# The built environment and cognitive disorders: results from the Cognitive Function and Ageing Study II

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## Abstract

### Introduction

Features of built environment have been related to behavior modification and might stimulate cognitive activity with a potential impact on cognitive health in later life. The aim of this study is to investigate cross-sectional associations between features of land use, cognitive impairment and dementia and also explore urban and rural differences in these associations.

### Methods

Postcodes of the 7505 community-based participants (age 65+) in the Cognitive Function and Ageing Study II (collected in 2008–2011) were linked to environmental data from government statistics. A multilevel logistic regression was used to investigate associations between cognitive impairment (defined as MMSE≤25), dementia (GMS-AGECAT organicity level≥3) and land use features, including natural environment availability and land use mix, fitting interaction terms with three rural/urban categories. Data were analyzed in 2015.

### Results

Associations between features of land use and cognitive impairment were not linear. After adjusting for individual-level factors and area deprivation, living in areas with high land use mix was associated with a nearly 30% decreased odds of cognitive impairment (OR: 0.72; 95%CI: 0.58, 0.89). This was similar, yet non-significant, for dementia (OR: 0.70; 95%CI: 0.46, 1.06). In urban conurbations, living in areas with high natural environment availability was associated with 30% reduced odds of cognitive impairment (OR: 0.70; 95%CI: 0.50, 0.97).

**Conclusions**

Non-linear associations between features of land use and cognitive impairment were confirmed in this new cohort of older people in England. Both a lack and overload of environmental stimulation may be detrimental to cognition in later life.

## Introduction

Dementia and cognitive impairment in older age have been recently recognized to be an important public health issue.[1] Although a wide range of risk factors have been identified,[2] prevention or risk reduction strategies have largely focused on individual-level factors such as lifestyle, health and medical conditions.[3] Potential environmental determinants have rarely been explored in existing studies or been taken into account during policy planning on dementia prevention or risk reduction.[4,5] Since important environmental influences on lifestyle and health conditions have been widely recognized in public health research and used to develop potential interventions to promote individual and community health, aspects of the environment may also play a preventive role for cognitive disorders. In particular, recent studies have reported a higher prevalence of dementia in rural than urban areas,[6,7] together with an inverse relationship between cognitive function and area deprivation,[8-10] which is typically taken to measure economic and material disadvantages (e.g. unemployment, low education and household overcrowding)[11] and widely used as a proxy of environmental conditions of local areas. This may suggest environmental characteristics at the small area level, usually defined as the community- or neighborhood-level, could have some influence on cognitive health.

Several built environmental features such as land use mix, natural environment availability, and street connectivity have been related to physical activity,[12] depression[13,14] and levels of social interaction,[15] which are known risk or protective factors for dementia and cognitive decline.[2,16] The built environment may influence these lifestyle factors and increase cognitive reserve and general health throughout the lifecourse. In addition to these potential indirect pathways, a recent review[17] has suggested a direct association between environmental characteristics, sensory stimulation and cognitive performance. Exposure to natural environment has been related to attention restoration.[18,19] while more interactive environments, such as those with mixed land use, may provide a “brain training” setting and perceptual stimulation.[7,17] Counter to this is the potential overload of multiple stimulation caused by environmental stress in urban areas, which could have a negative effect on cognitive performance.[17]

The complexity of built environmental features in relation to cognition in later life has been reported in recent epidemiological studies[20,21] as well as in our earlier analysis using a follow-up investigation of the Medical Research Council Cognitive Function and Ageing Study (MRC CFAS).[22] Based on 2424 people aged 74 or above across England in 2001, our earlier report suggests potential non-linear associations between cognitive impairment and features of land use, including natural environment availability and land use mix.[22] Increased odds of cognitive impairment were found in both high and low levels of natural environment availability and land use mix. This might imply that both a lack and overload of environmental stimulation could be detrimental to cognitive function in later life.

Environmental features at the small area level can vary greatly between urban and rural areas, with different meanings to residents.[23] For example, most green space in rural areas is likely to be agricultural fields, which might not be suitable for recreation and physical activity. The heterogeneity of rural and urban contexts can influence interactions of older people with their local environments[7] and thus the relationships between small area level factors and cognitive function might be different in urban and rural settings.

