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Social and physical neighbourhood characteristics and 10-year incidence of depression and anxiety in older adults: Results from the Longitudinal Aging Study Amsterdam

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ABSTRACT

Objective: A growing literature suggests that neighbourhood characteristics are associated with mental health outcomes, but the evidence in older adults is inconsistent. We investigated the association of neighbourhood characteristics, pertaining to demographic, socio-economic, social and physical environment domains, with the subsequent 10-year incidence of depression and anxiety, in Dutch older adults.

Methods: In the Longitudinal Aging Study Amsterdam depressive and anxiety symptoms were assessed four times between 2005/2006 and 2015/2016, using the Center for Epidemiological Studies Depression Scale (n = 1365) and the Anxiety subscale of the Hospital Anxiety and Depression Scale (n = 1420). Neighbourhood-level data on urban density, percent population over 65 years of age, percent immigrants, average house price, average income, percent low-income earners, social security beneficiaries, social cohesion, safety, proximity to retail facilities, housing quality, percent green space, percent water coverage, air pollution (particulate matter (PM2.5)), and traffic noise, were obtained for study baseline years 2005/2006. Cox proportional hazard regression models, clustered within neighbourhood, were used to estimate the association between each neighbourhood-level characteristic and the incidence of depression and anxiety.

Results: The incidence of depression and anxiety was 19.9 and 13.2 per 1000 person-years, respectively. Neighbourhood characteristics were not associated with the incidence of depression. However, various neighbourhood characteristics were associated with an increased incidence of anxiety, including: higher urban density level, higher percent immigrants, greater proximity to retail facilities, lower housing quality score, lower safety score, higher PM2.5 levels and less green space.

Conclusion: Our results indicate that several neighbourhood characteristics are associated with anxiety but not with depression incidence in older age. Several of these characteristics have the potential to be modifiable and thus could serve as a target for interventions at the neighbourhood-level in improving anxiety, provided that future studies replicate our findings and provide further evidence for a causal effect.

1. Introduction

There is compelling evidence that alongside numerous individual-level socio-economic, psychosocial, behavioral, psychological, physical, and biological factors, environmental factors contribute to the multifaceted aetiology of mental health (Diez Roux and Mair, 2010). The impact of the environment on mental health is present at all stages of life and has been shown to accumulate across the life course (Pearce et al., 2018). The environment is of particular importance later in life as older adults tend to spend more time in their area of residence due to physical morbidity and disability (Büchtemann et al., 2012) and becoming pensioned (Seifert and König, 2019). Objective

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neighbourhood data can be used as estimators of the social and the physical environment to identify characteristics that increase the risk of mental health problems and those that promote good mental health.

A large part of the research on neighbourhoods and mental health in later adulthood is focused on depressive symptoms in relation to neighbourhood socio-economic status (SES) and demographic characteristics and, to a lesser extent, on neighbourhood social and physical characteristics. An earlier review reported that 25% of 81 neighbourhood demographic and socio-economic characteristics investigated remained significantly associated with depressed mood in older adults after adjustment for individual-level variables (Julien et al., 2012). A recent meta-analysis found a robust association between neighbourhood SES and possible depression in older adults (Barnett et al., 2018). However, regarding the second most studied environmental characteristic, urban density, a null association with depressive symptoms was found. Additional robust associations identified in this review were for personal-/crime-related safety and air pollution. Furthermore, a meta-analysis of ambient air pollution and depression in adults did not find an association, except for short-term nitrogen dioxide exposure (Fan et al., 2019). Regarding social environment characteristics, although the review by Barnett et al. did not find an association with social connectedness, a meta-analysis of individuals 50 years of age and older found a positive association between a lack of social cohesion and depression (Baranyi et al., 2020). The evidence is also inconsistent regarding green space as some studies reported a protective effect of green space on depression (Banay et al., 2019; Perrino et al., 2019), yet other studies did not find an association (Noordzij et al., 2021; Pun et al., 2018). In sum, although several reviews and meta-analyses summarize the association between environment characteristics and depression, the evidence remains mixed.

Several neighbourhood characteristics pertaining to the physical and the social environment have been shown to be associated with anxiety in several adult studies (Generaal et al., 2019a; Zijlema et al., 2015) and meta-analyses (Baranyi et al., 2021; Braithwaite et al., 2019; Lan et al., 2020). In older adults, there are only a few studies investigating possible environmental determinants of anxiety. A large British study assessing the longitudinal association between urban density and anxiety in adults over 75 showed that those living in areas of high urban density have a higher risk of anxiety (Walters et al., 2004). Additionally, an association between air pollution and anxiety symptoms has also been reported in older adults (Pun et al., 2017). One study investigating the onset of anxiety in 35–74 year olds, found an association with noise nuisance (Beutel et al., 2020). Anxiety has mostly been investigated in relation to physical environment characteristics, and with the exception of crime, there is a lack of studies investigating neighbourhood characteristics pertaining to the demographic, socio-economic and social domains in relation to anxiety in older adults. For example, social cohesion, pertaining to the social domain, is an emerging important characteristic that has been linked to depression but no studies investigating the impact of objectively collected social cohesion on anxiety have been conducted to our knowledge. Depression and anxiety are often comorbid, therefore there is a need for further studies which examine both outcomes simultaneously for a clearer picture of mental health and place.

