Urbanicity and psychotic experiences: Social adversities, isolation and exposure to natural environments predict psychosis

Moana Beyer [a,*], Timothy R. Brick [b], Simone Kühn [a,c]

[a] *Max Planck Institute for Human Development, Lise Meitner Group for Environmental Neuroscience, Lentzeallee 94, Berlin, 14195, Germany*
[b] *Pennsylvania State University, Department of Human Development and Family Studies, 231 Health & Human Development, University Park, 16802, USA*
[c] *University Medical Center Hamburg-Eppendorf, Department of Psychiatry and Psychotherapy, Martinistraße 52, Hamburg, 20251, Germany*

ARTICLE INFO

ABSTRACT

Background: Research has shown that incidence rates of psychotic experiences are higher in urban areas, defined by their population density, and that an increasing number of people move to cities. Thus, it is critical to understand which characteristics of cities drive this association. To date, efforts to explore urban risk have predominantly focused on a few or single preselected candidate factors and clinical populations.
Methods: We aimed to identify the best predictors of psychotic experiences (PE) in a subclinical population, considering 26 factors describing the physical and social environment. Two feature selection models were employed, i.e., a Boruta algorithm, a random forests approach, and an elastic net penalised logistic regression model.
Results: Individual-specific social environment features emerged as the most robust predictors of PE, including childhood adversity, stressful life events, social isolation and low household income. Exposure to natural environments was found to be negatively associated with PE.
Conclusions: Spending more time in residential natural environments could be an actionable target for preventing and treating psychosis.

1. Introduction

In the general population, the lifetime prevalence of psychotic disorders is estimated to be around 3% (Perälä et al., 2007). For psychotic experiences (PEs), including hallucinations, delusions, disorganised thought and psychotic fear, this figure is notably higher: approximately 5.3% of people report psychotic experiences in their lifetime (Linscott & Os, 2012). In cities, the risk of developing psychotic experiences or psychotic disorders, such as schizophrenia, is even more elevated. This association has been consistently observed among individuals who currently reside in (Fett et al., 2019; Gottesman & Gould, 2003; Os et al., 2008b; Sundquist et al., 2004), grew up in (Mortensen et al., 1999; Vassos et al., 2012) or were born in (Laursen & Munk-Olsen, 2007; Mortensen et al., 1999; Solmi et al., 2019) cities. Given the global trend of urbanisation, with projections indicating that 68% of the world's population will reside in urban areas by 2050 (Ritchie & Roser, 2018), it becomes imperative to discern the characteristics of urban settings that play a role in the manifestation of psychosis.

1.1. The role of the physical environment

Cities are typically defined based on population density, which has been consistently linked to higher risks of psychotic experiences (Linscott & Os, 2012; Os et al., 2008a) and psychotic disorders (Os et al., 2008a; Sariaslan et al., 2014). However, the urban risk may not solely stem from living in a densely populated area but is more likely attributed to the cumulative effects of various environmental and social stressors associated with urbanicity (Galea et al., 2011; Rapp et al., 2015).

For instance, a growing body of scientific evidence has shown that limited exposure and access to nature have adverse impacts on mental health (van den Berg, Maas, Verheij, & Groenewegen, 2010; van den Berg et al., 2015; Bratman et al., 2012, 2015; Fong et al., 2018; Gascon et al., 2015; Lee & Maheswaran, 2010; Shanahan et al., 2016). Exposure to nature can be delineated into exposure and access to residential green (vegetation) and blue spaces (water bodies), which have both been found to benefit mental health (Gascon et al., 2015, 2017; Kondo et al., 2018; McCormick, 2017; Völker & Kistemann, 2011) and decrease the risk of psychosis (Chang et al., 2019; Engemann et al., 2018, 2020). A

---

* Corresponding author.
E-mail addresses: beyer@mpib-berlin.mpg.de (M. Beyer), tbrick@psu.edu (T.R. Brick), kuehn@mpib-berlin.mpg.de (S. Kühn).

Danish case registry study observed that low exposure to nature was associated with a 1.5-fold increased risk of developing schizophrenia (Engemann et al., 2018). Furthermore, exposure to nature has been linked to reduced (Engemann et al., 2018; Gidlöf-Gunnarsson & Öhrström, 2007; Nowak et al., 2006) and urbanicity to higher levels of air and noise pollution (Heinz et al., 2013; Kelly et al., 2010). Previous studies on air pollution have predominantly focused on particulate matter (PM), which refers to microscopic particles suspended in the Earth's atmosphere. However, it seems that PM can only partially account for the risk of developing psychosis (Attademo et al., 2017). Another recent review reported no significant association between long-term exposure to $PM_{2.5}$ or PM_{10} and psychosis (Braithwaite et al., 2019). Organic compounds, i.e., oxides of nitrogen (NO_x), particularly nitrogen dioxide (NO_2), were identified as significant modifiers between urban residency and psychotic experiences during adolescence (Newbury et al., 2019). Furthermore, noise pollution has been postulated to have an adverse impact on general health and well-being, similar to the effects of chronic stress (Jariwala et al., 2017).

1.2. The role of the social environment

Access to green spaces and unpolluted areas are associated with various socio-economic factors, including income and housing prices, which may confound the association between mental health risks and residential environments (Adler & Snibbe, 2003; Weich et al., 2002). Likewise, adverse neighbourhood-related socio-environmental factors were associated with higher incidence rates of psychotic disorders (Allardyce et al., 2005; Ivory et al., 2011; Kirkbride et al., 2008; Kirkbride et al., 2007b; Omer et al., 2014; O'Donoghue et al., 2016; Richardson et al., 2018; Sariaslan et al., 2014; Veling et al., 2014; Zammit et al., 2010) and psychotic experiences (Binbay et al., 2023). For example, Bhavsar et al. (2014) reported that crime and educational deprivation were significant predictors of schizophrenia incidence, adjusting for population density and ethnicity. Another study found that increased inequality was associated with a higher incidence of schizophrenia, but only in the most deprived areas (Boydell et al., 2004). Additionally, an elevated incidence of psychotic disorders has been observed among children and adolescents residing in neighbourhoods characterised by low social cohesion and high crime rates (Newbury et al., 2016; Polanczyk et al., 2010).

In contrast, a large-scale study in China found that rural upbringing was linked to increased and not decreased risk for PEs (Wang et al., 2019). In this study, rural areas were characterised by higher levels of social stress and economic deprivation, which, in turn, have been linked to an increased risk of PE (DeVylder et al., 2018). Likewise, urban residency may protect against psychosis due to better healthcare or resource access, particularly in less developed countries (Hou et al., 2018). This may, amongst other reasons, explain why DeVylder et al. (2018) could not find an association between urban residence and psychosis in low and middle-income countries.

1.3. The role of social and sociodemographic factors

Just as social and psychological stress has been linked to one's neighbourhood (Wang et al., 2019), it has also been associated with psychosis (Green et al., 2014) and PEs (Campbell & Morrison, 2007; DeVylder et al., 2018; Mamah et al., 2021; Turley et al., 2019).

Additionally, Stilo et al. (2016) suggested that first-episode psychosis patients experienced more social disadvantages in adulthood, such as living below the official poverty level, residing in overcrowded conditions, and living alone. Multiple other studies have found a similar link between low socioeconomic status (SES) and psychotic experiences (e.g. Linscott & Os, 2012; Loch et al., 2017; Mamah et al., 2021; Os et al., 2008a). SES may also be decreased by social disadvantage, discrimination and unstable housing situations (Veling & Adriaanse, 2013).

Moreover, there is evidence that individuals with psychosis have higher levels of loneliness compared to the general population (Chrostek et al., 2016; Meltzer et al., 2012; Stain et al., 2012). However, there is also evidence that loneliness already occurs before the onset of psychosis (Häfner et al., 1999; Moller & Husby, 2000) and in individuals with psychotic experiences (Chau et al., 2019; V. A. Morgan et al., 2012; Narita, Stickley, & DeVylder, 2020; Narita et al., 2022; Stain et al., 2012). In a study by Narita, Stickley, and DeVylder (2020), loneliness was still positively correlated with psychotic experiences when adjusted for adverse childhood experiences, sociodemographic factors and common mental disorders.

Furthermore, higher incidence rates of psychosis have been documented among Black, Asian and ethnic minority and migrant populations, who more frequently reside in urban areas (Bourque et al., 2010; Cantor-Graae & Selten, 2005; Coid et al., 2008; Del-Ben et al., 2019; Selten et al., 2019; Tortelli et al., 2018). Various explanations have been proposed to elucidate ethnic disparities in psychosis, such as structural and systemic racism, discrimination, ethnic minority status, ethnic density, access to health services, use of cannabis, poorer social support and social disadvantages (Austin et al., 2020; Gayer-Anderson & Morgan, 2012; Leaune et al., 2018; Linscott & Os, 2012). Evidence suggests that the risk of PEs for ethnic minorities is not or only partially explained by cumulative social disadvantage (C. I. Cohen & Marino, 2013; Selten et al., 2019; Veling & Adriaanse, 2013). In a meta-analysis, ethnic minority position was found to be a consistent risk factor for psychotic disorders and PEs, with the risk level differing across ethnic groups and within countries (Leaune et al., 2018).

Children who live in poverty (Gillham et al., 1998; Kim & Drake, 2018) and are part of the racial/ethnic minority (Kim & Drake, 2018; Maguire-Jack et al., 2015; Putnam-Hornstein et al., 2013) are also disproportionately often victims of child maltreatment. Notably, in a study by Kim and Drake (2018), Whites showed higher maltreatment rates compared to Blacks and Hispanics at similar poverty levels. In turn, childhood adversities, including sexual and physical abuse, neglect and parental death, have been identified as risk factors for psychosis (Matheson et al., 2012; C. Morgan & Fisher, 2006; Reeves et al., 2014; Nierop et al., 2014; Daalman, 2012; Fisher et al., 2012; Varese et al., 2012; Trotta et al., 2015). Furthermore, the consumption of cannabis has been proposed as a potential explanatory factor for the association between psychosis and urban residence. There is consistent, widely acknowledged evidence linking cannabis use to an increased risk of developing schizophrenia (Arseneault, 2002; Di Forti et al., 2015; Os, 2002) and other psychotic disorders (Arseneault et al., 2004; Di Forti et al., 2019; Gage et al., 2016; Henquet, 2005; Minozzi et al., 2009; Moore et al., 2007; Semple et al., 2005). The prevalence of cannabis use seems to be higher in urban populations (Coughlin et al., 2019; Hasin et al., 2019).

Lastly, incidence rates of psychotic disorders are higher among men (Jongsma et al., 2019; J. McGrath et al., 2004), and men frequently experience an earlier onset of psychosis than women (Ochoa et al., 2012). Additionally, vulnerability to environmental risk factors may vary across different age groups (Pedersen, 2001).

1.4. Cumulative effects of these risk factors

Most of these risk factors of PE are not independent but are highly correlated, pleiotropic and interactive (Guloksuz et al., 2018). For example, communities with low SES or minority groups are disproportionately exposed to environmental hazards, such as air pollution and noise, tend to reside in neighbourhoods lacking greenspace and access to health services and experience more psychosocial stress, including discrimination and racism (Europe, 2012; Hajat et al., 2015; Morello-Frosch & Shenassa, 2006; O'Neill et al., 2003). However, many studies have adopted a hypothesis-driven one-exposure to one-outcome approach, akin to the candidate-gene approach or only investigated a subset of potential risk factors. Just as many genetic factors contribute to the genetic risk of psychosis, environmental factors are likely to

contribute to psychosis risk cumulatively (Nierop et al., 2013).

To date, most studies have predominately focused on investigating the impact of urbanicity on psychotic disorders in clinical samples, with schizophrenia being the prototypical disorder. Although 80% of PEs are transitory, about 20% persist, and 7% progress to full-blown psychotic disorders (Kaymaz et al., 2012; Linscott & Os, 2012; Zammit et al., 2013). Hence, the identification of urbanicity-related risk factors associated with PEs holds the potential to inform the development of targeted preventative strategies and could potentially reduce the likelihood of psychosis.

In combination, there are only a few papers, that we are aware of, that investigate how multiple different aspects of an urban environment are associated with psychotic experiences. There have been investigations about features of the physical environment in adolescence (e.g., Bouter et al., 2023; Newbury et al., 2019), neighbourhood characteristics at birth (e.g., Solmi et al., 2019), neighbourhood and individual-specific socioeconomic features as well as other factors in adulthood (e.g., Binbay et al., 2023; Zammit et al., 2010). Most of these studies tackled the statistical challenge posed by high intercorrelations and interactions of environmental features by using hierarchical and adjusted regression models. However, certain feature selection methods may be better suited for this type of research question, as they a) can handle interdependencies between environmental exposures better, b) can handle large feature spaces, i.e., facilitate a more data-driven approach, and c) allow for conclusions about the generalisability of the results (Orrù et al., 2012). We implemented these algorithms in an adult sample to determine how well long-term exposure to a particular environment predicted PEs above and beyond more widely known risk factors and identify which urbanicity-related factors held relatively greater importance.