Our earlier analysis was based on the 10-year follow-up of MRC CFAS in 2001, focusing on survivors and responders from the baseline sample.[22] The key findings from this work are described in Table 1, along with resultant hypotheses to be tested here. The earlier findings might have limitations relating to selection bias and could be outdated given recent changes in dementia occurrence.[24] The aim of this study is to examine whether findings from MRC CFAS can be replicated in the Cognitive Function and Ageing Study II, a new cohort starting from 2008 and representing the current older population in England. We further explore the potential for rural and urban differences in associations.

# Methods

## Study population

The Cognitive Function and Ageing Study II (CFAS II) is a population-based epidemiological study of people aged 65 or over in England. The primary purpose of the study is to investigate the epidemiology of dementia in the current UK older population and to explore changes in dementia prevalence and incidence over two decades. In order to compare the estimates with those from 1991 (MRC CFAS), CFAS II includes three of the original study centers in England (Newcastle upon Tyne, Nottingham and Cambridgeshire) and used identical study designs and methods apart from merged screen and assessment stages. The sampling frame is based on primary care registration including over 2500 community-based and institutionalized people with equal numbers of the 65-74 and 75+ age groups from each center. The baseline interviews (2008–2011) were delivered by trained interviewers using the standardized computerized interview in the participants' residence. Full details of the study design and methods are published elsewhere.[24]

The total sample size of the CFAS II baseline was 7796.[24] The analysis here excluded 105 people who did not complete the interview but where a dementia diagnosis was derived from medical records and other relevant information. Since those living in care home settings might interact differently with their local environments, 185 people living in institutions were also excluded, together with one person aged 64. This left 7505 for this study, comprising all the community-based participants across the three English centers. CFAS II was approved by relevant local research ethics committees and obtained informed consent from participants.[24] This secondary data analysis does not require new IRB approval.

**Individual-level measurements**

Information on age, gender and education was recorded at the interview. Education was divided into three groups: nine or fewer years of education, 10-11 years and 12 years or above.[25] Since several chronic conditions are related to cognitive disorders in older age,[2] numbers of chronic illnesses, including vascular risk factors (hypertension, diabetes, stroke, heart attack, angina, low blood pressure) and sensory impairment (hearing and vision impairment), were recorded based on self-reported information in the interview.

A structured assessment was used to measure cognitive function and mental status. Cognitive impairment was defined as a Mini-Mental State Examination (MMSE) score of 25 or below, aligned with the previous CFAS II analysis.[25] Dementia cases were defined as organicity level three and above using the Geriatric Mental Status and the algorithm of the Automatic Geriatric Examination for Computer Assisting Taxonomy.[26]

**Environmental measurements, area deprivation and rural/urban categories**

Using the National Statistics Postcode Directory,[27] postcodes of the CFAS II participants were mapped to Lower-layer Super Output Areas (LSOA), a small geographical unit developed for the UK census with an average of 1500 residents per unit. For each LSOA, information for the Index of Multiple Deprivation 2010 (IMD 2010) and Generalized Land Use 2005 were obtained from the Neighborhood Statistics repository (www.neighbourhood.statistics.gov.uk) and were linked to the CFAS II study areas.

Area deprivation was measured using the IMD 2010, which summarized seven domains of characteristics related to deprivation (income, employment, education and training, health and disability, barriers to housing and services, living environment and crime) based on data collected in 2007–2008.[11] The Generalized Land Use 2005 dataset provided areas of different types of land use in LSOAs, and was used to calculate measures of land use mix and natural environment availability for the residential LSOA of each participant. The measure of land use mix was calculated based on literature[28] with a range from 0 (lowest heterogeneity of land use) to 1 (highest). A high level of land use mix indicates a close integration of different land uses such as residential, commercial and recreational areas. The measure of the natural environment availability was based on the percentage of greenspace and private gardens in each LSOA. The environmental measurements were divided into quintiles, aligned with the MRC CFAS analysis and UK Census reports.[9,29]

The 2011 Rural/Urban Classification for Small Areas Geographies provided rural/urban categories for all the LSOAs in England.[30] This analysis used three urban categories: Major Conurbation (mean population density (PD):35.5 persons per hectare), Minor Conurbation (PD:22.6), City and Town (PD:16.5); and two rural categories: Town and Fringe (PD:5.9), Village and Dispersed (PD:0.5).[31] In order to increase the statistical power of the analyses these categories were combined into three types: Urban Conurbation (Major and Minor Conurbation), Urban City and Town and Rural areas (Town and Fringe, Village and Dispersed) based on the similarity of their environmental features.