Although there are indications of an impact of environmental characteristics on symptoms of depression and, to a lesser extent, anxiety, the evidence is mixed, and it is unclear on two important issues when considering older adults. The first issue is their prospective, long-term association. Most of the evidence regarding the impact of the environment comes from cross-sectional studies. There is a need for longitudinal studies to clarify to what extent neighbourhood characteristics have a causal effect on mental health outcomes and investigate the causal pathways underlying the observed effects in old age. A first step is conducting a prospective study, such as examining the onset of mental health outcomes. A study investigating the incidence of depression and anxiety provides an opportunity to investigate the longitudinal association with exposure to the neighbourhood environment, helping to rule out reverse causation. Furthermore, although there are a few studies on the onset of mental health outcomes in adults (e.g. Galea et al., 2007), it is imperative to investigate incidence in older adults. The associations in older age might differ given the characteristics of this group (e.g. older people may have different symptoms than younger people (Christensen et al., 1999)) and individual risk factors (Beekman et al., 2000). Only a few studies have examined the link between environmental determinants and the onset of depression and anxiety in old age. These were conducted in older women (Banay et al., 2019; Kioumourtzoglou et al., 2017) and in adults 18–79 years of age (Kim et al., 2016) regarding depression, and in older adults and adults 35–74 years of age (Pun et al., 2017; Beutel et al., 2020) regarding anxiety. Secondly, given that a neighbourhood is characterized by both its physical and its social environment (Diez Roux and Mair, 2010), neighbourhood measures can be thought of as belonging to the socio-economic, demographic, physical or social domains. Investigating the impact of multiple domains of neighbourhood characteristics on mental health outcomes, as opposed to a single aspect, avoids the possible pitfall that investigating only one domain may lead to an insufficient understanding of the importance of others. Given that almost half of the adults over the age of 65 which suffer of depression have comorbid anxiety (Aartjan et al., 2000), examining the onset of depression and anxiety in the same sample, in relation to neighbourhood characteristics that span several domains, can further detangle the impact of environment on mental health.

This study aimed to examine the association of multiple objectively measured neighbourhood environment characteristics with the 10-year incidence of depression and anxiety in older adults in the Netherlands. For this study, we enriched Longitudinal Aging Study Amsterdam (LASA) with neighbourhood data pertaining to the demographic, socio-economic, social and physical environment domains. In particular, we investigated the following neighbourhood characteristics: urban density, percent population over 65 years of age, percent immigrants, average house price, average income, percent low-income earners, social security beneficiaries, social cohesion, safety, proximity to retail facilities, housing quality, percent green space, percent water coverage, air pollution, and traffic noise.

2. Methods

2.1. Sample

We used data from two LASA cohorts covering the period 2005–2016. LASA sampling details, data collection and attrition are described in detail elsewhere (Huisman et al., 2011; Hoogendijk et al., 2020). Briefly, LASA is a nationally representative, longitudinal study on the physical, emotional, cognitive, and social functioning of older adults in the Netherlands. It was established in 1992 and is still ongoing. LASA data are collected by trained interviewers in a face-to-face main interview and in a separate medical interview, including clinical tests, in the home of the respondents. LASA participants were selected from three different regions of the Netherlands: the secularized western part, the mainly protestant northeast and the dominantly catholic south. The sample was selected from 11 municipalities located in and around the cities of Amsterdam, Oss and Zwolle. These regions contained urbanized and rural areas and were sampled to derive a nationally representative sample of Dutch older adults (Huisman et al., 2011). The first cohort was initiated in 1992 (n = 3107) and followed up about every 3 years. A second cohort was recruited in 2002 (n = 1002) using the same sampling procedure and sampling frame, face-to-face interviews and self-administered questionnaires. The first cohort was comprised of participants who were 55–85 years old at baseline, born between 1908 and 1937. The second cohort was comprised of participants who were 55–64 years old at baseline, born between 1938 and 1947. The LASA study was approved by the Ethical Review Board of the VU University

Medical Center and all respondents provided informed consent.

2.2. Incidence of depression and anxiety

Depressive symptoms were measured with the Center for Epidemiologic Studies Depression Scale (CES-D) (Radloff, 1977). Anxiety symptoms were measured with the Anxiety subscale of the Hospital Anxiety and Depression Scale (HADS-A) (Zigmond and Snaith, 1983). A cut-off score of 16 or more identified individuals at risk with clinical depression and a cut-off score of 8 points or higher identified anxious participants (Bjelland et al., 2002). The specific scale cut-off points were used to identify and exclude depressed and anxious participants from the baseline sample. The identification of incident cases was established as a score surpassing the established cut-off point and a clinically relevant increase in the score between subsequent assessments and baseline. This was operationalized as 0.5 times the standard deviation of the average score at baseline (Norman et al., 2003). Therefore a participant with a CES-D score higher or equal to 16 on one of the follow-up measurements and a change of 4 points or more between baseline and follow-up score was classified as having depression. An individual with anxiety was identified based on a HADS-A score higher or equal to 8, in addition to a change of 2 points or more between the baseline and the follow-up measurement.

2.3. Study sample

For our study, we selected the 2005/2006 wave (n = 2165) as the baseline, because this was the first wave in which both Cohort 1 and Cohort 2 were simultaneously assessed, providing a large sample with a large age range (Supplementary Fig. 1). In order to study incidence, we selected LASA participants who were not depressed or anxious at baseline, following them over ten years. The ages of the participants at baseline ranged from 57 to 97 years of age, capturing various stages of later life. Follow-up incidence data was obtained for the three subsequent waves, in 2008/2009, 2011/2012 and 2015/2016. In order to generate the depression subsample, we excluded 132 respondents with missing outcome data at the 2005/2006 wave and 312 depressed respondents (identified via a clinically relevant cut-off score), generating a sample consisting of non-depressed respondents. A further 263 participants who had missing depression data across the three subsequent waves, and 93 participants missing data on covariates, were excluded. The result was a baseline sample of 1365 participants without depression. The anxiety subsample was generated in the same manner, excluding the following number of participants: 264 with missing data on anxiety at the 2005/2006 wave, 185 anxious individuals, 283 without available data on the three subsequent waves analyzed, and 13 missing data on covariates. This resulted in a baseline sample of 1420 participants without anxiety. To calculate correlations between neighbourhood characteristics, we generated a sample of participants with at least one outcome measurement and at least one neighbourhood characteristic available (n range: 1478 to 1540).