2. Methods

2.1. Participants

Data were obtained from the United Kingdom (UK) Biobank, a comprehensive database comprising a general adult population cohort of over 500,000 British individuals aged 40 to 69 (Sudlow et al., 2015). Among this cohort, 157,348 participants participated in the online mental health questionnaire, which included questions regarding their PEs (Davis et al., 2020). Informed consent was obtained from all participants, and the UK Biobank received ethical approval from the National Research Ethics Service. This research was conducted under UK Biobank approval (application number 64615).

Only participants who maintained the same residential address since baseline were included in the analysis to ensure consistent long-term exposure to the same physical environment. Participants with missing data regarding psychotic information were excluded from the study. Furthermore, we checked all features and participants for more than 25% of missing data. This cut-off was chosen to exclude potentially non-random missingness of data. More specifically, for some participants, all the data about their social and/or physical environment was missing. As the missingness may be systematic, we excluded these individuals from the final analysis. As a result, 2116 samples were dropped from the analysis. We employed a non-parametric multivariate imputation approach to address the remaining incomplete data using a chained random forest combined with predictive mean matching (Mayer, 2021). This imputation method was selected to enhance the sample's representativeness and, consequently, improve the generalisability of the resulting prediction model (Gorelick, 2006; Moons et al., 2022). The final sample consisted of 22952 participants (*Table 1*), of whom 1.15% reported at least one PE within the last year at the second follow-up assessment.

Table 1
Demographic information in cases and controls in the entire dataset.

	Total	Cases	Controls
N	22952	265	22687
Age (in years, mean ± SD)	64.45 ± 7.64	62.21 ± 7.78	64.47 ± 7.63
Females	12004 (52.3%)	148 (55.85%)	11856 (44.74%)
Long-term residence (in years, mean ± SD)	26.38 ± 11.13	24.71 ± 10.88	26.4 ± 11.13
Living in an urban area	19148 (83.43%)	224 (84.53%)	18924 (83.41%)
Living in town and fringe	1835 (7.99%)	21 (7.92%)	1814 (8%)
Living in village	1335 (5.82%)	18 (6.79%)	1317 (5.81%)
Living in hamlet or isolated dwelling	634 (2.76%)	2 (0.75%)	632 (2.79%)

2.2. Psychotic experiences

Participants were asked if they had experienced PEs in the last year. PEs included seeing a vision, hearing a voice, believing that something strange was trying to communicate with them or that there was a plot against them. A positive answer to either of these experiences led to the classification of PEs. The data were collected in 2016, i.e., six to ten years after the baseline measures.

2.3. Predictors

Based on the literature, 26 candidate variables were selected. These variables can be broadly categorised into three groups: Eleven factors describe the physical environment, seven features capture the social neighbourhood environment, and eight refer to the individual-specific social environment and sociodemographic information. These predictors are described in Table 2. The Supplementary Materials (Fig. 3) provide additional details on the intercorrelations among these variables.

2.4. Algorithms

We aimed to develop an accurate prediction model for PEs while identifying the urbanicity-related variables that enable a good prediction and contain more information than noise, i.e., produce a parsimonious model.

We employed a Boruta algorithm, a wrapper built around a random forest classifier algorithm (Breiman, 2001; Kursa & Rudnicki, 2010b). A random forest classifier is an ensemble learning algorithm that combines multiple decision trees, each trained on a random subset of features and data (Breiman, 2001). The Boruta algorithm follows a three-step process for variable selection: (1) Shadow attributes are produced by shuffling values of the original attributes across objects. (2) A random forest model is trained on the extended dataset, including the original and the shadow attributes, and normalised permutation variable importance scores are computed. (3) The algorithm uses statistical testing to compare the z-scores of the original attributes with those of the shadow attributes. Variables with lower *z*-scores than the shadow features are removed from the model. This process is repeated iteratively until all features are classified or a predetermined number of runs has been performed. Here, we ran the Boruta algorithm with 500 iterations. This algorithm was deemed the most powerful approach compared to other variable selection methods using random forests (Degenhardt et al., 2019; Kursa, 2013). It can detect non-linear relationships, effectively protect against overfitting, and is well-equipped to handle collinearity and interaction between variables, which is particularly important when working with environmental variables. The analysis was carried out using the 'Boruta' package (Kursa & Rudnicki, 2010a), built around the package 'randomForest' (Liaw & Wiener, 2002) in R (version 4.2.1; R Core Team, 2023).

Table 2
Urbanicity-related predictors.

Features	Unit	Range	Assessment	Description
physical environment				
population density	categorical	1–4	0	Participants' home postcodes were combined with data from the 2001 census from the Office of National Statistics, using the Geoconvert tool from Census Dissemination Unit. The variable was classified into urban (4), town (3), village (2) and rural (1).
exposure to green space	% * hours	0–1773.68	0/2	The percentage of the home location classified as greenspace, calculated as a weighted mean of the land use percentage coverage for the 2001 Census Output Areas based on the 2005 Generalised Land Use Database for England, buffered at 1000 m, multiplied by the average annual time spent outdoors.
exposure to blue space	% * hours	0–476.59	0/2	The percentage of the home location classified as water, buffered at 1000 m, multiplied by the average annual time spent outdoors
exposure to natural environment	% * hours	0–1853.1	0/2	The percentage of the natural environment was obtained from the Land Cover Map (LCM) 2007, buffered at 1000 m, multiplied by the average annual time spent outdoors. This was made up of the proportion of broadleaf and coniferous woodland, arable, improved and semi-natural grassland, mountain, heath, bog, salt- and freshwater and coastal rocks.
exposure to domestic garden	% * hours	0–487.41	0/2	The percentage of domestic garden from the generalised land use database for England (GLUD) 2005 data at the 2001 Census Output Area level, buffered at 1000 m, multiplied by the average annual time spent outdoors
coastal distance	kilometres	0.06–102.61	0	The distance from each participant's residence location to the coast
nitrogen oxides	micro-g/m3	19.74–231.24	0	The measure of nitrogen oxide based on the LUR estimate from 2010
nitrogen dioxide	micro-g/m3	12.93–89.55	0	The measure of nitrogen dioxide drawn from the LUR estimate for the annual average of 2010
particulate matter (PM10)	micro-g/m3	11.78–25.3	0	Particulate matter with a diameter less than or equal to 10 µm, also drawn from the LUR estimate for the annual average of 2010
particulate matter (PM2.5)	micro-g/m3	8.17–18.52	0	Particulate matter with a diameter less than or equal to 2.5 µm according to the LUR estimate for the annual average of 2010
noise pollution	dB	42.1–72.21	0	Sound level overnight between 23:00 and 07:00
social environment				
crime	numeric	−2.73–3.81	0	The risk of personal and material victimisation at a small area level, including violence, burglary, theft and criminal damage
education deprivation	numeric	0.02–96.19	0	The average point scores of selected educational examinations, proportion of young people not receiving age-appropriate education, secondary school absence rate, and proportion of adults with no or low qualifications
housing deprivation	numeric	0.34–58.43	0	Includes household overcrowding, homelessness, difficulty of access to owner-occupation and road distance to the nearest General Practitioner surgery, supermarket, primary school and post office.
living environment deprivation	numeric	0.08–92.99	0	Social and private housing in poor condition, houses with central heating, air quality, and road traffic accidents
employment deprivation	numeric	0.01–0.5	0	Involuntary exclusion from the labour market, e.g., by counting the claimants of jobseeker's allowance, incapacity benefit, severe disablement allowance and employment support allowance in a working age population
health deprivation	numeric	−2.99–2.9	0	Premature death and the impairment of quality of life by poor health: the years of potential life lost, comparative illness and disability ratio, measures of acute morbidity and the proportion of adults under 60 suffering from mood or anxiety disorders
income deprivation	numeric	0.01–0.7	0	The number of individuals receiving income support, income-based jobseeker's allowance, pension credit, subsistence support or accommodation support, or having an equivalised income below 60% of the median before housing costs
sociodemographic variables				
sex	categorical	0–1	0	The biological sex of the participant, provided by the National Health Services or given via self-report
age	years	44.64–81.76	2	The age of the participant
household income	categorical	1–5	2	The average total income before tax received by your household
ethnic background	categorical	0–1	0	Having a white (0) or non-white (1) ethnic background
cannabis use	categorical	0–3	2	Four levels of cannabis consumption: never consumed cannabis (0) and consumption in 1–10 occasions (1), 11–100 occasions (2) and more than 100 times (3), as self-reported
childhood adversity	categorical	0–5	2	Summary score of physical and emotional abuse by a family member and child molestation based on a self-report questionnaire; answers to the three questions were coded as never true (0), rarely or sometimes true (1) and often or very often true (2), resulting in a 6-level score of childhood adversity.
social isolation	categorical	0–1	2	Binary answer to the question 'Do you often feel lonely?'
stressful events	categorical	0–7	2	Experience of serious illness, injury or assault to oneself (2) or close realtive (2), death of close relative (2), spouse or partner (2), marital separation/divorce (1) and financial difficulties (1), experienced in the last two years, resulting in an 8-level score.

For categorical variables, the range refers to the factor levels of the variable. Data were extracted from two time points, i.e., from baseline (0) and from a second time point (2).

Although different variable selection methods may lead to models with similar prediction performance, the sets of selected variables may differ (Kursa, 2013). To ensure the robustness of feature selection, we trained a second feature selection model, i.e., an elastic net penalised logistic regression. A penalised (also called regularised or shrinkage) logistic regression method is a classification algorithm that incorporates a penalty term into the loss function, resulting in regression coefficients shrunken toward zero. An elastic net regularisation combines the L1 and L2 regularisations, integrating the strengths of the least absolute shrinkage and selection operator (LASSO; Tibshirani, 1996) and Ridge (Hoerl & Kennard, 1970) methods, respectively. This hybrid approach allows for selecting a parsimonious model through the LASSO term while considering the collinearity between variables via the Ridge penalty. Note that the L2 (Ridge) penalty provides a strong regularisation for large values, while the L1 (LASSO) penalty forces smaller terms to zero. The elastic net's two hyperparameters, α and λ, provide the ability to either balance or select between the values of these two regularisation terms and to determine the total weight of regularisation to

apply, that is, whether and by how much to reduce the impact of or remove remaining features. In contrast to the Boruta algorithm, elastic net models require tuning of their hyperparameters, α and λ. Optimal hyperparameters were selected by exhaustive grid search, testing 25 possible values spread space of possible or likely candidate values. We implemented a 10-fold cross-validation (CV) to choose the best set, which was repeated five times with different fold selections to ensure stability and reliability of the results using the R package 'caret' (Kuhn, 2022).

Furthermore, we fitted two non-selective models, i.e., random forest and an unpenalised logistic regression, to compare the generalisability of the selective to these non-selective models. Numeric data were centred and scaled for the logistic regression models to allow for the comparison between regression coefficients.

2.5. Evaluating the feature selection

To assess each feature's contribution to the models' overall performances, we compared their mean variable importance (VI). In the logistic regression models, variable importance was determined as the absolute value of the t-statistic for each model parameter (Kuhn, 2022). In the random forest models, VI was measured as the Mean Decrease Gini. This measure quantifies the total reduction in node impurities, as measured by the Gini index, resulting from splitting on the variable, averaged over all decision trees in the random forest (Han et al., 2016, pp. 219–224).

Partial dependence plots (PDP) were generated to visually examine the marginal effects of the individual features on the predicted outcome in the tree-based models. PDPs assume independence between the feature for which the plot is computed and the other variables.

2.6. Evaluating the predictive power

The external validity of the models was established by predicting PEs in an independent test dataset. We applied a 10-fold cross-validation, i. e., the models were trained on nine of the folds and then tested on the remaining data. This process was repeated ten times, with each fold used as the test set exactly once. Because tree-based methods tend to under-perform in highly unbalanced datasets (Gu et al., 2008), the training data were balanced by randomly selecting control participants without PEs. Using the base function 'sample' (R Core Team, 2023), the same number of controls as individuals with PEs were drawn from the training data. The training dataset contained 490 participants (245 with PEs). Subsequently, the resulting models were tested on 2296 participants, of whom 20 reported at least one PE.