**Statistical analysis**

Multilevel logistic regression was used to investigate the association between two environmental factors (land use mix and natural environment availability), and the outcomes of cognitive impairment and dementia before adjustment (Model 1) and then adjusted for individual-level factors (age, gender, education and numbers of chronic illnesses) (Model 2). Further adjustment for area deprivation was conducted to control for the potential influence of socioeconomic disadvantage and other unmeasured related factors (Model 3). Given potential non-linear relationships, a likelihood ratio test was used to test for heterogeneity.

To investigate how associations might differ in urban and rural contexts, interaction terms between the two environmental factors and the rural/urban categories were included in regression models adjusting for individual-level factors. To retain adequate statistical power, the analysis focused only on cognitive impairment and the two environmental measures were re-categorized into tertiles, with the lowest tertile in urban conurbations being the reference group. Data were analyzed in 2015 using STATA 12.0.

## Results

Distributions of individual-level factors are reported in Table 2. Among the 7505 participants, the median age was 74 years (interquartile range: 11) and 54% were women. The prevalence of cognitive impairment and dementia increased with older age and lower education levels. Higher prevalence of cognitive impairment was found in women, those with two or more chronic conditions and those living in rural areas but these differences were not observed for dementia.

In Table 3, the associations between features of land use and cognitive impairment were not linear (Model 1) and these patterns persisted after adjusting for individual-level factors (Model 2). The odds decreased from the first to third quintile but increased with higher levels of land use mix and natural environment availability. The lowest odds of cognitive impairment was found in the third quintile of land use mix (OR: 0.69; 95%CI: 0.56, 0.86) and natural environment availability (OR: 0.81; 95%CI: 0.67, 0.99). Although the associations with dementia did not achieve statistical significance, lower odds also appeared in the third or fourth quintile of land use mix and natural environment availability. After further adjusting for area deprivation, the odds of cognitive impairment and dementia were reduced in areas with high land use mix (Model 3). Living in areas with high land use mix was associated with 30% decreased odds of cognitive impairment (OR: 0.72; 95%CI: 0.58, 0.89). A similar reduction was observed for dementia (OR: 0.70; 95%CI: 0.46, 1.06), although this was not statistically significant.

Figure 1 shows the associations between cognitive impairment and features of land use across the rural/urban categories. Two groups in rural areas did not have estimates due to small sample sizes.

Although the odds of cognitive impairment was slightly higher in rural areas than the reference group (the lowest tertile in urban conurbations), the associations between cognitive impairment and land use mix were not substantially different across rural/urban settings. Living in areas with high natural environment availability was associated with up to 30% lower odds (OR: 0.70; 95%CI: 0.50, 0.97) of cognitive impairment in urban conurbations while the associations were unclear in urban city and town areas and rural areas.

## Discussion

### Main findings

Building on our previous analysis, this study used a new cohort of older people in England to investigate the associations between features of land use, cognitive impairment and dementia and further explored potential urban and rural differences in more detail. This analysis further confirms the U-shaped associations that both high and low levels of land use mix and natural environment availability are associated with increased odds of cognitive disorders. After adjusting for individual-level factors and area deprivation, living in high land use mix areas was associated with a nearly 30% lower odds of cognitive impairment and dementia. The analysis of rural/urban differences shows a potential dose-response relationship between cognitive impairment and natural environment in urban conurbations. Despite overlapping 95% confidence intervals for the middle and high tertiles, a 30% reduction in odds of cognitive impairment was observed for those living in areas of the highest natural environment availability.

**Strengths and limitations**

This study was based on a multicenter population-based cohort of a current older population in England, including participants from a wide variety of socio-demographic backgrounds and environmental contexts. Cognitive assessment and dementia diagnosis were based on a structured interview to avoid potential variation in diagnostic standards. Further, the dataset was generally complete with a low percentage of missing data (<2%).

Due to the cross-sectional nature of the data, the ability to determine causality is limited and reverse causality is possible as older people might need to change their residence to receive care from family members or health services as a result of poor cognitive and functional abilities. Unfortunately, information on relocation in recent years was not available in CFAS II. Nevertheless, 95% of the cohort reported that they had lived in their local area for over five years. Although we recognize the same area may not equate to exactly the same address, this suggests relocation bias may be minimal. Some environmental factors such as traffic intensity could be potential confounding factors but they were not adjusted in the analysis due to lack of available data. Whilst, a number of lifestyle and social engagement measures are available for the cohort, they are relatively simple. Given that this analysis is cross-sectional and that the potential role of factors such as lifestyle is unclear, we chose not to investigate them further here as potential mediation and moderation is better investigated in future longitudinal research with appropriate follow-up measurements.