2.4. Social and physical neighbourhood characteristics

Objective neighbourhood data for approximately all neighbourhoods in the Netherlands was made available by the Geoscience and Health Cohort Consortium (GECCO) project (Timmermans et al., 2018; Lakerveld et al., 2020). We selected neighbourhood characteristics based on earlier publications with the aim to examine a broad range of characteristics (Generaal et al., 2019a, Generaal et al., 2019b). We investigated the following neighbourhood characteristics pertaining to the demographic domain: urban density, percent population over 65 years of age, and percent immigrants. Socio-economic domain neighbourhood characteristics assessed were: neighbourhood socioeconomic position (SEP) index (NSEP), average house price, average income, percent low-income earners, and social security beneficiaries per 1000 homes. Four indicators of the Dutch 'livability score' (Leefbaarometer) (Leidelmeijer et al., 2008): social cohesion, safety score, proximity to retail facilities score, and housing quality score, were included in the analysis as social environment domain measures. Data on NSEP index was retrieved at the 4-digit postal code area-level. Data on urban density, percent population over 65 years of age, percent immigrants, average house price, average income per resident, percent low-income earners, social securities beneficiaries, social cohesion, safety score, proximity to retail facilities score and housing quality score were retrieved at the neighbourhood-level. Physical environment domain characteristics: percent green, percent water coverage, air pollution, and noise, were aggregated to mean values of the 4-digit postal code. In the Netherlands, 4-digit postal code areas (average area size: 8.3 km^2) and neighbourhoods (average area size: 3.1 km^2) are administrative areas. These areas include, on average, approximately 1870 and 630 households, respectively (Timmermans et al., 2018).

Urban density was operationalized as the average number of addresses per square km (km^2), within a circle with a radius of 1 km around the individual's residence. It is classified into five categories: not urbanized (<500 addresses/km^2), hardly urbanized (500–1000 addresses/km^2), moderately urbanized (1000–1500 addresses/km^2), strongly urbanized (1500–2500 addresses/km^2) and extremely urbanized (≥2500 addresses/km^2). Percent population over 65 is the proportion of residents over 65 years of age living in the neighbourhood. Percent immigrants in the neighbourhood was calculated as the number of Western and non-Western immigrants expressed as whole percentages of the residents in the neighbourhood. An immigrant is defined as someone who has at least one parent born abroad, whereas an individual both of whose parents were born in the Netherlands is considered Dutch. These data on the neighbourhood demographic characteristics were obtained from Statistics Netherlands for the year 2005 (CBS. Statistics Netherlands, 2005).

The NSEP index was composed using factor analysis based on the educational level, income, and labor market position of inhabitants within the 4-digit postal code area. This data was obtained for 2005 from the Netherlands Institute of Social Research (Knol, 1998). A lower NSEP index indicates a lower neighbourhood position. The average income in the neighbourhood was operationalized as the average disposable income (the total income of an individual, reduced by paid insurance premiums and taxes) per person, for the previous year, per neighbourhood. Percent low-income earners in the neighbourhood was devised as the percent of income recipients earning less than 40% point of the national income distribution (13,000 euros) over a 52 week period of income earning. The average house price indicates the mean dwelling (main residence, homes with practice space and recreational homes) value per neighbourhood. The social security beneficiaries measure was defined as the number of persons receiving benefits per 1000 people, in the neighbourhood. These four measures were obtained from Statistics Netherlands for the year 2005 (CBS. Statistics Netherlands, 2005).

The four measures of neighbourhood social environment have been developed by the Netherlands Ministry of the Interior and Kingdom Relations as part of the assessment of neighbourhood livability, the 2008 Leefbaarometer (Leidelmeijer et al., 2008). The social cohesion score is based on 11 indicators of various types of family composition (the prevalence of: couples with young children, older couples without children, young singles, middle-age singles, the proportion of elderly residents and of families with children, the homogeneity of families with older children and of families with young children), prevalence of owner occupants, and relocation rates. The safety score is composed of five indicators: nuisance, car thefts, (property) destruction, violent crime and disturbance of public order. The proximity to retail facilities measure was composed of three indicators: the concentration of supermarkets, shopping centers and banks. A housing quality score was composed of 13 indicators of housing quality including the year it was built, presence of gardens and other housing characteristics. Each indicator was included in the overall measure with a positive or negative

consequence (e.g. flats taller than 4 stories would be a deleterious addition to the house score), and each score ranges from −50 to 50.