Random forests were constructed using the features previously selected by the Boruta model in more than half of the CV folds to evaluate the performance of the Boruta algorithm. Balanced accuracy was calculated to identify how often the classifiers were correct at predicting the experience of psychosis, taking the unequal representation of classes into account. Sensitivity, i.e., how well the models detected participants with PEs, and specificity, i.e., how well the models avoided false alarms, were also computed. Root mean square errors (RMSE) were used to evaluate and compare the quality of predictions. In addition, we calculated the area under the receiver operating characteristic curve (AUC) to capture the model's ability to discriminate between the positive, i.e., PEs, and negative classes, i.e., controls, across all possible classification thresholds. The AUC is robust to class imbalance.

3. Results

3.1. Feature selection

The Boruta algorithm selected six features which consistently demonstrated high importance across multiple cross-validation folds. Those features were childhood adversity, social isolation, stressful

events, age, living environment and exposure to natural environments.

The elastic net penalised regression model selected 12 variables that exhibited significant importance. All these features were also picked by the Boruta algorithm except for living environment deprivation. In order of decreasing mean variable importance, the elastic net regression selected stressful events, childhood adversity, household income, social isolation, cannabis, age, exposure to natural environments, education deprivation, crime, exposure to blue space, coastal distance, housing and living environment deprivation. The number of features chosen can be mathematically explained by the tuned hyperparameter of $\overline{\alpha} = 0.43$ (range 0 – 1, where 0.5 represents equal weights for LASSO and Ridge penalties), which indicates a slightly greater impact of the Ridge penalty term. However, the composite penalty term $\overline{\lambda}$ had a value of 0.06 (range from 0 to infinity), suggesting that the overall weight of the regularisation term was low.

When considering the combined information from both feature selection models, childhood adversity and stressful life events emerged as the two most robust predictors of PEs, followed by social isolation and age. These variables were selected in 80% – 100% of the cross-validation folds. Exposure to natural environments was repeatedly selected by both feature selection models but was only chosen 60% of the time and only reached relatively high variable importance in the Boruta model ($\overline{VI} = 2.6$) compared to, for example, childhood adversity ($\overline{VI} = 10.75$) and social isolation ($\overline{VI} = 7.72$). In contrast, household income showed the third highest variable importance in the elastic net but was not selected by the Boruta algorithm. Education deprivation, crime and living environment deprivation showed comparable feature importances in the Boruta algorithm as exposure to natural environments but were not reliably selected (from $\overline{VI} = 2.58$ to $\overline{VI} = 2.76$). As selected by the two feature selection models, standardised variable importances are visualised in Fig. 1 and listed in Table 3. A colour-coded version of the table, including the results of the random forest and logistic regression, is provided in the Supplementary Materials (Table 1). A complete list of the unstandardised variable importances of the Boruta algorithm and regression coefficients of the elastic net regression of all features, including individual factor levels, can be found in Table 4.

Based on the analysis of the partial dependence plots and the regression coefficients obtained from the logistic regression models (detailed in Fig. 5 in the Supplementary Materials), the following directions of effects were found: Childhood trauma exhibited a positive trend, i.e., the more trauma was experienced, the higher the probability that the model would classify a participant as having psychotic experiences. A similar trend was observed for stressful events and social isolation. Moreover, the Boruta model yielded predictions of a higher risk of PE before age 65, followed by a sudden decrease thereafter. The predicted probability of PE displayed a non-monotonic reduction with increasing exposure to natural environments and decreasing levels of living environment deprivation. Further examination of two-dimensional partial dependence plots derived from the Boruta model revealed that before age 65, a deprived living environment was associated with an increased predicted risk of psychotic experiences. Conversely, low exposure to natural environments was linked to an elevated probability of psychotic experiences across all ages (Fig. 6 in the Supplementary Materials). Additionally, the Boruta model predicted a high likelihood of PE for low exposure to natural environments irrespective of the level of living environment deprivation. The model further suggests that social isolation and the experience of stressful events attenuate the negative impact of a deprived living environment on the predicted risk of PE (Fig. 7 in the Supplementary Materials).

3.2. Predictive power

The models demonstrated prediction accuracies and AUC above the chance level between 0.62 and 0.64, indicating low to moderate accuracy. The models could correctly identify individuals with PEs 63.9% –
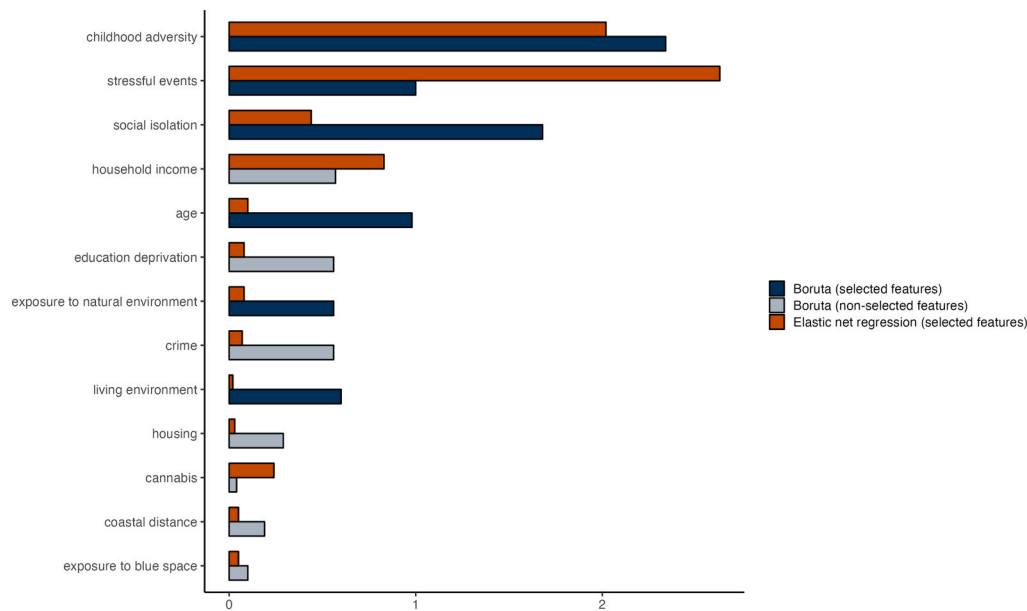
Fig. 1. Feature importance.

Table 3
Feature importance and selection frequency.

	Variable importance		Selection frequency	
	Boruta	Elastic net regression	Boruta	Elastic net regression
childhood adversity [a]	2.34 (1.42) [b]	2.02 (1.3) [b]	100%	80%
stressful events [a]	1 (1.31) [b]	2.63 (3.15) [b]	90%	64%
social isolation	1.68 (1.44) [b]	0.43 (0.12) [b]	90%	100%
age	0.98 (1.32) [b]	0.1 (0.07) [b]	90%	90%
household income [a]	0.57 (0.9)	0.83 (0.48) [b]	50%	68%
exposure to natural environment	0.57 (0.68) [b]	0.08 (0.14) [b]	60%	60%
education deprivation	0.56 (0.66)	0.08 (0.06) [b]	50%	100%
crime	0.56 (0.95)	0.06 (0.03) [b]	50%	90%
living environment	0.6 (0.97) [b]	0.01 (0.01) [b]	70%	50%
housing	0.29 (0.61)	0.03 (0.03) [b]	10%	60%
cannabis	0.04 (0.25)	0.24 (0.37) [b]	0%	47%
coastal distance	0.19 (0.48)	0.05 (0.05) [b]	0%	90%
exposure to blue space	0.1 (0.47)	0.05 (0.07) [b]	10%	80%

This table lists the features' mean variable importance, along with their standard deviations, and selection frequency across the cross-validation (CV). Only features selected by either of the selective algorithms in more than half of the CV folds are included. The variables are ranked based on their mean predictive importance as calculated by the two feature selection algorithms. To facilitate comparability between the models, the feature importance was scaled. Note that for logistic regressions, categorical variables' levels have been summarised into a single feature to ensure comparability.

[a] Feature was selected in more than half of the CV folds.
[b] Values are averaged across levels of this variable. Information about the individual levels of these variables is provided in the Supplementary Materials.

79.17% of the time. However, the models demonstrated a limited capacity to avoid misclassification of individuals reporting PEs, as evidenced by the specificity measures falling between 40.5% and 63%. These values per model can be found in Table 5. With only six selected features, Boruta produced the most parsimonious and sparse model (depicted in Fig. 5 of the Supplementary Materials).

4. Discussion

This study aimed to predict psychotic experiences (PEs) by identifying the key variables characterising an individual's urban environment. PEs seem to be associated with and potentially arise from an accumulation of social and environmental stressors. We identified five variables that consistently emerged as important across feature selection methods and dataset splits, i.e., childhood adversity, stressful events in the past two years, social isolation, age and exposure to natural environments. Population density was not selected as a predictor of PEs.

In our analyses, we achieved a moderate level of predictive ability for PEs in independent datasets, which aligns with the well-established understanding that psychosis is influenced by both genetic and environmental factors, with 30% – 50% explained by genetics and 50% – 70% by the environment (Ronald, 2015; Zavos et al., 2014).

This study's most novel and noteworthy finding is the evidence supporting the protective role of exposure to natural environments against PEs. Natural environment refers to surroundings comprising green and blue spaces with little or no apparent evidence of human presence or intervention. In our sample, exposure to natural environments close to one's home address was highly correlated with exposure to greenspace ($r = 0.98$) while being only weakly associated with blue space ($r = 0.24$). Thus, the measure of the natural environment used in this study primarily seems to capture the presence of green natural environments. Our findings support the work of Boers et al. (2018), who reported significantly lower amounts of residential green but not blue space in psychotic patients compared to a subclinical population. This highlights the importance of considering the quantity and quality of green spaces when designing residential areas.

Natural environments have high restorative and salutogenic properties, which can re-calibrate psychological and physiological systems, including improving immune function, decreasing blood pressure, facilitating the restoration of attention and fatigue, improving mood and reducing depressive symptoms (Amoly et al., 2014; Berman et al., 2008;

Table 4
Variable importance and regression coefficients of all candidate variables.

Features	Boruta			Elastic net regression		
	Mean variable importance	Number of Selections	Decision	Mean regression coefficient	Number of Selections	Decision
Age	4.53	9	Confirmed	−0.13	9	Confirmed
Cannabis use	0.17	0	Rejected			
Cannabis use level 1				0.07	6	Confirmed
Cannabis use level 2				0.01	5	Rejected
Cannabis use level 3				−0.04	3	Rejected
Childhood adversity	10.75	10	Confirmed			
Childhood adversity level 1				0.04	4	Rejected
Childhood adversity level 2				0.55	10	Confirmed
Childhood adversity level 3				0.59	9	Confirmed
Childhood adversity level 4				0.77	9	Confirmed
Childhood adversity level 5				0.73	8	Confirmed
Coastal distance	0.86	0	Rejected	0.06	9	Confirmed
Crime	2.58	5	Rejected	0.09	9	Confirmed
Education deprivation	2.59	5	Rejected	0.10	10	Confirmed
Employment deprivation	1.87	3	Rejected	0.02	2	Rejected
Ethnic background	−0.04	0	Rejected	−0.19	3	Rejected
Exposure to blue space	0.45	1	Rejected	0.07	8	Confirmed
Exposure to domestic garden	−0.44	0	Rejected	0.00	2	Rejected
Exposure to green space	1.39	1	Rejected	0.03	3	Rejected
Exposure to natural environment	2.60	6	Confirmed	−0.11	6	Confirmed
Health deprivation	0.76	1	Rejected	−0.01	2	Rejected
Household income	2.62	5	Rejected			
Household income level 2				0.00	5	Rejected
Household income level 3				−0.14	9	Confirmed
Household income level 4				0.01	3	Rejected
Household income level 5				−0.91	10	Confirmed
Housing deprivation	1.35	1	Rejected	−0.04	6	Confirmed
Income deprivation	1.98	3	Rejected	−0.03	4	Rejected
Living environment deprivation	2.76	7	Confirmed	0.00	5	Rejected
Nitrogen dioxide	2.02	4	Rejected	0.03	5	Rejected
Nitrogen oxides	2.14	4	Rejected	−0.02	5	Rejected
Noise pollution	−0.20	0	Rejected	0.02	4	Rejected
Particulate matter (PM10)	0.38	1	Rejected	0.03	5	Rejected
Particulate matter (PM2.5)	2.11	3	Rejected	0.01	5	Rejected
Population density	−0.04	0	Rejected			
Population density level 2				0.26	4	Rejected
Population density level 3				0.17	4	Rejected
Population density level 4				−0.06	4	Rejected
Sex	−0.18	0	Rejected	0.02	4	Rejected
Social isolation	7.72	9	Confirmed	0.58	10	Confirmed
Stressful events	4.60	9	Confirmed			
Stressful events level 1				0.40	9	Confirmed
Stressful events level 2				0.03	2	Rejected
Stressful events level 3				0.37	7	Confirmed
Stressful events level 4				0.15	4	Rejected
Stressful events level 5				0.97	10	Confirmed
Stressful events level 6				1.06	8	Confirmed
Stressful events level 7				0.48	5	Rejected

The number of selections refers to the frequency with which each variable was selected across cross-validation folds. If a variable was chosen in half or less than half of the cross-validation folds, it was rejected, as listed in the columns "Decision". Variable importances and regression coefficients were averaged across cross-validation folds.