The LSOAs in rural areas (median:11500 $m^2$) were much bigger than those in urban areas (median:350 $m^2$) but variations in environmental factors were generally small across geographical units. Skewed distributions of environmental factors in rural areas caused small sample size for some interaction terms and insufficient power to test urban/rural differences. Further, boundaries of LSOAs might not reflect the actual activity space of those living in a community. Although this study included over 7500 people, the low prevalence of dementia limits statistical power to detect variation across quintiles.

**The built environment and cognition in later life**

The findings of non-linear relationships suggest that environments with especially low or high levels of land use diversity might be associated with a lack or overload of cognitive stimulation, and this could be detrimental to cognition in later life. Recent longitudinal studies in the US have investigated features related to land use mix and also suggested their complex relationships with cognitive decline.[20,21] The Chicago Health and Aging Project including 6518 people aged 65+ showed that living in a neighborhood with community centers and public transport was associated with faster rate of cognitive decline over the 18-year observation period.[20] This finding differs from an earlier study in Chicago, which reported a positive association between cognitive function and neighborhood resources (libraries, recreational centers, parks).[10] Although a higher level of street integration and connectivity were both assumed to be representative of a more walkable environment, a small study (N=64) in Kansas reported differential associations between these two environmental factors and both baseline and change in cognitive function over two years.[21] Although caution is needed in the interpretation of these factors in different socio-political and cultural contexts, these results might correspond to our findings and suggest complicated interactions between the environment and cognitive stimulation.

Although mixed land uses could provide more interactive environments for social and cognitively stimulating activities, areas with particularly high land use mix also might be associated with the presence of environmental stressors, such as noise, heavy traffic and social disorder. These features could lead to overload of cognitive and sensory stimulation, overwhelming the potential benefits of being close to local services and resources.[17] In this study, further controlling for area deprivation, a proxy of poor quality environment, did attenuate the increased odds of cognitive impairment and dementia in the highest level of land use mix. Another possibility could be that features related to high land use mix might support individuals with cognitive impairment to continue living in their local communities. Alternatively some older people could suffer from environmental stress in high land use mix areas but might not be able to move away due to economic disadvantage.[32]

The association between cognitive impairment and natural environment availability appears to differ in urban and rural settings. While exposure to green space can be beneficial to psychological restoration,[18,33] rural areas with very high natural environment availability may have more social isolation[34] and a consequent lack of cognitive stimulation. In contrast to rural areas, a linear relationship was found in urban conurbations. In addition to the beneficial influence on physical activity,[12] green space in urban settings has been suggested to buffer against stress[33] and might also reduce stimulation overload.[17]

**Future research directions and public health implications**

The findings of this study reinforce the earlier observed association between environment and cognition in later life. Policy planning on dementia prevention or risk reduction may consider aspects of environment and address such population-level determinants. In recent years, several policies around aging and wellbeing have started to focus on creating supportive environments for health.[35] Although high land use mix and naturel environment availability have been suggested to support active and healthy ageing,[12,35] instead of emphasizing an unidirectional impact of certain environmental features, achieving a balance between support and stimulation from local environments could be particularly important for cognitive health in older people.

Features related to a walkable environment seem to have unexpected associations with cognition in older age. Population-based longitudinal studies are needed to clarify causal directions and investigate underlying mechanisms considering both direct and indirect pathways via physical activity, social interactions and other potential mediators. Future studies may also consider the quality and types of green space[36] as these may provide insights into urban/rural differences in associations observed.

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## References


1 World Health Organisation. *Dementia: a public health priority*. Geneva: World Health Organisation, 2012.

2 Blazer DG, Yaffe K, Liverman CT. *Cognitive Aging: Progress in Understanding and Opportunities for Action*. Washington DC: Institute of Medicine, 2015

3 Wu Y-T, Fratiglioni L, Matthews FE, Lobo A, Breteler MMB, Skoog I, et al. Dementia in western Europe: epidemiological evidence and implications for policy making. *Lancet Neurol*. 2016;15(1):116-24.

4 Farrow M. *An Australia Government Initiative. Towards a Dementia Prevention Policy for Australia: Implications of the Current Evidence.* Canberra: Alzheimer's Australia, 2010

5 Alzheimer's Disease International. *Policy brief - risk factors for dementia*. London: Alzheimer's Disease International, 2012.