Percent green space is a measure of the proportion of the area covered by green space defined as recreation areas, such as parks, agricultural land and forest/nature. Percent water coverage is a measure of the proportion of the total land, of the neighbourhood, covered in water including inland water, sea and lakes. These two measures were calculated using an overlay operation in a standard GIS-package (ArcMap version 10.4) that involved land-use data and neighbourhood delineations from Statistics Netherlands. This study used percent green space and percent water coverage data from 2006 (CBS. Statistics Netherlands, 2006). Traffic noise in the neighbourhood was measured as the daily mean noise of road, rail, and air traffic, in decibels, and averaged over a 24 h period. This data was modeled by the Netherlands Environmental Assessment Agency by using the Empara Noisetool with a resolution of 25 by 25 m (PBL, 2000). In this study, we used data from 2007. Air pollution was calculated as the annual average concentration of the mean blackness of particulate matter ≤2.5 μm in aerodynamic diameter (PM2.5), at the respondent's home address. These values were calculated by the Institute for Risk Assessment Sciences as part of the European Study of Cohorts for Air Pollution Effects (ESCAPE-project) using land-use regression models for the year 2009. This data is described in detail elsewhere (Eeftens et al., 2012).

2.5. Covariates

The covariates, age, sex, years of education, and household income (in categories), were collected at the individual level and described previously (). An additional covariate, the number of years in the neighbourhood, was collected via the 2005/2006 questionnaire. We did not include ethnicity as a covariate since approximately 99% of the sample self-identified as Dutch, at baseline.

2.6. Statistical analyses

Pairwise correlations were calculated for the neighbourhood characteristics. Individual-level variables and baseline neighbourhood characteristics were described per the depression and anxiety subsamples separately. We used a Cox regression, with a cluster on the 4-digit postal code or the neighbourhood, to obtain hazard ratios (HR) and the number of cases for the two outcomes assessed. Each neighbourhood characteristic was modeled separately because of high correlations between neighbourhood characteristics (Table 1). The time-to-event was defined as the mid-point of the interval between the two waves in which it occurred. Deceased participants and participants who dropped out were censored and the time-to-event was calculated in the same manner. Neighbourhood characteristics were entered into the model as Z-scores. The proportional of hazard assumption was checked by plotting Schoenfeld residuals and checking the trend over time (Therneau and Grambsch, 2000). All analyses were performed in STATA 14. Associations were considered to be statistically significant at $p \leq 0.05$.

3. Results

Less than 15% of the correlations among neighbourhood characteristics were strong ($r \geq 0.70$), indicating that the neighbourhood characteristics investigated cover a wide, non-overlapping range of environment indicators (Table 1). Urban density was the characteristic with the most strong correlations; approximately half of the participants lived in higher density neighbourhoods (over 1000 addresses per square kilometer (/km^2)). Higher urban density was correlated with percent immigrants, social security beneficiaries, lower safety score, proximity to retail facilities score, lower housing quality score, and air pollution (r range: 0.64 to 0.74). The strongest correlations were between percent immigrants and the following: social security beneficiaries, safety score, and housing quality score (r range: −0.80 to 0.87).

Baseline individual-level characteristics of the participants and neighbourhood characteristics in the depression and the anxiety subsamples are similar (Table 2). The average age of the participants was 70 years. Participants lived on average 25 years in their neighbourhood (standard deviation = 16.7). At baseline, the average CES-D score was 5.7, and the average HADS-D score was 2.3, in each separate subsample. Over 10,716 person-years, 213 depression cases emerged with an event rate of 19.9 per 1000 person-years. Over 11,157 person-years, 147 anxiety cases emerged with an event rate of 13.2 per 1000 person-years. Supplementary Table (ST) 1 presents summaries of individual characteristics at the baseline of cases versus non-cases. There were 74 participants developed both outcomes.

Point estimates mainly indicate small associations between neighbourhood characteristics and incident depression, and there was no statistically significant evidence for these associations (Table 3). Neighbourhood characteristics were not associated with the incidence of depression in models adjusted for age, sex, education, income and number of years in the neighbourhood (Table 3) or in univariate models (Model 1 in ST 2). The highest urban density level was moderately associated with depression incidence (hazard ratio (HR) = 1.46), however, the confidence interval (CI) of the association showed that both a small negative association (lower limit = 0.91) and a substantial positive association (upper limit = 2.33) in the population were compatible with the data.

The rates of incidence and HRs for anxiety are presented in Table 4. The two highest levels of urban density (more than 1500 addresses/km^2), were associated with an increased incidence of anxiety (HR (L4: 1500 to < 2500 addresses/km^2) = 2.10; 95% CI = 1.10, 4.01 and HR (L5: >2500 addresses/km^2) = 2.08, 95% CI = 1.12, 3.88) compared to living in neighbourhoods of 500 addresses/km^2 or less. An increased incidence of anxiety was associated with percent immigrants (HR = 1.21, 95% CI = 1.03, 1.43), proximity to retail facilities score (HR = 1.26, 95% CI = 1.08, 1.46), and air pollution (HR = 1.20, 95% CI = 1.03, 1.40), over 10 years. A decreased risk of anxiety was associated with safety score (HR = 0.82, 95% CI = 0.70, 0.97), housing quality score (HR = 0.80, 95% CI = 0.67, 0.95) and percent green (HR = 0.76 95% CI = 0.65,0.89). The magnitude of the HRs, and the 95% CIs, of the neighbourhood characteristics associated with anxiety were similar in the univariate model and the sex and age adjusted model, and also in the fully adjusted model (shown as Model 3 in ST 3).