Table 5
Mean predictive ability of the different model approaches.

	Accuracy	Sensitivity	Specificity	RMSE	AUC
Boruta	64.19%	65.37%	63%	0.59	0.64
Elastic net regression	62.12%	66.75%	57.5%	0.58	0.62
Random forests	62.45%	63.9%	61%	0.60	0.62
Logistic regression	59.84%	79.17%	40.5%	0.46	0.60

Note that due to the high intercorrelations of the predictors, the logistic regression's assumptions are violated, and it was only calculated for comparison. RMSE = root mean square error, AUC = area under the receiver operating characteristic curve.

Bratman et al., 2012; Ebisu et al., 2016; Fong et al., 2018; Hartig et al., 2014; James et al., 2015; R. Kaplan and Kaplan, 1989; Kuo, 2015; Maas et al., 2009; Markevych et al., 2017; Preuβ et al., 2019; G. A. Rook, 2013; G. A. W. Rook et al., 2013; Twohig-Bennett & Jones, 2018; Ulrich et al.,

1991). Several mechanisms have been proposed through which exposure to nature may benefit mental and physical health. The attention restoration theory (ART) suggests that natural environments can help to restore cognitive functioning (R. Kaplan & Kaplan, 1989; S. Kaplan, 1995; S. Kaplan and Talbot, 1983; Ohly et al., 2016). According to the stress reduction theory (SRT), being in nature can facilitate recovery from psychophysiological stress and promote relaxation (Ulrich, 1983; Ulrich et al., 1991; Ward Thompson et al., 2012). Additionally, exposure to natural environments can encourage healthful activities, such as physical activity and socialising (James et al., 2015; Kaczynski & Henderson, 2007; Maas et al., 2008; Markevych et al., 2017; Twohig-Bennett & Jones, 2018). The causality of this effect has been established through intervention studies. For instance, participants who engaged in walks through a natural environment showed decreased levels of rumination and reduced neural activity in the amygdala, a brain region associated with the risk for mental illness and stress, compared to those who took a walk in an urban environment (Bratman et al., 2015; Sudimac et al.,

2022). Genes, as the alternative player, may influence psychosis risk by altering the sensitivity to (gene-environment interaction) or by increasing the exposure to certain environments (gene-environment correlation). The evidence speaks for the latter in schizophrenia (Engemann et al., 2020) and psychosis patients (Boers et al., 2018).

Furthermore, living environment deprivation was repeatedly selected by the Boruta model, which was assembled by describing the overall air quality exposure, including outdoor and indoor living environments, e.g., housing conditions. Previous studies have established these environmental attributes as contributors to psychosis (Attademo et al., 2017; V. A. Morgan et al., 2012, 2016; Newbury et al., 2019; Nowak et al., 2006). However, air pollution by itself was not deemed important in the present analyses.

Nonetheless, the most predictive variables of PEs in the present sample captured individual-specific social stressors. Both types of stressors, i.e., during childhood and in later life, have already been extensively discussed in the literature (Daalman, 2012; Linscott & Os, 2012; Matheson et al., 2012; C. Morgan & Fisher, 2006; Nierop et al., 2014; Reeves et al., 2014; Schäfer & Fisher, 2011; Trotta et al., 2015; Varese et al., 2012). Moreover, the present results add evidence to the dose-response association between childhood traumatic experiences and PEs (Coughlan & Cannon, 2017; Cunningham et al., 2015; Dam et al., 2012; Shevlin et al., 2010; Trotta et al., 2015; Varese et al., 2012), aligning with the vulnerability-stress model or diathesis-stress model. This model states that susceptibility to psychosis results from an interaction of (epi)genetic risk factors and early social stress (Guloksuz et al., 2019; Monroe & Simons, 1991; Zubin & Spring 1977). Moreover, stressful life events, regardless of the time at which they occur, can lead to abnormal activity of the hypothalamic-pituitary-adrenal (HPA) axis, triggering a cascade of neurophysiological processes, dysfunction of dopaminergic neurotransmission and neural circuits relevant for facilitating onset, exacerbation and relapse of schizophrenia and psychosis (Collip et al., 2007; Corcoran et al., 2012; Faravelli et al., 2010; Grace, 2016; Howes et al., 2004; Howes & Kapur, 2009; Winkel et al., 2008; Yuii et al., 2007). However, the presence of greenspace may attenuate these detrimental health impacts of stressful life events van den Berg et al., 2010.

Additionally, the impact of stressors, as well as recovery from psychosis, may also be mitigated by social support (Heinrichs et al., 2003; Lim et al., 2013; Temesgen et al., 2018). Previous research has demonstrated that social isolation, particularly long-lasting isolation, renders the individual more vulnerable to psychotic disorders (Appiah-Kusi et al., 2017; Badcock et al., 2015; Kirkbride et al., 2007a; Kirkbride et al., 2007c; Morgan et al., 2016; Stain et al., 2012) and mental health issues in general (Cohen, McGowan, Fooskas, & Rose, 1984; S. Cohen and Wills, 1985; House, 2001; Leavy, 1983). Our study found evidence linking social isolation to PEs in accordance with these findings. This may support the social defeat hypothesis, which posits that long-term social defeat, i.e., the feeling of being excluded from the majority group or social exclusion, can lead to sensitisation of the mesolimbic dopamine system and increase the risk for psychotic disorders (Selten & Cantor-Graae, 2005, 2007; Selten et al., 2013).

The present study also identified an association between age and the existence of PEs. Younger age has been previously reported in the literature as a significant demographic risk factor of PEs (Brandizzi et al., 2014; Linscott & Os, 2012; Loch et al., 2017) and psychosis (Kirkbride et al., 2008; Os et al., 2008a), and the negative trend found by the elastic net regression is consistent with these findings. However, the examination of the PDPs suggests a possible period of higher sensitivity in the early 60s and before the age of 65 in general (see Fig. 5 in Supplementary Materials). Although such examination is exploratory, this finding suggests that future work should apply time-varying models capable of detecting multiple sensitive periods (e.g., a TVEM; Shiyko et al., 2014).

Lastly, our results suggest a weak link between PEs and specific forms of social deprivation. On an individual-specific level, our findings indicated that lower household income is associated with an increased risk

of reporting PEs, aligning with previous work (Burns & Esterhuizen, 2008; Karcher et al., 2021; Linscott & Os, 2012; Loch et al., 2017; Mamah et al., 2021; V. A. Morgan et al., 2016; Stilo et al., 2016). On a neighbourhood level, the results revealed a non-linear increase in PE risk among participants whose neighbourhoods were characterised by deprived living environments, attenuated crime rates and education deprivation. Multiple studies have linked the elevated risk of psychosis and schizophrenia to social deprivation in general (Anderson et al., 2012; Bhavsar et al., 2014; Croudace et al., 2000; Hardoon et al., 2013; Kirkbride et al., 2007a; Kirkbride et al., 2012; Kirkbride et al., 2007b; Kirkbride et al., 2007c; Linscott & Os, 2012; Omer et al., 2014; Veling et al., 2014), education deprivation (Bhavsar et al., 2014) and crime rates (Bhavsar et al., 2014). Interestingly, when participants come from socioeconomically deprived neighbourhoods or have low education levels, the association between the presence of green spaces in the living environment and health outcomes is particularly pronounced (Twohig-Bennett & Jones, 2018).

No link between air pollution and PEs was captured with the present analysis and study design in accordance with previous research (Braithwaite et al., 2019). A potential explanation for the lack of findings may be the time of exposure: Research has shown that individuals are particularly vulnerable to air pollution early in life. For example, Bradley et al. (2023) found a link between early life exposure to air pollution and psychotic-like experiences. Future studies may instead focus on this time window of exposure. In contrast, air pollution in the present analysis was captured only a few years before the measurement of PE risk.

Furthermore, ethnic background was not deemed important in the present analyses in line with previous research (see meta-analysis: Leaune et al., 2018). A meta-analysis by Tortelli et al. (2018) indicated that accounting for life and social adversity events mitigated the impact of ethnicity on subclinical psychosis prevalence rates. In our analysis, the variable importances of childhood adversity and current life stress may have decreased the effect of ethnicity. Arguably more crucially, the present operationalisation of ethnic background disregarded diversity and personal experiences tied to ethnicity. Future studies should focus on variables such as perceived personal discrimination and racism, ethnic identity, migration status and own-group density (Bouhaddani et al., 2019; Das-Munshi et al., 2012; Leaune et al., 2018).

Exposure to greenspace was infrequently selected despite its high correlation with the frequently chosen variable describing exposure to natural environments. The L1 regularisation may have dominated the L2 penalty in the elastic net model, selecting only one variable and setting the coefficient of correlated variables to zero. In contrast, the Boruta follows an all-relevant variable selection method, and surprisingly, only one variable was chosen. This may happen due to inherent randomness in the model produced by the shadow features and the random forest variability. Additionally, Boruta considers both main effects and interactions between features. If the two correlated variables are highly redundant in terms of predictive power, the algorithm might choose one over the other based on its internal criteria.

Likewise, exposure to domestic gardens was also not chosen. Although several theories cover why and how urban green may affect mental and physical health, the most commonly proposed pathways are reducing harm by alleviating heat, noise and air pollution, relieving mental and physiological stress and promoting healthful activities, e.g., exercise and socialising (Markevych et al., 2017). Domestic gardens may not facilitate interpersonal interactions and physical activity to the extent observed in natural environments. However, future studies ought to investigate this further.

In summary, this study suggests that the urbanicity effect for psychotic experiences represents a proxy of individual-specific features of the social and physical environment. Individuals with a high risk of PEs encounter social adversities and present with deficient tools to handle these stressors effectively, including a lack of social support.

Interestingly, beyond those social factors, less exposure to natural environments around the home address was also predictive of PEs. Potential underlying neurobiological mechanisms of these associations could be alterations in the HPA axis (Corcoran et al., 2012; Steinheuser et al., 2014; Winkel et al., 2008), inflammation (Baumeister et al., 2015; Powell et al., 2013), altered brain functioning (Akdeniz et al., 2014; Lederbogen et al., 2011; Sudimac et al., 2022) and brain structural (Habets et al., 2011; Haddad et al., 2014; Kühn et al., 2017) and neurochemical dysfunction (Collip et al., 2007; Howes et al., 2004; Mizrahi, 2015; Selten et al., 2017; Yuii et al., 2007).

4.1. Limitations

This study was not without limitations. Firstly, due to the restraints of data availability, we could not control the amount of time participants spent at their homes and in their neighbourhoods. Additionally, the data on the physical environment were collected several years before the mental health assessment. Thus, the present analyses were conducted under the assumption that the characteristics of the environment did not undergo drastic changes over time. Although our two approaches capture both linear (elastic net regression) and non-linear (Boruta) relationships with the outcome, some types of relationships may not be identified as clearly by these approaches. For example, it may be the case that a more complex combination of factors is required to see a strong effect of education deprivation or that crime rates matter to a small enough fraction of the population that its effects are difficult to see. Similarly, our decision to consider Likert-scale items as categorical may have influenced the selection of variables, especially for the elastic net regression. Future investigation into the effects of these factors may provide additional information. Furthermore, the generalisability of the present findings is somewhat limited since the UK Biobank sample consisted primarily of older individuals, with the youngest participant being 45 years old. Nevertheless, the number of extensive datasets that encompass numerous variables describing the physical environment and capture psychotic experiences is extremely limited. To address this, we currently plan to investigate subclinical psychosis and paranoia in twins. The sample was also subject to a volunteer bias, which may have excluded individuals with more severe forms of PEs. To measure the environmental impact, we only included participants with long-term residence in the final analyses, thereby introducing further bias in the sample. Most importantly, we cannot entirely dismiss that the choice of residential location may be confounded with genetics, i.e., via selective migration, or some other selection criteria. Further, this analysis does not directly test causation; individuals with pre-existing mental disorders might tend to move to a lower socioeconomic status and cluster in urban areas, i.e., social drift hypothesis (Colodro-Conde et al., 2018; Saraceno & Barbui, 1997; Sariaslan et al., 2016). Conversely, individuals with better psychological health may actively seek out residential environments that offer greater exposure to natural surroundings. However, multiple studies have provided evidence against these theories (Krabbendam, 2005; Os et al., 2000; Paksarian et al., 2017). Lastly, no objective measurements of PEs or clinical validation of psychosis were included in the UK Biobank data.

