities and Local Government. English indices of deprivation 2010. UK government.

UK government. Department for Environment, Food & Rural Affairs, 2015. Open data: strategic noise mapping (2012). UK government. https://www.gov.uk/government/publications/open-data-strategic-noise-mapping.

van Nes, A., Yamu, C., 2021. Analysing linear spatial relationships: The measures of connectivity, integration, and choice. In: van Nes, A., Yamu, C. (Eds.), Introduction to Space Syntax in Urban Studies. Springer International Publishing, pp. 35–86. https://doi.org/10.1007/978-3-030-59140-3_2.

Vassilaki, M., Aakre, J.A., Castillo, A., et al., 2022. Association of neighborhood socioeconomic disadvantage and cognitive impairment. Alzheimers Dement. https://doi.org/10.1002/alz.12702.

Ward C, Palmer AK, Brockett T, et al. Perceptions, preferences and barriers: a qualitative study of greenspace and under-representation in LeedsUK, People and nature. 2023; 5(4):1284–1298. doi: https://doi.org/10.1002/pan3.10507.

Welsh government, 2011. Welsh index of multiple deprivation. Welsh government.

Welsh government, 2015. Environmental noise mapping 2012. Welsh government. https://datamap.gov.wales/layergroups/inspire-wg:EnvironmentalNoiseMapping?Environmental+Noise+Mapping+2012+-+Noise+Action+Plan+-+Agglomerations=.

Wilker, E.H., Osman, M., Weisskopf, M.G., 2023. Ambient air pollution and clinical dementia: systematic review and meta-analysis. BMJ 381, e071620. https://doi.org/10.1136/bmj-2022-071620.

Wood, D., Evangelopoulos, D., Beevers, S., Kitwiroon, N., Katsouyanni, K., 2022. Exposure to ambient air pollution and the incidence of dementia in the elderly of England: the ELSA cohort. Int. J. Environ. Res. Public Health 19 (23), 15889.

Wu, Y.T., Kitwiroon, N., Beevers, S., et al., 2024. The longitudinal associations between ambient air pollution exposure and dementia in the UK: results from the cognitive function and ageing study II and Wales. BMC Public Health 24 (1), 1233. https://doi.org/10.1186/s12889-024-18723-3.

Yu, Y., Su, J., Jerrett, M., et al., 2023. Air pollution and traffic noise interact to affect cognitive health in older Mexican Americans. Environ. Int. 173, 107810. https://doi.org/10.1016/j.envint.2023.107810.

Yuchi, W., Sbihi, H., Davies, H., Tamburic, L., Brauer, M., 2020. Road proximity, air pollution, noise, green space and neurologic disease incidence: a population-based cohort study. Environ. Health 19 (1), 8. https://doi.org/10.1186/s12940-020-0565-4.