4. Discussion

We examined the prospective association between multiple neighbourhood characteristics, pertaining to socio-economic, demographic, physical, and social domains, and the onset of depression and anxiety, in older adults. Results revealed that several neighbourhood characteristics were associated with incident anxiety, but none were associated with incident depression. Living in neighbourhoods characterized by higher urban density, percent immigrants, proximity to retail facilities and air pollution was associated with a higher risk of incident anxiety. On the other hand, living in neighbourhoods with higher safety and housing quality scores, and more green space, was associated with a lower risk of incident anxiety. Living in urban dense areas increased the risk of incident anxiety by about twice compared to those living in the least urban dense areas. The associations between these seven neighbourhood characteristics and incident anxiety were significant in both the crude and the individual-level SEP adjusted models. The HRs were approximately the same in both models, indicating that these neighbourhood characteristics influence the risk of anxiety onset beyond the influence of individual characteristics. This incidence study gives insight into possible environmental factors affecting the incidence of anxiety by positioning the exposure to precede the onset of anxiety. Unlike a cross-sectional study, it minimizes the risk of selection bias and reduces reverse causality.

Table 1
Pairwise correlation coefficients of neighbourhood characteristics for LASA sample that includes participants with data available for at least one outcome (n range: 1478 to 1540).

				1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
	L1: <500		14%															
	L2: 500 to <1000		35%															
1. Urban density, addresses/km2 (n = 1539)	L3: 1000 to<1500		5%															
	L4: 1500 to<2500		25%															
	L5: >2500		21%															
	Mean	**SD**	**Range**															
2. % Population over 65 (n = 1520)	14.5	7.7	1–69	0.22														
3. % Immigrants (n = 1520)	19.5	18.0	0–87	0.70	0.04													
4. Neighbourhood SEP index (n = 1530)	0.04	0.9	−4.7 – 2.6	−0.48	−0.05	−0.70												
5. Average house price, [1000 euros](n = 1520)	213.1	70.6	88–553	−0.37	−0.11	−0.32	0.51											
6. Average income per resident, [1000 euros] (n = 1478)	12.2	1.9	8–23	0.18	0.28	−0.03	0.33	0.46										
7. % Low-income earners (n = 1478)	39.6	5.5	21–56	−0.10	0.03	−0.02	−0.31	−0.49	−0.64									
8. Social security beneficiaries [/1000 homes] (n = 1492)	40.0	41	0–253	0.64	0.04	0.87	−0.81	−0.47	−0.20	0.19								
9. Social cohesion score (n = 1537)	2.0	13.2	−32.7–46.0	−0.37	0.32	−0.40	0.37	0.23	0.02	0.00	−0.46							
10. Safety score (n = 1537)	3.5	28.4	−49.9–46.4	−0.71	−0.11	−0.81	0.63	0.23	−0.15	0.02	−0.73	0.52						
11. Proximity to retail facilities score (n = 1537)	−2.5	24.2	−41.7–48.7	0.70	0.20	0.56	−0.43	−0.14	0.28	−0.08	0.45	−0.41	−0.71					
12. Housing quality score (n = 1537)	−2.1	27.4	−49.0–49.5	−0.74	−0.25	−0.80	0.69	0.39	−0.10	0.05	−0.73	0.37	0.81	−0.64				
13. % Green space (n = 1512)	57.3	37.0	0–98.8	−0.57	−0.20	−0.49	0.44	0.15	−0.11	−0.04	−0.42	0.22	0.71	−0.65	0.62			
14. % Water coverage (n = 1512)	5.1	6.8	0–58.7	0.22	−0.05	0.23	−0.12	0.14	0.13	−0.26	0.12	−0.02	−0.34	0.12	−0.28	−0.35		
15. Air pollution: PM2.5 absorbance (10–5/m) (n = 1539)	1.2	0.2	0.9–2.0	0.73	0.12	0.66	−0.37	−0.02	0.32	−0.17	0.51	−0.33	−0.71	0.74	−0.59	−0.58	0.24	
16. Traffic noise (Lden in dB/24 h) (n = 1539)	53.2	3.3	36.0–64.1	0.47	0.20	0.53	−0.29	0.01	0.26	−0.23	0.40	−0.15	−0.53	0.50	−0.50	−0.38	0.31	0.67

Abbreviations:/km^2 refers to per square kilometer. SEP refers to socio-economic position. PM refers to particulate matter. Lden refers to level day-evening-night. dB refers to decibels.

Table 2
Baseline characteristics of the depression and the anxiety samples.