4.2. Conclusions

Despite the limitations of this study, we argue that these results have clinical implications. PEs have adverse health outcomes, such as suicidal behaviour (Bromet et al., 2017; DeVylder et al., 2015; Narita, Wilcox, & DeVylder, 2020), psychiatric comorbidities (DeVylder et al., 2014a; Kelleher et al., 2012; J. J. McGrath et al., 2016) and greater need for psychiatric intervention (DeVylder et al., 2014b; Murphy et al., 2010). Individuals with PEs have a 4-fold increased risk of psychotic disorder and a 3-fold risk for mental disorders (Healy et al., 2019). This makes early intervention critical. Encouraging individuals at risk for or with PEs to increase their time spent in natural environments, ideally with other people, may represent a cost-effective, easily administered prevention and intervention strategy with minimal, if any, side effects (Van den Berg, 2017). Taking this one step further, if policymakers advocate for readily accessible, high-quality natural environments, we may prevent the progression to psychosis in individuals with or with a high risk of psychotic experiences without active interventions.

CRediT authorship contribution statement

Moana Beyer: Formal analysis, Methodology, Visualization, Writing – original draft. **Timothy R. Brick:** Writing – review & editing. **Simone Kühn:** Conceptualization, Supervision, Writing – review & editing.

Declaration of generative AI and AI-assisted technologies in the writing process

During the preparation of this work, the author(s) used ChatGPT in order to improve language and readability. After using this tool/service, the author(s) reviewed and edited the content as needed and take(s) full responsibility for the content of the publication.

Declaration of Competing interest

The authors declare no conflict of interests.

Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.jenvp.2024.102293.

References

Adler, N. E., & Snibbe, A. C. (2003). The role of psychosocial processes in explaining the Gradient between socioeconomic status and health. *Current Directions in Psychological Science, 12*(4), 119–123. https://doi.org/10.1111/1467-8721.01245

Akdeniz, C., Tost, H., Streit, F., Haddad, L., Wüst, S., Schäfer, A., Schneider, M., Rietschel, M., Kirsch, P., & Meyer-Lindenberg, A. (2014). Neuroimaging evidence for a role of neural social stress processing in ethnic MinorityAssociated environmental risk. *JAMA Psychiatry, 71*(6), 672. https://doi.org/10.1001/jamapsychiatry.2014.35

Allardyce, J., Gilmour, H., Atkinson, J., Rapson, T., Bishop, J., & McCreadie, R. G. (2005). Social fragmentation, deprivation and urbanicity: Relation to first-admission rates for psychoses. *British Journal of Psychiatry, 187*(5), 401–406. https://doi.org/10.1192/bjp.187.5.401

Amoly, E., Dadvand, P., Forns, J., López-Vicente, M., Basagaña, X., Julvez, J., Alvarez-Pedrerol, M., Nieuwenhuijsen, M. J., & Sunyer, J. (2014). Green and blue spaces and Behavioral development in Barcelona Schoolchildren: The BREATHE project. *Environmental Health Perspectives, 122*(12), 1351–1358. https://doi.org/10.1289/ehp.1408215

Anderson, K. K., Fuhrer, R., Abrahamowicz, M., & Malla, A. K. (2012). The incidence of first-episode schizophrenia-Spectrum psychosis in adolescents and young adults in Montreal: an estimate from an Administrative Claims database. *Canadian Journal of Psychiatry, 57*(10), 626–633. https://doi.org/10.1177/070674371205701007

Appiah-Kusi, E., Fisher, H. L., Petros, N., Wilson, R., Mondelli, V., Garety, P. A., Mcguire, P., & Bhattacharyya, S. (2017). Do cognitive schema mediate the association between childhood trauma and being at ultra-high risk for psychosis? *Journal of Psychiatric Research, 88*, 89–96. https://doi.org/10.1016/j.jpsychires.2017.01.003

Arseneault, L. (2002). Cannabis use in adolescence and risk for adult psychosis: Longitudinal prospective study. *BMJ, 325*(7374), 1212–1213. https://doi.org/10.1136/bmj.325.7374.1212

Arseneault, L., Cannon, M., Witton, J., & Murray, R. M. (2004). Causal association between cannabis and psychosis: Examination of the evidence. *British Journal of Psychiatry, 184*(2), 110–117. https://doi.org/10.1192/bjp.184.2.110

Attademo, L., Bernardini, F., Garinella, R., & Compton, M. T. (2017). Environmental pollution and risk of psychotic disorders: A review of the science to date. *Schizophrenia Research, 181*, 55–59. https://doi.org/10.1016/j.schres.2016.10.003

Austin, A. E., Lesak, A. M., & Shanahan, M. E. (2020). Risk and protective factors for child maltreatment: A review. *Current Epidemiology Reports, 7*(4), 334–342. https://doi.org/10.1007/s40471-020-00252-3

Badcock, J. C., Shah, S., Mackinnon, A., Stain, H. J., Galletly, C., Jablensky, A., & Morgan, V. A. (2015). Loneliness in psychotic disorders and its association with cognitive function and symptom profile. *Schizophrenia Research, 169*(1–3), 268–273. https://doi.org/10.1016/j.schres.2015.10.027

Baumeister, D., Akhtar, R., Ciufolini, S., Pariante, C. M., & Mondelli, V. (2015). Childhood trauma and adulthood inflammation: A meta-analysis of peripheral C-reactive protein, interleukin-6 and tumour necrosis factor-α. *Molecular Psychiatry, 21*(5), 642–649. https://doi.org/10.1038/mp.2015.67

Berman, M. G., Jonides, J., & Kaplan, S. (2008). The cognitive benefits of interacting with nature. *Psychological Science, 19*(12), 1207–1212. https://doi.org/10.1111/j.1467-9280.2008.02225.x

Bhavsar, V., Boydell, J., Murray, R., & Power, P. (2014). Identifying aspects of neighbourhood deprivation associated with increased incidence of schizophrenia. *Schizophrenia Research, 156*(1), 115–121. https://doi.org/10.1016/j.schres.2014.03.014

Binbay, T., Erel, B., Set, R. T., Kırlı, U., Ergül, C., Elbi, H., & Alptekin, K. (2023). The association of social inequality with the onset, persistence, and progression of psychotic experiences along the extended psychosis phenotype: A 6-year follow-up study in a community-based sample. *Social Psychiatry and Psychiatric Epidemiology*. https://doi.org/10.1007/s00127-023-02422-2

Boers, S., Hagoort, K., Scheepers, F., & Helbich, M. (2018). Does residential green and blue space promote recovery in psychotic disorders? A cross-sectional study in the Province of Utrecht, The Netherlands. *International Journal of Environmental Research and Public Health, 15*(10), 2195. https://doi.org/10.3390/ijerph15102195

Bouhaddani, S. el, Domburgh, L. van, Schaefer, B., Doreleijers, T. A. H., & Veling, W. (2019). Psychotic experiences among ethnic majority and minority adolescents and the role of discrimination and ethnic identity. *Social Psychiatry and Psychiatric Epidemiology, 54*(3), 343–353. https://doi.org/10.1007/s00127-019-01658-1

Bourque, F., Ven, E. van der, & Malla, A. (2010). A meta-analysis of the risk for psychotic disorders among first- and second-generation immigrants. *Psychological Medicine, 41*(5), 897–910. https://doi.org/10.1017/s0033291710001406

Bouter, D. C., Ravensbergen, S. J., Lakerveld, J., Hoogendijk, W. J. G., & Grootendorst-van Mil, N. H. (2023). Associations between the urban environment and psychotic experiences in adolescents. *Schizophrenia Research, 260*, 123–131. https://doi.org/10.1016/j.schres.2023.08.016

Boydell, J., Os, J. van, McKenzie, K., & Murray, R. M. (2004). The association of inequality with the incidence of schizophrenia. *Social Psychiatry and Psychiatric Epidemiology, 39*(8), 597–599. https://doi.org/10.1007/s00127-004-0789-6

Bradley, M., Dean, K., Lim, S., Laurens, K. R., Harris, F., Tzoumakis, S., O'Hare, K., Carr, V. J., & Green, M. J. (2023). Early life exposure to air pollution and psychotic-like experiences, emotional symptoms, and conduct problems in middle childhood. *Social Psychiatry and Psychiatric Epidemiology*. https://doi.org/10.1007/s00127-023-02533-w

Braithwaite, I., Zhang, S., Kirkbride, J. B., Osborn, D. P. J., & Hayes, J. F. (2019). Air pollution (particulate matter) exposure and associations with depression, anxiety, bipolar, psychosis and Suicide risk: A systematic review and meta-analysis. *Environmental Health Perspectives, 127*(12), Article 126002. https://doi.org/10.1289/ehp4595

Brandizzi, M., Schultze-Lutter, F., Masillo, A., Lanna, A., Curto, M., Lindau, J. F., Solfanelli, A., Listanti, G., Patanè, M., Kotzalidis, G., Gebhardt, E., Meyer, N., Di Pietro, D., Leccisi, D., Girardi, P., & Fiori Nastro, P. (2014). Self-reported attenuated psychotic-like experiences in help-seeking adolescents and their association with age, functioning and psychopathology. *Schizophrenia Research, 160*(1–3), 110–117. https://doi.org/10.1016/j.schres.2014.10.005

Bratman, G. N., Hamilton, J. P., & Daily, G. C. (2012). The impacts of nature experience on human cognitive function and mental health. *Annals of the New York Academy of Sciences, 1249*(1), 118–136. https://doi.org/10.1111/j.1749-6632.2011.06400.x

Bratman, G. N., Hamilton, J. P., Hahn, K. S., Daily, G. C., & Gross, J. J. (2015). Nature experience reduces rumination and subgenual prefrontal cortex activation. *Proceedings of the National Academy of Sciences, 112*(28), 8567–8572. https://doi.org/10.1073/pnas.1510459112

Breiman, L. (2001). Random forests. *Machine Learning, 45*(1), 5–32. https://doi.org/10.1023/a:1010933404324

Bromet, E. J., Nock, M. K., Saha, S., Lim, C. C. W., Aguilar-Gaxiola, S., Al-Hamzawi, A., Alonso, J., Borges, G., Bruffaerts, R., Degenhardt, L., Girolamo, G. de, Jonge, P. de, Florescu, S., Gureje, O., Haro, J. M., He, Y., Hu, C., Karam, E. G., Kovess-Masfety, V., … McGrath, J. J. (2017). Association between psychotic experiences and subsequent suicidal thoughts and Behaviors. *JAMA Psychiatry, 74*(11), 1136. https://doi.org/10.1001/jamapsychiatry.2017.2647

Burns, J. K., & Esterhuizen, T. (2008). Poverty, inequality and the treated incidence of first-episode psychosis. *Social Psychiatry and Psychiatric Epidemiology, 43*(4), 331–335. https://doi.org/10.1007/s00127-008-0308-2

Campbell, M. L. C., & Morrison, A. P. (2007). The relationship between bullying, psychotic-like experiences and appraisals in 1416-year olds. *Behaviour Research and Therapy, 45*(7), 1579–1591. https://doi.org/10.1016/j.brat.2006.11.009

Cantor-Graae, E., & Selten, J.-P. (2005). Schizophrenia and migration: A meta-analysis and review. *American Journal of Psychiatry, 162*(1), 12–24. https://doi.org/10.1176/appi.ajp.162.1.12

Chang, H.-T., Wu, C.-D., Pan, W.-C., Lung, S.-C. C., & Su, H.-J. (2019). Association between surrounding greenness and schizophrenia: A Taiwanese cohort study. *International Journal of Environmental Research and Public Health, 16*(8), 1415. https://doi.org/10.3390/ijerph16081415

Chau, A. K. C., Zhu, C., & So, S. H.-W. (2019). Loneliness and the psychosis continuum: A meta-analysis on positive psychotic experiences and a meta-analysis on negative psychotic experiences. *International Review of Psychiatry, 31*(5–6), 471–490. https://doi.org/10.1080/09540261.2019.1636005