6 Russ TC, Batty GD, Hearnshaw GF, Fenton C, Starr JM. Geographical variation in dementia: systematic review with meta-analysis. *Int J Epidemiol*. 2012;41(4):1012-32.

7 Cassarino M, O'Sullivan V, Kenny RA, Setti A. Environment and Cognitive Aging: A Cross-Sectional Study of Place of Residence and Cognitive Performance in the Irish Longitudinal Study on Ageing. *Neuropsychology*. 2016;30(5):543-57

8 Wu Y-T, Prina AM, Brayne C. The association between community environment and

cognitive function: a systematic review. *Soc Psychiatry Psychiatr Epidemiol*. 2015;50(3):351-62.

9 Basta NE, Matthews FE, Chatfield MD, Brayne C, MRC CFAS. Community-level socio-economic status and cognitive and functional impairment in the older population. *Eur J Public Health*. 2008;18(1):48-54.

10 Clarke PJ, Ailshire JA, House JS, Morenoff JD, King K, Melendez R, et al. Cognitive function in the community setting: the neighbourhood as a source of 'cognitive reserve'? *J Epidemiol Community Health*. 2012;66(8):730-6.

11 UK government Department for Communities and Local Government. *English indices of deprivation 2010*. London: Department for Communities and Local Government, 2011.

12 Van Cauwenberg J, De Bourdeaudhuij I, De Meester F, Van Dyck D, Salmon J, Clarys P, et al. Relationship between the physical environment and physical activity in older adults: A systematic review. *Health Place*. 2011;17(2):458-69.

13 Saarloos D, Alfonso H, Giles-Corti B, Middleton N, Almeida OP. The Built Environment and Depression in Later Life: The Health In Men Study. *Am J Geriatr Psychiatry*. 2011;19(5):461-70.

14 Wu Y-T, Prina AM, Jones A, Matthews FE, Brayne C, MRC CFAS. Older people, the natural environment and common mental disorders: cross-sectional results from the Cognitive

Function and Ageing Study. *BMJ Open*. 2015;5(9):e007936.

15 Renalds A, Smith TH, Hale PJ. A Systematic Review of Built Environment and Health. Family & Community Health. 2010;33(1):68-78.

16 Norton S, Matthews FE, Barnes DE, Yaffe K, Brayne C. Potential for primary prevention of Alzheimer's disease: an analysis of population-based data. *Lancet Neurol*. 2014;13(8):788-94.

17 Cassarino M, Setti A. Environment as 'Brain Training': A review of Geographical and Physical Environmental Influences on Cognitive Ageing. *Ageing Res Rev*. 2015;23:167-82

18 Gamble, K.R., Howard, J.H., Howard, D.V., 2014. Not just scenery: viewing naturepictures improves executive attention in older adults. *Exp Aging Res*. 40,513–530.

19 Berman, M.G., Jonides, J., Kaplan, S., 2008. The cognitive benefits of interacting with nature. *Psychol Sci*. 19, 1207–1212

20 Clarke PJ, Weuve J, Barnes L, Evans DA, Mendes de Leon CF. Cognitive decline and the neighborhood environment. *Ann Epidemiol*. 2015;25(11):849-54.

21 Watts A, Ferdous F, Diaz Moore K, Burns JM. Neighborhood Integration and Connectivity Predict Cognitive Performance and Decline. *Gerontol Geriatr Med*. 2015;1.

22 Wu Y-T, Prina AM, Jones AP, Barnes LE, Matthews FE, Brayne C, MRC CFAS. Community environment, cognitive impairment and dementia in later life: results from the

Cognitive Function and Ageing Study. *Age Ageing*. 2015;44(6):1005-11.

23 Macintyre S, Ellaway, A., Cummins, S. Place effects on health: how can we conceptualise, operationalise and measure them? *Soc Sci Med*. 2002;55(125-139).

24 Matthews FE, Arthur A, Barnes LE, Bond J, Jagger C, Robinson L, et al. A two-decade comparison of prevalence of dementia in individuals aged 65 years and older from three geographical areas of England: results of the Cognitive Function and Ageing Study I and II. *Lancet*. 2013;382(9902):1405-12.

25 Jagger C, Matthews FE, Wohland P, Fouweather T, Stephan BCM, Robinson L, et al. A comparison of health expectancies over two decades in England: results of the Cognitive Function and Ageing Study I and II. *Lancet*. 2016;387(10020):779-86

26 Copeland JR, Dewey ME, Griffiths-Jones HM. A computerized psychiatric diagnostic system and case nomenclature for elderly subjects: GMS and AGECAT. *Psychol Med*. 1986;16:89–99.