	Depression Sample	Anxiety Sample
Baseline sample n	1365	1420
Person-level sociodemographic factors		
Age [years], mean (SD), range	70.0 (8.4) 57-97	70.2 (8.6) 57-97
Women, %	52.4	53.4
Education [years], mean (SD)	10.1 (3.4)	10.1 (3.4)
Income (household) [€ net/month], mean (SD)	1537.4 (690.2)	1520.0 (697.5)
Number of years in the neighbourhood, mean (SD), range	25.6 (16.7), 0 - 91	25.3 (16.7), 0 - 91
Neighbourhood characteristics		
Urban density		
L1: <500 addresses/km^2, %	14.3	13.7
L2: 500 to <1000 addresses/km^2, %	34.4	34.7
L3: 1000 to<1500 addresses/km^2, %	5.9	5.1
L4: 1500 to <2500 addresses/km^2,%	25	25.5
L5: >2500 addresses/km^2, %	20.4	21.1
% Population over 65, mean (SD), range	14.3 (7.5), 1 - 69	14.4 (7.6), 1 - 69
% Immigrants, mean (SD), range	19.3 (17.7), 0 - 87	19.4 (17.9), 0 - 87
Neighbourhood SEP index, mean (SD), range	0.07 (0.9), −4.8 - 2.6	0.05 (0.9), −4.8 - 2.6
Average house price [1000 euros], mean (SD), range	214.4 (71.8), 88 - 673	213.6 (71.0), 88 - 553
Average income per resident [1000 euros], mean (SD), range	12.3 (2.0), 8 - 23	12.3 (2.0), 8 - 23
% Low-income earners, mean (SD), range	39.4 (5.6), 21 - 56	39.5 (5.6), 21 - 54
Social security beneficiaries [/1000 homes], mean (SD), range	39.0 (40.1), 0 - 253	39.4 (40.6), 0 - 253
Social cohesion score, mean (SD), range	1.8(12.9), −47.7 - 46.0	2.0(12.9), −32.7 - 47.5
Safety score, mean (SD), range	3.9 (28.1), −49.9 - 46.4	3.9 (28.1), −49.9 - 46.4
Proximity to retail facilities score, mean (SD), range	−2.8 (23.9), −41.7 - 48.7	−2.5 (24.2), −41.7 - 48.7
Housing quality score, mean (SD), range	−1.8 (27.1), −49.0 - 49.4	−2.1 (27.2), −49.0 - 49.4
% Green space, mean (SD), range	58.5 (36.9), 0–98.8	57.1 (37.3), 0–98.8
% Water, mean (SD), range	5.1 (6.8), 0–58.7	5.3 (7.2), 0–58.7
Air pollution [$PM_{2.5}$ absorbance (10^{-5}/m)], mean (SD), range	1.2 (0.2), 0.86–1.9	1.2 (0.2), 0.86–1.9
Traffic noise [Lden in dB/24 h], mean (SD), range	53.2 (3.3), 36.0–64.1	51.9 (3.1), 34.5–61.9
Depression Incidence		
Baseline depressive symptoms, mean CES-D score (SD), range	5.7 (4.2), 0-15	
Depressed cases (over 9 years)	213	
Person-years	10,716	
Event rate per 1000 person-years	19.9	
Anxiety Incidence		
Baseline anxiety symptoms, mean HADS-A score (SD), range		2.3 (2.1), 0-7
Anxiety cases (over 9 years)		147
Person-years		11,157
Event rate per 1000 person-years		13.2

Incidence rate is the number of events per 1000 person years.

Although urban density is forthrightly operationalized in our study as the number of addresses/km^2, as an environmental determinant, it is a fuzzy and complex measure. Higher urban density has been shown to be associated with the prevalence of anxiety in older adults in two studies (Walters et al., 2004). In working-age adults, a meta-analysis of 20 population studies found a higher prevalence of anxiety disorders in urban areas versus rural area. (Peen et al., 2010). Compared to low dense areas, urban dense neighbourhoods are characterized by varying, and often detrimental, physical (e.g. increased noise from traffic) and social (e.g. concentration of low-income residents) attributes (Ventimiglia and Seedat, 2019). Additional adverse factors found in highly dense areas include higher air pollution, lack of green space and selective migration (e.g. persons with poorer mental health move to worse-off neighbourhoods) (Krabbendam et al., 2021). The accumulation of these risk factors may lead to anxiogenic environments that are likely to alter biological stress-regulation pathways, e.g. higher amygdala activation and deregulation of the mesolimbic dopamine and limbic systems (Ventimiglia and Seedat, 2019). In our sample, urban density was strongly correlated ($r \geq 0.7$) with five other neighbourhood characteristics that were also associated with an increased risk of anxiety: percent immigrants, safety score, housing quality score, proximity to retail facilities score, and air pollution. Urban density is a result of social, economic, and urban planning policies and, thus is most likely a determinant of these neighbourhood characteristics. Percent immigrants is a likewise multifaceted neighbourhood characteristic. In the Netherlands, a large proportion of immigrants are second-generation immigrants (Stronks et al., 2009), and likely born in the same neighbourhood they reside in (Bolt and van Kempen, 2003). Our investigating was conducted in a sample composed of native Dutch older participants. In earlier work we presented the 'group conflict theory' as a possible explanation for the link between this measure and anxiety (). This theory postulates that in ethically heterogeneous neighbourhoods, anti-immigration feelings and ethnic prejudice could arise as a result of a defensive reaction to perceived or real intergroup competition over scarce resources, such as housing (Cea D'Ancona, 2018). It would lead to negative attitudes towards immigrants, particularly in retired residents (Tulin et al., 2021). The finding regarding incident anxiety in our sample of native Dutch participants might be picking up on this social tension. Participants living in neighbourhoods with lower safety scores, an objective measure of crime in the neighbourhood, had a higher risk of developing anxiety. Crime in the neighbourhood impacts mental health in direct and indirect ways (Lorenc et al., 2012), including exposing individuals to increased social stress, causing systematic inflammation in the body, lower physical activity, and engaging in maladaptive coping strategies (Baranyi et al., 2021). Although higher scores for proximity to retail services and housing quality are positive attributes of the 'Livability score' of Dutch neighbourhoods (Leidelmeijer et al., 2008), their associations with the risk of incident anxiety differs in direction. It is not surprising that living closer to shopping centers, supermarkets, and banks is a risk for onset anxiety as this measure is a proxy for higher urban density. On the other hand, the lower housing quality score indicates the quality of the homes in the neighbourhood based on their surroundings and built properties, pointing to anxiogenic living conditions such as crowding (Lancee and Pardos-Prado, 2013). Green space has been established as a health-promoting characteristic of the neighbourhood environment and it could be protective of anxiety onset via several pathways such as stress reduction, improved social cohesion, and increasing physical activity (Dadvand et al., 2019; Beyer et al., 2014). An increased amount of green space, sometimes operationalized as the amount of parks and nature, has been reported to be associated with less anxiety in older adults (Pun et al., 2018; Bustamante et al., 2022). Possible pathways linking air pollution to anxiety are neuroinflammation, oxidative stress, cerebrovascular damage, and neurodegeneration (Braithwaite et al., 2019). Fine particulate matter has been shown to be associated with incident moderate-to-severe anxiety symptoms in older adults (Pun et al., 2017). An additional important finding of this study is that neither of the SES neighbourhood characteristics nor social cohesion was associated with incident anxiety. In line with our findings, a previous study showed that older adults living in the most socio-economically deprived areas were not at a higher risk of increasing symptoms of anxiety (Walters et al., 2004). Having checked the impact of five separate measures of neighbourhood SES characteristics, a comprehensive investigation, we could conclude that it is possible that neighbourhood SES is not causally linked to anxiety incidence. Analyses in larger samples with more variation in the exposure data are needed to clarify this further.