Chrostek, A., Grygiel, P., Anczewska, M., Wciórka, J., & Świtaj, P. (2016). The intensity and correlates of the feelings of loneliness in people with psychosis. *Comprehensive Psychiatry, 70*, 190–199. https://doi.org/10.1016/j.comppsych.2016.07.015

Cohen, C. I., & Marino, L. (2013). Racial and ethnic Differences in the prevalence of psychotic symptoms in the general population. *Psychiatric Services, 64*(11), 1103–1109. https://doi.org/10.1176/appi.ps.201200348

Cohen, L. H., McGowan, J., Fooskas, S., & Rose, S. (1984). Positive life events and social support and the relationship between life stress and psychological disorder. *American Journal of Community Psychology, 12*(5), 567–587. https://doi.org/10.1007/bf00897213

Cohen, S., & Wills, T. A. (1985). Stress, social support, and the buffering hypothesis. *Psychological Bulletin, 98*(2), 310–357. https://doi.org/10.1037/0033-2909.98.2.310

Coid, J. W., Kirkbride, J. B., Barker, D., Cowden, F., Stamps, R., Yang, M., & Jones, P. B. (2008). Raised incidence rates of all psychoses among migrant groups. *Archives of General Psychiatry, 65*(11), 1250. https://doi.org/10.1001/archpsyc.65.11.1250

Collip, D., Myin-Germeys, I., & Van Os, J. (2007). Does the Concept of "Sensitization" provide a Plausible mechanism for the Putative link between the environment and schizophrenia? *Schizophrenia Bulletin, 34*(2), 220–225. https://doi.org/10.1093/schbul/sbm163

Colodro-Conde, L., Couvy-Duchesne, B., Whitfield, J. B., Streit, F., Gordon, S., Kemper, K. E., Yengo, L., Zheng, Z., Trzaskowski, M., Zeeuw, E. L. de, Nivard, M. G., Das, M., Neale, R. E., MacGregor, S., Olsen, C. M., Whiteman, D. C., Boomsma, D. I., Yang, J., Rietschel, M., … Martin, N. G. (2018). Association between population density and genetic risk for schizophrenia. *JAMA Psychiatry, 75*(9), 901. https://doi.org/10.1001/jamapsychiatry.2018.1581

Corcoran, C. M., Smith, C., McLaughlin, D., Auther, A., Malaspina, D., & Cornblatt, B. (2012). HPA axis function and symptoms in adolescents at clinical high risk for schizophrenia. *Schizophrenia Research, 135*(1–3), 170–174. https://doi.org/10.1016/j.schres.2011.11.035

Coughlan, H., & Cannon, M. (2017). Does childhood trauma play a role in the aetiology of psychosis? A review of recent evidence. *BJPsych Advances, 23*(5), 307–315. https://doi.org/10.1192/apt.bp.116.015891

Coughlin, L. N., Bonar, E. E., Bohnert, K. M., Jannausch, M., Walton, M. A., Blow, F. C., & Ilgen, M. A. (2019). Changes in urban and rural cigarette smoking and cannabis use from 2007 to 2017 in adults in the United States. *Drug and Alcohol Dependence, 205*, Article 107699. https://doi.org/10.1016/j.drugalcdep.2019.107699

Croudace, T. J., Jones, P. B., & Harrison, G. L. (2000). Nonlinear relationship between a measure of social deprivation and the incidence of psychosis in Nottingham. *Schizophrenia Research, 41*(1), 80. https://doi.org/10.1016/s0920-9964(00)90489-4

Cunningham, T., Hoy, K., & Shannon, C. (2015). Does childhood bullying lead to the development of psychotic symptoms? A meta-analysis and review of prospective studies. *Psychosis, 8*(1), 48–59. https://doi.org/10.1080/17522439.2015.1053969

Daalman, K. (2012). Childhood trauma and auditory verbal hallucinations. *Schizophrenia Research, 136*, S66–S67. https://doi.org/10.1016/s0920-9964(12)70248-7

Dam, D. S. van, Ven, E. van der, Velthorst, E., Selten, J. P., Morgan, C., & Haan, L. de (2012). Childhood bullying and the association with psychosis in non-clinical and clinical samples: A review and meta-analysis. *Psychological Medicine, 42*(12), 2463–2474. https://doi.org/10.1017/s0033291712000360

Das-Munshi, J., Bécares, L., Boydell, J. E., Dewey, M. E., Morgan, C., Stansfeld, S. A., & Prince, M. J. (2012). Ethnic density as a buffer for psychotic experiences: Findings from a national survey (EMPIRIC). *British Journal of Psychiatry, 201*(4), 282–290. https://doi.org/10.1192/bjp.bp.111.102376

Davis, K. A. S., Coleman, J. R. I., Adams, M., Allen, N., Breen, G., Cullen, B., Dickens, C., Fox, E., Graham, N., Holliday, J., Howard, L. M., John, A., Lee, W., McCabe, R.,

McIntosh, A., Pearsall, R., Smith, D. J., Sudlow, C., Ward, J., … Hotopf, M. (2020). Mental health in UK Biobank development, implementation and results from an online questionnaire completed by 157 366 participants: A reanalysis. *BJPsych Open, 6*(2). https://doi.org/10.1192/bjo.2019.100

Degenhardt, F., Seifert, S., & Szymczak, S. (2019). Evaluation of variable selection methods for random forests and omics data sets. *Briefings in Bioinformatics, 20*(2), 492–503. https://doi.org/10.1093/bib/bbx124

Del-Ben, C. M., Shuhama, R., Loureiro, C. M., Ragazzi, T. C. C., Zanatta, D. P., Tenan, S. H. G., Ferreira Santos, J. L., Louzada-Junior, P., Santos, A. C. dos, Morgan, C., & Menezes, P. R. (2019). Urbanicity and risk of first-episode psychosis: Incidence study in Brazil. *British Journal of Psychiatry, 215*(6), 726–729. https://doi.org/10.1192/bjp.2019.110

DeVylder, J. E., Burnette, D., & Yang, L. H. (2014a). Co-occurrence of psychotic experiences and common mental health conditions across four racially and ethnically diverse population samples. *Psychological Medicine, 44*(16), 3503–3513. https://doi.org/10.1017/s0033291714000944

DeVylder, J. E., Kelleher, I., Lalane, M., Oh, H., Link, B. G., & Koyanagi, A. (2018). Association of urbanicity with psychosis in low- and middle-income countries. *JAMA Psychiatry, 75*(7), 678. https://doi.org/10.1001/jamapsychiatry.2018.0577

DeVylder, J. E., Lukens, E. P., Link, B. G., & Lieberman, J. A. (2015). Suicidal ideation and Suicide Attempts among adults with psychotic experiences. *JAMA Psychiatry, 72* (3), 219. https://doi.org/10.1001/jamapsychiatry.2014.2663

DeVylder, J. E., Oh, H. Y., Corcoran, C. M., & Lukens, E. P. (2014b). Treatment seeking and Unmet need for Care among Persons reporting psychosis-like experiences. *Psychiatric Services, 65*(6), 774–780. https://doi.org/10.1176/appi.ps.201300254

Di Forti, M., Marconi, A., Carra, E., Fraietta, S., Trotta, A., Bonomo, M., Bianconi, F., Gardner-Sood, P., O'Connor, J., Russo, M., Stilo, S. A., Marques, T. R., Mondelli, V., Dazzan, P., Pariante, C., David, A. S., Gaughran, F., Atakan, Z., Iyegbe, C., … Murray, R. M. (2015). Proportion of patients in south London with first-episode psychosis attributable to use of high potency cannabis: A case-control study. *The Lancet Psychiatry, 2*(3), 233–238. https://doi.org/10.1016/s2215-0366(14)00117-5

Di Forti, M., Quattrone, D., Freeman, T. P., Tripoli, G., Gayer-Anderson, C., Quigley, H., Rodriguez, V., Jongsma, H. E., Ferraro, L., La Cascia, C., La Barbera, D., Tarricone, I., Berardi, D., Szöke, A., Arango, C., Tortelli, A., Velthorst, E., Bernardo, M., Del-Ben, C. M., … Ven, E. van der (2019). The contribution of cannabis use to variation in the incidence of psychotic disorder across Europe (EU-GEI): A multicentre case-control study. *The Lancet Psychiatry, 6*(5), 427–436. https://doi.org/10.1016/s2215-0366(19)30048-3

Ebisu, K., Holford, T. R., & Bell, M. L. (2016). Association between greenness, urbanicity, and birth weight. *Science of the Total Environment, 542*, 750–756. https://doi.org/10.1016/j.scitotenv.2015.10.111

Engemann, K., Pedersen, C. B., Agerbo, E., Arge, L., Børglum, A. D., Erikstrup, C., Hertel, O., Hougaard, D. M., McGrath, J. J., Mors, O., Mortensen, P. B., Nordentoft, M., Sabel, C. E., Sigsgaard, T., Tsirogiannis, C., Vilhjálmsson, B. J., Werge, T., Svenning, J.-C., & Horsdal, H. T. (2020). Association between childhood green space, genetic liability, and the incidence of schizophrenia. *Schizophrenia Bulletin, 46*(6), 1629–1637. https://doi.org/10.1093/schbul/sbaa058

Engemann, K., Pedersen, C. B., Arge, L., Tsirogiannis, C., Mortensen, P. B., & Svenning, J.-C. (2018). Childhood exposure to green space A novel risk-decreasing mechanism for schizophrenia? *Schizophrenia Research, 199*, 142–148. https://doi.org/10.1016/j.schres.2018.03.026

Europe, W. R. O. for (2012). *Environmental health inequalities in europe. Assessment report.* Regional Office for Europe Copenhagen: World Health Organization.

Faravelli, C., Amedei, S. G., Rotella, F., Faravelli, L., Palla, A., Consoli, G., Ricca, V., Batini, S., Sauro, C. L., Spiti, A., & dell'Osso, M. C. (2010). Childhood traumata, Dexamethasone Suppression test and psychiatric symptoms: A trans-diagnostic approach. *Psychological Medicine, 40*(12), 2037–2048. https://doi.org/10.1017/s0033291710000115

Fett, A.-K. J., Lemmers-Jansen, I. L. J., & Krabbendam, L. (2019). Psychosis and urbanicity. *Current Opinion in Psychiatry, 32*(3), 232–241. https://doi.org/10.1097/yco.0000000000000486

Fisher, H. L., Schreier, A., Zammit, S., Maughan, B., Munafo, M. R., Lewis, G., & Wolke, D. (2012). Pathways between childhood Victimization and psychosis-like symptoms in the ALSPAC birth cohort. *Schizophrenia Bulletin, 39*(5), 1045–1055. https://doi.org/10.1093/schbul/sbs088

Fong, K. C., Hart, J. E., & James, P. (2018). A review of Epidemiologic studies on greenness and health: Updated literature through 2017. *Current Environmental Health Reports, 5*(1), 77–87. https://doi.org/10.1007/s40572-018-0179-y

Gage, S. H., Hickman, M., & Zammit, S. (2016). Association between cannabis and psychosis: Epidemiologic evidence. *Biological Psychiatry, 79*(7), 549–556. https://doi.org/10.1016/j.biopsych.2015.08.001

Galea, S., Uddin, M., & Koenen, K. (2011). The urban environment and mental disorders: Epigenetic links. *Epigenetics, 6*(4), 400–404. https://doi.org/10.4161/epi.6.4.14944

Gascon, M., Triguero-Mas, M., Martínez, D., Dadvand, P., Forns, J., Plasència, A., & Nieuwenhuijsen, M. (2015). Mental health benefits of long-term exposure to residential green and blue spaces: A systematic review. *International Journal of Environmental Research and Public Health, 12*(4), 4354–4379. https://doi.org/10.3390/ijerph120404354

Gascon, M., Zijlema, W., Vert, C., White, M. P., & Nieuwenhuijsen, M. J. (2017). Outdoor blue spaces, human health and well-being: A systematic review of quantitative studies. *International Journal of Hygiene and Environmental Health, 220*(8), 1207–1221. https://doi.org/10.1016/j.ijheh.2017.08.004

Gayer-Anderson, C., & Morgan, C. (2012). Social networks, support and early psychosis: A systematic review. *Epidemiology and Psychiatric Sciences, 22*(2), 131–146. https://doi.org/10.1017/s2045796012000406

Gidlöf-Gunnarsson, A., & Öhrström, E. (2007). Noise and well-being in urban residential environments: The potential role of perceived availability to nearby green areas. *Landscape and Urban Planning, 83*(2–3), 115–126. https://doi.org/10.1016/j.landurbplan.2007.03.003