27 Office for National Statistics. National Statistics Postcode Products. http://www.ons.gov.uk/ons/guide-method/geography/products/postcode-directories/-nspp-/index.html

28 Frank LD, Sallis JF, Conway TL, Chapman JE, Saelens BE, Bachman W. Many pathways from land use to health - Associations between neighborhood walkability and active

transportation, body mass index, and air quality. *J Am Plann Assoc*. 2006;72(1):75-87.

29 Office for National Statistics. Baby boys in most deprived areas show greatest increase in life expectancy. 2014. http://webarchive.nationalarchives.gov.uk/20160105160709/http://www.ons.gov.uk/ons/rel/subnational-health4/life-expec-at-birth-age-65/2006-08-to-2010-12/sty-life-expectancy-gap.html

30 UK Government, Department for Environment, Food and Rural Affairs. *The 2011 Rural Urban Classification: User Guide*. London: UK government, 2013.

31 Office for National Statistics. 2011 UK Census. Population density. 2013 https://www.nomisweb.co.uk/census/2011/qs102ew

32 Oswald F, Schilling O, Wahl H-W, GÄNG K. Trouble in paradise? reasons to relocation and objective environmental changes among well-off older adults. *J Environ Psychol*. 2002;22(3):273-88.

33 Hartig T. Green space, psychological restoration, and health inequality. *Lancet*. 2008;372(9650):1614-5.

34 Commission for Rural Communities. *Social isolation experienced by older people in rural communities*. Gloucester: Commission for Rural Communities, 2012. http://cdn.basw.co.uk/upload/basw_111815-1.pdf

35 World Health Organization Regional Office for Europe. *Background Paper. Innovation for age-friendly environments in Europe: joint AFE-INNOVNET and AFEE workshops for policy-makers*. Brussels: World Health Organization Regional Office for Europe, 2015.

36 Annerstedt M, Ostergren PO, Bjork J, Grahn P, Skarback E, Wahrborg P. Green qualities in the neighbourhood and mental health - results from a longitudinal cohort study in Southern Sweden. *BMC Public Health*. 2012;12:337.

## Title of figure

**Figure 1** Odds ratio of cognitive impairment by interaction terms between land use mix, natural environment availability and rural/urban categories (estimates adjusted for age, gender, education and chronic conditions)

**Table 1** Measurements of the built environment and hypotheses to be tested

| **Environmental factors** | **Definition** | **Data sources** | **Medical Research Council Cognitive Function and Ageing Study (MRC CFAS) findings[a]:** | **Cognitive Function and Ageing Study II (CFAS II) hypotheses[b]:** |
|---|---|---|---|---|
| Land use mix | The diversity of land uses (domestic, green space, commercial) in a defined area | Generalized Land Use 2001/2005 | (1) A potential non-linear association between cognitive impairment, dementia and land use mix: the odds decreased from the first to the third quartile but then slightly increased in the fourth quartile.<br>(2) A decreased odds of dementia in higher levels of land use mix after further adjusting for area deprivation | (1) Land use mix has a non-linear association with cognitive impairment and dementia.<br>(2) Outside urban conurbations, a higher level of land use mix is associated with lower odds of cognitive impairment and dementia. |
| Natural environment availability | Areas with natural vegetation such as grass, trees and plants | Generalized Land Use 2001/2005 | A potential non-linear association between cognitive impairment, dementia and natural environment: the odds decreased from the first to the third quartile but then slightly increased in the fourth quartile. | (1) There is a non-linear U-shaped association between natural environment availability, cognitive impairment and dementia.<br>(2) In urban conurbations, higher availability of the natural environment is linearly associated with lower odds of cognitive impairment and dementia. |

[a] Based on 2424 people aged 74+ in England (survivors and responders to the year-10 follow-up in 2001)

[b] The current study based on 7505 people aged 65+ in England (a representative sample of older people in England; baseline interview in 2008-2011)

**Table 2** Numbers and percentage of cognitive impairment and dementia cases by individual-level factors and rural/urban categories