Contrary to expectations, we did not find a significant association between neighbourhood characteristics and incident depression. In a previous LASA study, urban density and percent immigrants were associated with depressive symptoms (). Using the same environmental

Table 3
Adjusted HRs for incidence of depression as predicted by baseline neighbourhood characteristics.

					Fully adjusted model		
	n	No. of events	Person time	IR[a]	HR	95% CI	
Neighbourhood Demographic Characteristics							
Urban density	1365	213	10.71	19.87			
L1: (lowest)					1 (Ref)		
L2:					1.27	0.85	1.91
L3:					1.06	0.59	1.90
L4:					1.37	0.87	2.17
L5: (highest)					1.46	0.91	2.33
% Population over 65	1348	212	10.56	20.00	0.99	0.84	1.17
% Immigrants	1348	212	10.56	20.00	1.09	0.97	1.23
Neighbourhood Socio-economic Characteristics							
Neighbourhood SEP index	1358	212	10.65	19.89	0.92	0.80	1.05
Average house price	1348	212	10.56	20.00	1.05	0.91	1.22
Average income per resident	1309	206	10.23	20.12	1.07	0.93	1.23
% Low-income earners	1309	206	10.23	20.12	0.96	0.84	1.11
Social security beneficiaries	1323	209	10.35	20.17	1.05	0.93	1.18
Neighbourhood Social Environment Characteristics							
Social cohesion score	1363	213	10.70	19.90	0.95	0.82	1.09
Safety score	1364	213	10.70	19.90	0.94	0.83	1.07
Proximity to retail facilities score	1367	213	10.70	19.90	1.08	0.96	1.22
Housing quality score	1368	213	10.70	19.90	0.94	0.83	1.08
Neighbourhood Physical Environment Characteristics							
% Green space	1340	204	10.55	19.33	0.93	0.82	1.04
% Water	1340	204	10.47	19.48	0.90	0.79	1.03
Air pollution	1365	213	10.71	19.88	1.08	0.95	1.23
Traffic noise	1365	213	10.71	19.88	1.09	0.95	1.26

Model 1: Null model; Model 2: Model 1 including age and sex; Model 3: Fully adjusted model (includes sex, age, education, income, number of years in neighbourhood). IR refers to incidence rate, the number of events per 1000 person years.

Table 4
Adjusted HRs for incidence anxiety as predicted by baseline neighbourhood characteristics.

					Fully adjusted model		
	n	No. of events	Person time	IR[a]	HR	95% CI	
***Neighbourhood**Demographic Characteristics*							
Urban density	1420	147	11.16	13.17			
L1: (lowest)					1 (Ref)		
L2:					1.47	0.79	2.75
L3:					1.60	0.50	5.08
L4:					**2.10**	**1.10**	**4.01**
L5: (highest)					**2.08**	**1.12**	**3.88**
% Population over 65	1404	147	11.01	13.35	1.08	0.90	1.30
% Immigrants	1404	147	11.01	13.35	**1.21**	**1.03**	**1.43**
Neighbourhood Socio-economic Characteristics							
Neighbourhood SEP index	1413	145	11.11	13.05	0.93	0.79	1.10
Average house price	1404	147	11.01	13.35	1.04	0.84	1.27
Average income per resident	1364	142	10.69	13.28	1.10	0.94	1.30
% Low-income earners	1364	142	10.69	13.28	0.96	0.78	1.19
Social security beneficiaries	1379	146	10.80	13.51	1.09	0.92	1.31
Neighbourhood Social Environment Characteristics							
Social cohesion score	1418	147	11.14	13.19	0.90	0.72	1.12
Safety score	1418	147	11.14	13.19	**0.82**	**0.70**	**0.97**
Proximity to retail facilities score	1418	147	11.14	13.19	**1.26**	**1.08**	**1.46**
Housing quality score	1418	147	11.14	13.19	**0.80**	**0.67**	**0.95**
Neighbourhood Physical Environment Characteristics							
% Green space	1397	141	11.00	12.82	**0.76**	**0.65**	**0.89**
% Water	1397	141	11.00	12.82	1.11	0.87	1.42
Air pollution	1420	147	11.16	13.17	**1.20**	**1.03**	**1.40**
Traffic noise	1420	147	11.16	13.17	1.10	0.93	1.31

Model 1: Null model; Model 2: Model 1 including age and sex; Model 3: Fully adjusted model (includes sex, age, education, income, number of years in neighbourhood). IR refers to incidence rate, the number of events per 1000 person years. Results in bold ($p \leq 0.05$) are regarded as statistically significant.