Gillham, B., Tanner, G., Cheyne, B., Freeman, I., Rooney, M., & Lambie, A. (1998). Unemployment rates, single parent density, and indices of child poverty: Their relationship to different categories of child abuse and neglect. *Child Abuse & Neglect, 22*(2), 79–90. https://doi.org/10.1016/s0145-2134(97)00134-8

Gorelick, M. H. (2006). Bias arising from missing data in predictive models. *Journal of Clinical Epidemiology, 59*(10), 1115–1123. https://doi.org/10.1016/j.jclinepi.2004.11.029

Gottesman, I. I., & Gould, T. D. (2003). The Endophenotype Concept in Psychiatry: Etymology and strategic Intentions. *American Journal of Psychiatry, 160*(4), 636–645. https://doi.org/10.1176/appi.ajp.160.4.636

Grace, A. A. (2016). Dysregulation of the dopamine system in the pathophysiology of schizophrenia and depression. *Nature Reviews Neuroscience, 17*(8), 524–532. https://doi.org/10.1038/nrn.2016.57

Green, M. J., Girshkin, L., Teroganova, N., & Quidé, Y. (2014). *Stress, schizophrenia and bipolar disorder*. Springer Berlin Heidelberg. https://doi.org/10.1007/7854_2014_290

Gu, Q., Cai, Z., Zhu, L., & Huang, B. (2008). Data mining on imbalanced data sets. In *2008 International Conference on Advanced computer theory and Engineering*. https://doi.org/10.1109/icacte.2008.26

Guloksuz, S., Pries, L.-K., Delespaul, P., Kenis, G., Luykx, J. J., Lin, B. D., Richards, A. L., Akdede, B., Binbay, T., Altınyazar, V., Yalınçetin, B., Gümüş-Akay, G., Cihan, B., Soygür, H., Ulaş, H., Cankurtaran, E., Kaymak, S. U., Mihaljevic, M. M., Petrovic, S. A., … Os, J. van (2019). Examining the independent and joint effects of molecular genetic liability and environmental exposures in schizophrenia: Results from the EUGEI study. *World Psychiatry, 18*(2), 173–182. https://doi.org/10.1002/wps.20629

Guloksuz, S., Rutten, B. P. F., Pries, L.-K., Have, M. ten, Graaf, R. de, Dorsselaer, S. van, Klingenberg, B., Os, J. van, & Ioannidis, J. P. A. (2018). The Complexities of evaluating the exposome in Psychiatry: A data-driven Illustration of challenges and some Propositions for Amendments. *Schizophrenia Bulletin, 44*(6), 1175–1179. https://doi.org/10.1093/schbul/sby118

Häfner, H., Löffler, W., Maurer, K., Hambrecht, M., & Heiden, W. an der (1999). Depression, negative symptoms, social stagnation and social decline in the early course of schizophrenia. *Acta Psychiatrica Scandinavica, 100*(2), 105–118. https://doi.org/10.1111/j.1600-0447.1999.tb10831.x

Habets, P., Marcelis, M., Gronenschild, E., Drukker, M., & Os, J. van (2011). Reduced Cortical Thickness as an outcome of Differential sensitivity to environmental risks in schizophrenia. *Biological Psychiatry, 69*(5), 487–494. https://doi.org/10.1016/j.biopsych.2010.08.010

Haddad, L., Schafer, A., Streit, F., Lederbogen, F., Grimm, O., Wust, S., Deuschle, M., Kirsch, P., Tost, H., & Meyer-Lindenberg, A. (2014). Brain structure correlates of urban upbringing, an environmental risk factor for schizophrenia. *Schizophrenia Bulletin, 41*(1), 115–122. https://doi.org/10.1093/schbul/sbu072

Hajat, A., Hsia, C., & O'Neill, M. S. (2015). Socioeconomic disparities and air pollution exposure: A global review. *Current Environmental Health Reports, 2*(4), 440–450. https://doi.org/10.1007/s40572-015-0069-5

Han, H., Guo, X., & Yu, H. (2016). *2016 7th IEEE international conference on software engineering and service science (ICSESS)*. https://doi.org/10.1109/ICSESS.2016.7883053

Hardoon, S., Hayes, J. F., Blackburn, R., Petersen, I., Walters, K., Nazareth, I., & Osborn, D. P. J. (2013). Recording of severe mental illness in United Kingdom primary Care, 20002010. *PLoS One, 8*(12), Article e82365. https://doi.org/10.1371/journal.pone.0082365

Hartig, T., Mitchell, R., Vries, S. de, & Frumkin, H. (2014). Nature and health. *Annual Review of Public Health, 35*(1), 207–228. https://doi.org/10.1146/annurev-publhealth-032013-182443

Hasin, D. S., Shmulewitz, D., & Sarvet, A. L. (2019). Time trends in US cannabis use and cannabis use disorders overall and by sociodemographic subgroups: A narrative review and new findings. *The American Journal of Drug and Alcohol Abuse, 45*(6), 623–643. https://doi.org/10.1080/00952990.2019.1569668

Healy, C., Brannigan, R., Dooley, N., Coughlan, H., Clarke, M., Kelleher, I., & Cannon, M. (2019). Childhood and adolescent psychotic experiences and risk of mental disorder: A systematic review and meta-analysis. *Psychological Medicine, 49*(10), 1589–1599. https://doi.org/10.1017/s0033291719000485

Heinrichs, M., Baumgartner, T., Kirschbaum, C., & Ehlert, U. (2003). Social support and oxytocin interact to suppress cortisol and subjective responses to psychosocial stress. *Biological Psychiatry, 54*(12), 1389–1398. https://doi.org/10.1016/s0006-3223(03)00465-7

Heinz, A., Deserno, L., & Reininghaus, U. (2013). Urbanicity, social adversity and psychosis. *World Psychiatry, 12*(3), 187–197. https://doi.org/10.1002/wps.20056

Henquet, C. (2005). The environment and schizophrenia: The role of cannabis Use. *Schizophrenia Bulletin, 31*(3), 608–612. https://doi.org/10.1093/schbul/sbi027

Hoerl, A. E., & Kennard, R. W. (1970). Ridge regression: Biased estimation for Nonorthogonal problems. *Technometrics, 12*(1), 55–67. https://doi.org/10.1080/00401706.1970.10488634

Hou, C.-L., Chen, M.-Y., Cai, M.-Y., Chen, Z.-L., Cai, S.-B., Xiao, Y.-N., & Jia, F.-J. (2018). Antipsychotic-free status in community-dwelling patients with schizophrenia in China. *The Journal of Clinical Psychiatry, 79*(3). https://doi.org/10.4088/jcp.17m11599

House, J. S. (2001). Social isolation Kills, but how and why? *Psychosomatic Medicine, 63* (2), 273–274. https://doi.org/10.1097/00006842-200103000-00011

Howes, O. D., & Kapur, S. (2009). The dopamine hypothesis of schizophrenia: Version III–the final common pathway. *Schizophrenia Bulletin, 35*(3), 549–562. https://doi.org/10.1093/schbul/sbp006

Howes, O. D., McDonald, C., Cannon, M., Arseneault, L., Boydell, J., & Murray, R. M. (2004). Pathways to schizophrenia: The impact of environmental factors. *The International Journal of Neuropsychopharmacology, 7*(5), S7–S13. https://doi.org/10.1017/s1461145704004122

Ivory, V. C., Collings, S. C., Blakely, T., & Dew, K. (2011). When does neighbourhood matter? Multilevel relationships between neighbourhood social fragmentation and mental health. *Social Science & Medicine, 72*(12), 1993–2002. https://doi.org/10.1016/j.socscimed.2011.04.015

James, P., Banay, R. F., Hart, J. E., & Laden, F. (2015). A review of the health benefits of greenness. *Current Epidemiology Reports, 2*(2), 131–142. https://doi.org/10.1007/s40471-015-0043-7

Jariwala, H. J., Syed, H. S., Pandya, M. J., & Gajera, Y. M. (2017). Noise pollution & human health: A review. *Indoor and Built Environment, 1*(1), 1–4.

Jongsma, H. E., Turner, C., Kirkbride, J. B., & Jones, P. B. (2019). International incidence of psychotic disorders, 200217: A systematic review and meta-analysis. *The Lancet Public Health, 4*(5), e229–e244. https://doi.org/10.1016/s2468-2667(19)30056-8

Kühn, S., Düzel, S., Eibich, P., Krekel, C., Wüstemann, H., Kolbe, J., Martensson, J., Goebel, J., Gallinat, J., Wagner, G. G., & Lindenberger, U. (2017). In search of features that constitute an "enriched environment" in humans: Associations between geographical properties and brain structure. *Scientific Reports, 7*(1). https://doi.org/10.1038/s41598-017-12046-7

Kaczynski, A. T., & Henderson, K. A. (2007). Environmental correlates of physical activity: A review of evidence about Parks and Recreation. *Leisure Sciences, 29*(4), 315–354. https://doi.org/10.1080/01490400701394865

Kaplan, S. (1995). The restorative benefits of nature: Toward an integrative framework. *Journal of Environmental Psychology, 15*(3), 169–182. https://doi.org/10.1016/0272-4944(95)90001-2

Kaplan, R., & Kaplan, S. (1989). *The experience of nature: A psychological perspective.* Cambridge university press.

Kaplan, S., & Talbot, J. F. (1983). *Psychological benefits of a wilderness experience.* Springer US. https://doi.org/10.1007/978-1-4613-3539-9_6

Karcher, N. R., Schiffman, J., & Barch, D. M. (2021). Environmental risk factors and psychotic-like experiences in children aged 910. *Journal of the American Academy of Child & Adolescent Psychiatry, 60*(4), 490–500. https://doi.org/10.1016/j.jaac.2020.07.003

Kaymaz, N., Drukker, M., Lieb, R., Wittchen, H.-U., Werbeloff, N., Weiser, M., Lataster, T., & Os, J. van (2012). Do subthreshold psychotic experiences predict clinical outcomes in unselected non-help-seeking population-based samples? A systematic review and meta-analysis, enriched with new results. *Psychological Medicine, 42*(11), 2239–2253. https://doi.org/10.1017/s0033291711002911

Kelleher, I., Keeley, H., Corcoran, P., Lynch, F., Fitzpatrick, C., Devlin, N., Molloy, C., Roddy, S., Clarke, M. C., Harley, M., Arseneault, L., Wasserman, C., Carli, V., Sarchiapone, M., Hoven, C., Wasserman, D., & Cannon, M. (2012). Clinicopathological significance of psychotic experiences in non-psychotic young people: Evidence from four population-based studies. *British Journal of Psychiatry, 201*(1), 26–32. https://doi.org/10.1192/bjp.bp.111.101543

Kelly, B. D., O'Callaghan, E., Waddington, J. L., Feeney, L., Browne, S., Scully, P. J., Clarke, M., Quinn, J. F., McTigue, O., Morgan, M. G., Kinsella, A., & Larkin, C. (2010). Schizophrenia and the city: A review of literature and prospective study of psychosis and urbanicity in Ireland. *Schizophrenia Research, 116*(1), 75–89. https://doi.org/10.1016/j.schres.2009.10.015

Kim, H., & Drake, B. (2018). Child maltreatment risk as a function of poverty and race/ethnicity in the USA. *International Journal of Epidemiology, 47*(3), 780–787. https://doi.org/10.1093/ije/dyx280

Kirkbride, J. B., Barker, D., Cowden, F., Stamps, R., Yang, M., Jones, P. B., & Coid, J. W. (2008). Psychoses, ethnicity and socio-economic status. *British Journal of Psychiatry, 193*(1), 18–24. https://doi.org/10.1192/bjp.bp.107.041566

Kirkbride, J. B., Boydell, J., Ploubidis, G. B., Morgan, C., Dazzan, P., McKenzie, K., Murray, R. M., & Jones, P. B. (2007a). Testing the association between the incidence of schizophrenia and social capital in an urban area. *Psychological Medicine, 38*(8), 1083–1094. https://doi.org/10.1017/s0033291707002085

Kirkbride, J. B., Fearon, P., Morgan, C., Dazzan, P., Morgan, K., Murray, R. M., & Jones, P. B. (2007b). Neighbourhood variation in the incidence of psychotic disorders in Southeast London. *Social Psychiatry and Psychiatric Epidemiology, 42*(6), 438–445. https://doi.org/10.1007/s00127-007-0193-0

Kirkbride, J. B., Jones, P. B., Ullrich, S., & Coid, J. W. (2012). Social deprivation, inequality, and the neighborhood-level incidence of psychotic Syndromes in East London. *Schizophrenia Bulletin, 40*(1), 169–180. https://doi.org/10.1093/schbul/sbs151

Kirkbride, J. B., Morgan, C., Fearon, P., Dazzan, P., Murray, R. M., & Jones, P. B. (2007c). Neighbourhood-level effects on psychoses: Re-examining the role of context. *Psychological Medicine, 37*(10), 1413–1425. https://doi.org/10.1017/s0033291707000499

Kondo, M., Fluehr, J., McKeon, T., & Branas, C. (2018). Urban green space and its impact on human health. *International Journal of Environmental Research and Public Health, 15*(3), 445. https://doi.org/10.3390/ijerph15030445

Krabbendam, L. (2005). Schizophrenia and urbanicity: A major environmental influence–Conditional on genetic risk. *Schizophrenia Bulletin, 31*(4), 795–799. https://doi.org/10.1093/schbul/sbi060

Kuhn, M. (2022). Caret: Classification and regression training. https://CRAN.R-project.org/package=caret.