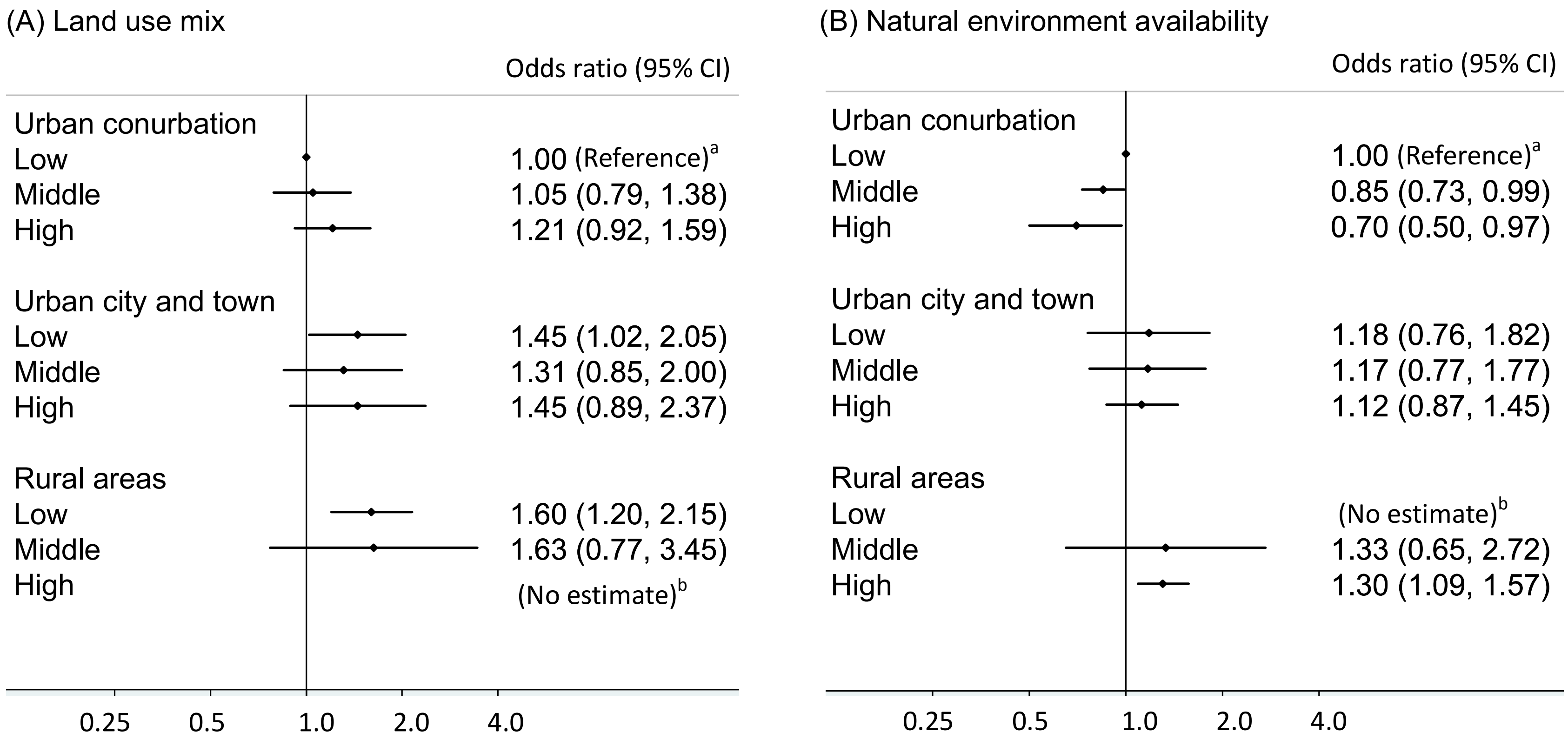
| | Cognitive impairment (MMSE≤25) | Dementia | Total |
|---|---|---|---|
| N (%) | 1756 (23.7) | 328 (4.4) | 7505 |
| Missing | 102 (1.4) | 1 (0.0) | |
| Age group | | | |
| 65-69 | 237 (12.4) | 15 (0.8) | 1923 |
| 70-74 | 327 (17.7) | 44 (2.4) | 1861 |
| 75-79 | 390 (24.9) | 69 (4.3) | 1594 |
| 80-84 | 406 (33.3) | 86 (7.0) | 1237 |
| 85+ | 396 (46.4) | 114 (12.8) | 890 |
| | ***p*****<0.01** | ***p*****<0.01** | |
| Gender | | | |
| Men | 695 (20.3) | 146 (4.2) | 3462 |
| Women | 1061 (26.6) | 182 (4.5) | 4043 |
| | ***p*****<0.01** | *p*=0.55 | |
| Education | | | |
| 12 years and above | 189 (11.6) | 36 (2.2) | 1644 |
| 10~11 years | 779 (20.3) | 129 (3.3) | 3871 |
| 9 year and below | 765 (40.4) | 147 (7.6) | 1946 |
| | ***p*****<0.01** | ***p*****<0.01** | |
| Numbers of chronic illness | | | |
| None | 376 (21.4) | 147 (8.0) | 1843 |
| One | 531 (22.6) | 72 (3.1) | 2357 |
| Two and more | 849 (25.8) | 109 (3.3) | 3305 |
| | ***p*****<0.01** | ***p*****<0.01** | |
| Rural/urban status | | | |
| Urban conurbation | 1088 (22.5) | 207 (4.2) | 4905 |
| Urban city and town | 261 (25.3) | 51 (4.9) | 1046 |
| Rural area | 407 (26.6) | 70 (4.5) | 1554 |
| | ***p*****<0.01** | *p*=0.62 | |