data, a large pooled analysis of eight Dutch cohorts found an association between higher urban density, lower NSEP, a higher number of social security beneficiaries, a higher percentage of non-Dutch residents, higher levels of air pollution, less green space, and lower safety score and depressive symptoms (Generaal et al., 2019b). However this analysis was cross-sectional and since both the prevalence of depression and neighbourhood characteristics are dynamic, perhaps only a snapshot of the association was captured. Cross-sectional associations may also not reflect the effects of neighbourhood exposures on depression from earlier in the life-course, or selection effects of people who are mentally vulnerable moving to worse-off neighbourhoods (Pearce et al., 2018). Regarding incidence of depression studies in old age, the risk of the onset of depression was associated with greenness and air pollution, in older women (Banay et al., 2019), and with air pollution in adults 15–79 years

of age. Although neighbourhood SES has been extensively studied in relation to depression, a systematic review revealed that the effects of neighbourhood SES reported in studies spanning five years or less were significant, but not in studies conducted over five years and longer (Richardson et al., 2015). Therefore it could be possible that neighbourhood SES characteristics do not have a longitudinal (causal) effect, on depression, and thus could explain our null-findings regarding incident depression.

There could be several explanations for finding risk factors for anxiety incidence but not for depression incidence. Although there is high comorbidity and symptom overlap between depression and anxiety (Penninx et al., 2021), these outcomes have different individual-level factors, e.g. biological factors may be more important in predicting depression at older age (Kvaal et al., 2008; Vink et al., 2008). In a cross-sectional study of Dutch adults, using the same exposures as in this study, anxiety disorder was associated with several neighbourhood socio-economic characteristics, social cohesion and safety, and traffic noise (Generaal et al., 2019a). Furthermore, anxiety disorder, but not depression, was associated with more air pollution, less green space, and more water in the neighbourhood. Our diversified findings are in line with the idea that depression may be more strongly related to loss, whereas anxiety may result from current and future threats (Eysenck et al., 2006).

Observational studies are not a sufficient basis for public health policy and findings need to be tested in intervention studies or, as a minimum, in quasi-experimental studies. Regarding our findings, more research is needed in order to clarify and replicate the pathways between the seven significant characteristics and the onset of anxiety and to confirm results. Additionally, the neighbourhood characteristics must be assessed in regards to how modifiable they are. Identifying and improving modifiable neighbourhood characteristics related to the development of mental health outcomes in older age may offer part of a solution to the current and future public health issues caused by growing global urban populations. For example, a study showed that moving to greener urban areas was associated with sustained mental health improvements, suggesting that environmental policies to increase urban green space may have sustainable public health benefits (Alcock et al., 2014). Although urban environments may serve as root causes of mental health (Galea, 2011) they are shaped by broader effects which are upstream. These include current, past, and future economic and housing policies which are nationally and culturally dependent. Given the complexity of the pathways between neighbourhood characteristics and mental health outcomes, advancing urban health calls for public health interventions based on results from complexity science (Galea, 2011; van der Wal et al., 2021).

The focal strength of our study is its longitudinal design investigating new cases of depression and anxiety. By measuring incidence, we positioned the neighbourhood characteristic before the occurrence of disease. This reduces both reverse causality and bias due to differential selection into certain neighborhoods, two major issues in cross-sectional studies. Additionally, we adjusted the models for the duration of residence to reduce the impact of selection bias in the neighbourhood (Hedman et al., 2012) and further clarify the impact on the development of mental health outcomes. Thirdly, our investigation was comprehensive. We investigated 16 neighbourhood characteristics, capturing various aspects of the neighbourhood environment using multiple measures. Among possible drawbacks to our study is the delineation of the neighbourhood, as a physical and a social sphere using administrative neighbourhood demarcations. Although older adults spend more time in their neighbourhood, the border of the neighbourhood is a census-imposed boundary. These spatial areas might not overlap with the actual space in which participants conduct their daily activities (Schaefer-McDaniel et al., 2010). Due to variations in patterns of social interactions and mobility, it could be that the neighbourhood data assigned to some participants does not capture the actual exposures. Furthermore, the objectively collected social neighbourhood data that we used might provide compositional rather than contextual information about neighbourhoods (Macintyre et al., 2002). In other words, these measures might say more about the people living in the neighbourhoods and the accumulation of individual risk factors than the neighbourhood context. However the results for anxiety incidence remained stable after adjustment for individual characteristics and clustering at the neighbourhood level was taken into account, giving us more confidence that contextual effects of the neighbourhood were indeed investigated.

In sum, our study found stronger associations between neighbourhood characteristics with the onset of anxiety as compared to the onset of depression. Interventions could be developed that test the potential protective effects of these characteristics, provided that additional studies investigating the onset of depression and anxiety in old age replicate our findings and provide further insight into the causal pathways between neighbourhood characteristics and mental health. Ultimately, public health approaches aimed at addressing the mental health in older adults should take into consideration that policy decisions regarding infrastructural and contextual neighbourhood characteristics will have an impact on mental health of residents, for better or worse. In order to address the challenges of an aging society, we should strive for the integration of public health approaches with social and housing policies.

Contributors

IM conducted the analyses, interpreted the findings, drafted the manuscript and critically revised the manuscript. EH contributed to the conception/design of the study, the methodology and commented on the manuscript. ET contributed to methodology section of the manuscript and reviewed the manuscript. DD, BP, MH contributed to the conception and design of the study, interpreted the findings and commented on the manuscript. All authors approved the final manuscript.

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Declaration of competing interest

None.

Data availability

The data that has been used is confidential.

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Appendix A. Supplementary data

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