*Note:* Boldface indicates statistical significance ($p<0.05$)

**Table 3** Unadjusted and adjusted odds ratios of cognitive impairment and dementia by quintiles of environmental factors

| | | Cognitive impairment (MMSE≤25) | | | Dementia | | |
|---|---|---|---|---|---|---|---|
| | | Model 1 | Model 2 | Model 3 | Model 1 | Model 2 | Model 3 |
| Environmental factors | | OR (95% CI) | OR (95% CI) | OR (95% CI) | OR (95% CI) | OR (95% CI) | OR (95% CI) |
| Land use mix | | | | | | | |
| (Lowest) | Q1 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 |
| | Q2 | 0.94 (0.74, 1.19) | 0.86 (0.70, 1.06) | 0.83 (0.69, 1.02) | 1.02 (0.71, 1.45) | 0.97 (0.67, 1.39) | 0.90 (0.62, 1.30) |
| | Q3 | 0.76 (0.60, 0.96) | 0.69 (0.56, 0.86) | 0.61 (0.50, 0.75) | 0.97 (0.68, 1.39) | 0.94 (0.65, 1.37) | 0.83 (0.57, 1.22) |
| | Q4 | 0.92 (0.73, 1.15) | 0.76 (0.62, 0.93) | 0.64 (0.52, 0.79) | 0.87 (0.60, 1.25) | 0.87 (0.60, 1.27) | 0.70 (0.46, 1.04) |
| (Highest) | Q5 | 1.06 (0.85, 1.32) | 0.91 (0.75, 1.12) | 0.72 (0.58, 0.89) | 0.97 (0.68, 1.39) | 0.93 (0.64, 1.34) | 0.70 (0.46, 1.06) |
| | | ***p*=0.03** | ***p*<0.01** | ***p*<0.01** | *p*=0.92 | *p*=0.96 | *p*=0.38 |
| Natural environment | | | | | | | |
| (Lowest) | Q1 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 |
| | Q2 | 0.93 (0.76, 1.13) | 0.89 (0.73, 1.07) | 0.91 (0.75, 1.09) | 0.89 (0.63, 1.25) | 0.85 (0.59, 1.22) | 0.88 (0.61, 1.27) |
| | Q3 | 0.80 (0.65, 0.97) | 0.81 (0.67, 0.99) | 0.89 (0.74, 1.08) | 0.72 (0.50, 1.03) | 0.73 (0.50, 1.07) | 0.81 (0.55, 1.19) |
| | Q4 | 0.85 (0.69, 1.05) | 0.94 (0.77, 1.14) | 1.10 (0.90, 1.35) | 0.95 (0.68, 1.33) | 0.92 (0.65, 1.31) | 1.07 (0.73, 1.58) |
| (Highest) | Q5 | 1.02 (0.81, 1.28) | 1.17 (0.95, 1.44) | 1.49 (1.20, 1.84) | 0.86 (0.61, 1.22) | 0.90 (0.62, 1.29) | 1.12 (0.75, 1.68) |
| | | *p*=0.13 | ***p*=0.01** | ***p*<0.01** | *p*=0.46 | *p*=0.59 | *p*=0.48 |

Model 1: Unadjusted model; Model 2: Adjusted for age, gender, education and numbers of chronic illness; Model 3: Adjusted for age, gender, education, numbers of chronic illness and area deprivation; MMSE: Mini-Mental State Examination; *p*: *p* value of test for heterogeneity; *Note:* Boldface indicates statistical significance ($p<0.05$)




Footnotes: [a] Reference group; [b] Estimates were not available due to small sample sizes.