Kuo, M. (2015). How might contact with nature promote human health? Promising mechanisms and a possible central pathway. *Frontiers in Psychology, 6.* https://doi.org/10.3389/fpsyg.2015.01093

Kursa, M. B. (2013). Robustness of random forest-based gene selection methods. https://doi.org/10.48550/ARXIV.1305.4525.

Kursa, M. B., & Rudnicki, W. R. (2010a). *Feature selection with the boruta package* (Vol. 36). https://doi.org/10.18637/jss.v036.i11

Kursa, M. B., & Rudnicki, W. R. (2010b). Feature selection with the**Boruta**Package. *Journal of Statistical Software, 36*(11). https://doi.org/10.18637/jss.v036.i11

Laursen, T. M., & Munk-Olsen, T. (2007). A comparison of selected risk factors for unipolar depressive disorder, bipolar affective disorder, schizoaffective disorder, and schizophrenia from a Danish population-based cohort. *The Journal of Clinical Psychiatry, 68*(11), 1673–1681. https://doi.org/10.4088/jcp.v68n1106

Leaune, E., Dealberto, M.-J., Luck, D., Grot, S., Zeroug-Vial, H., Poulet, E., & Brunelin, J. (2018). Ethnic minority position and migrant status as risk factors for psychotic symptoms in the general population: A meta-analysis. *Psychological Medicine, 49*(4), 545–558. https://doi.org/10.1017/s0033291718002271

Leavy, R. L. (1983). Social support and psychological disorder: A review. *Journal of Community Psychology, 11*(1), 3–21. https://doi.org/10.1002/1520-6629(198301)11:1<3::aid-jcop2290110102>3.0.co;2-e

Lederbogen, F., Kirsch, P., Haddad, L., Streit, F., Tost, H., Schuch, P., Wüst, S., Pruessner, J. C., Rietschel, M., Deuschle, M., & Meyer-Lindenberg, A. (2011). City living and urban upbringing affect neural social stress processing in humans. *Nature, 474*(7352), 498–501. https://doi.org/10.1038/nature10190

Lee, A. C. K., & Maheswaran, R. (2010). The health benefits of urban green spaces: A review of the evidence. *Journal of Public Health, 33*(2), 212–222. https://doi.org/10.1093/pubmed/fdq068

Liaw, A., & Wiener, M. (2002). *Classification and regression by randomForest* (Vol. 2, pp. 18–22). https://CRAN.R-project.org/doc/Rnews/.

Lim, M. H., Gleeson, J. F., Jackson, H. J., & Fernandez, K. C. (2013). Social relationships and quality of life moderate distress associated with delusional ideation. *Social Psychiatry and Psychiatric Epidemiology, 49*(1), 97–107. https://doi.org/10.1007/s00127-013-0738-3

Linscott, R. J., & Os, J. van (2012). An updated and conservative systematic review and meta-analysis of epidemiological evidence on psychotic experiences in children and adults: On the pathway from proneness to persistence to dimensional expression across mental disorders. *Psychological Medicine, 43*(6), 1133–1149. https://doi.org/10.1017/s0033291712001626

Loch, A. A., Chianca, C., Alves, T. M., Freitas, E. L., Hortêncio, L., Andrade, J. C., Bilt, M. T. van de, Fontoni, M. R., Serpa, M. H., Gattaz, W. F., & Rössler, W. (2017). Poverty, low education, and the expression of psychotic-like experiences in the general population of São Paulo, Brazil. *Psychiatry Research, 253*, 182–188. https://doi.org/10.1016/j.psychres.2017.03.052

Maas, J., Dillen, S. M. E. van, Verheij, R. A., & Groenewegen, P. P. (2009). Social contacts as a possible mechanism behind the relation between green space and health. *Health & Place, 15*(2), 586–595. https://doi.org/10.1016/j.healthplace.2008.09.006

Maas, J., Verheij, R. A., Spreeuwenberg, P., & Groenewegen, P. P. (2008). Physical activity as a possible mechanism behind the relationship between green space and health: A multilevel analysis. *BMC Public Health, 8*(1). https://doi.org/10.1186/1471-2458-8-206

Maguire-Jack, K., Lanier, P., Johnson-Motoyama, M., Welch, H., & Dineen, M. (2015). Geographic variation in racial disparities in child maltreatment: The influence of county poverty and population density. *Child Abuse & Neglect, 47*, 1–13. https://doi.org/10.1016/j.chiabu.2015.05.020

Mamah, D., Mutiso, V. N., & Ndetei, D. M. (2021). Psychotic-like experiences among 9,564 Kenyan adolescents and young adults. *Psychiatry Research, 302*, Article 113994. https://doi.org/10.1016/j.psychres.2021.113994

Markevych, I., Schoierer, J., Hartig, T., Chudnovsky, A., Hystad, P., Dzhambov, A. M., Vries, S. de, Triguero-Mas, M., Brauer, M., Nieuwenhuijsen, M. J., Lupp, G., Richardson, E. A., Astell-Burt, T., Dimitrova, D., Feng, X., Sadeh, M., Standl, M., Heinrich, J., & Fuertes, E. (2017). Exploring pathways linking greenspace to health: Theoretical and methodological guidance. *Environmental Research, 158*, 301–317. https://doi.org/10.1016/j.envres.2017.06.028

Matheson, S. L., Shepherd, A. M., Pinchbeck, R. M., Laurens, K. R., & Carr, V. J. (2012). Childhood adversity in schizophrenia: A systematic meta-analysis. *Psychological Medicine, 43*(2), 225–238. https://doi.org/10.1017/s0033291712000785

Mayer, M. (2021). missRanger: Fast imputation of missing values. https://CRAN.R-project.org/package=missRanger.

McCormick, R. (2017). Does access to green space impact the mental well-being of children: A systematic review. *Journal of Pediatric Nursing, 37*, 3–7. https://doi.org/10.1016/j.pedn.2017.08.027

McGrath, J. J., Saha, S., Al-Hamzawi, A., Andrade, L., Benjet, C., Bromet, E. J., Browne, M. O., Caldas de Almeida, J. M., Chiu, W. T., Demyttenaere, K., Fayyad, J., Florescu, S., Girolamo, G. de, Gureje, O., Haro, J. M., Have, M. ten, Hu, C., Kovess-Masfety, V., Lim, C. C. W., … Kessler, R. C. (2016). The Bidirectional associations between psychotic experiences and DSM-IV mental disorders. *American Journal of Psychiatry, 173*(10), 997–1006. https://doi.org/10.1176/appi.ajp.2016.15101293

McGrath, J., Saha, S., Welham, J., El Saadi, O., MacCauley, C., & Chant, D. (2004). A systematic review of the incidence of schizophrenia: The distribution of rates and the influence of sex, urbanicity, migrant status and methodology. *BMC Medicine, 2* (1). https://doi.org/10.1186/1741-7015-2-13

Meltzer, H., Bebbington, P., Dennis, M. S., Jenkins, R., McManus, S., & Brugha, T. S. (2012). Feelings of loneliness among adults with mental disorder. *Social Psychiatry and Psychiatric Epidemiology, 48*(1), 5–13. https://doi.org/10.1007/s00127-012-0515-8

Minozzi, S., Davoli, M., Bargagli, A. M., Amato, L., Vecchi, S., & Perucci, C. A. (2009). An overview of systematic reviews on cannabis and psychosis: Discussing apparently conflicting results. *Drug and Alcohol Review, 29*(3), 304–317. https://doi.org/10.1111/j.1465-3362.2009.00132.x

Mizrahi, R. (2015). Social stress and psychosis risk: Common neurochemical Substrates? *Neuropsychopharmacology, 41*(3), 666–674. https://doi.org/10.1038/npp.2015.274

Moller, P., & Husby, R. (2000). The Initial Prodrome in schizophrenia: Searching for Naturalistic core Dimensions of experience and behavior. *Schizophrenia Bulletin, 26*(1), 217–232. https://doi.org/10.1093/oxfordjournals.schbul.a033442

Monroe, S. M., & Simons, A. D. (1991). Diathesis-stress theories in the context of life stress research: Implications for the depressive disorders. *Psychological Bulletin, 110*(3), 406–425. https://doi.org/10.1037/0033-2909.110.3.406

Moons, K. G. M., Altman, D. G., Reitsma, J. B., Loannidis, J. P. A., Macaskill, P., Steyerberg, E. W., Vickers, A. J., Ransohoff, D. F., & Collins, G. S. (2022). Transparent reporting of a multivariable prediction model for individual prognosis or diagnosis (TRIPOD): Explanation and elaboration. Translation in to Russian. *Digital Diagnostics, 3*(3), 232–322. https://doi.org/10.17816/dd110794

Moore, T. H., Zammit, S., Lingford-Hughes, A., Barnes, T. R., Jones, P. B., Burke, M., & Lewis, G. (2007). Cannabis use and risk of psychotic or affective mental health outcomes: A systematic review. *The Lancet, 370*(9584), 319–328. https://doi.org/10.1016/s0140-6736(07)61162-3

Morello-Frosch, R., & Shenassa, E. D. (2006). The environmental "Riskscape" and social inequality: Implicationsfor explaining Maternal and child health disparities. *Environmental Health Perspectives, 114*(8), 1150–1153. https://doi.org/10.1289/ehp.8930

Morgan, C., & Fisher, H. (2006). Environment and schizophrenia: Environmental factors in schizophrenia: Childhood trauma–A critical review. *Schizophrenia Bulletin, 33*(1), 3–10. https://doi.org/10.1093/schbul/sbl053

Morgan, V. A., Waterreus, A., Carr, V., Castle, D., Cohen, M., Harvey, C., Galletly, C., Mackinnon, A., McGorry, P., McGrath, J. J., Neil, A. L., Saw, S., Badcock, J. C., Foley, D. L., Waghorn, G., Coker, S., & Jablensky, A. (2016). Responding to challenges for people with psychotic illness: Updated evidence from the survey of high impact psychosis. *Australian and New Zealand Journal of Psychiatry, 51*(2), 124–140. https://doi.org/10.1177/0004867416679738

Morgan, V. A., Waterreus, A., Jablensky, A., Mackinnon, A., McGrath, J. J., Carr, V., Bush, R., Castle, D., Cohen, M., Harvey, C., Galletly, C., Stain, H. J., Neil, A. L., McGorry, P., Hocking, B., Shah, S., & Saw, S. (2012). People living with psychotic illness in 2010: The second Australian national survey of psychosis. *Australian and New Zealand Journal of Psychiatry, 46*(8), 735–752. https://doi.org/10.1177/0004867412449877

Mortensen, P. B., Pedersen, C. B., Westergaard, T., Wohlfahrt, J., Ewald, H., Mors, O., Andersen, P. K., & Melbye, M. (1999). Effects of Family history and place and Season of birth on the risk of schizophrenia. *New England Journal of Medicine, 340*(8), 603–608. https://doi.org/10.1056/nejm199902253400803

Murphy, J., Shevlin, M., Houston, J., & Adamson, G. (2010). A population based analysis of subclinical psychosis and help-seeking behavior. *Schizophrenia Bulletin, 38*(2), 360–367. https://doi.org/10.1093/schbul/sbq092

Narita, Z., Banawa, R., Zhou, S., DeVylder, J., Koyanagi, A., & Oh, H. (2022). Loneliness and psychotic experiences among US university students: Findings from the Healthy Minds Study 2020. *Psychiatry Research, 308*, Article 114362. https://doi.org/10.1016/j.psychres.2021.114362

Narita, Z., Stickley, A., & DeVylder, J. (2020). Loneliness and psychotic experiences in a general population sample. *Schizophrenia Research, 218*, 146–150. https://doi.org/10.1016/j.schres.2020.01.018

Narita, Z., Wilcox, H. C., & DeVylder, J. (2020). Psychotic experiences and suicidal outcomes in a general population sample. *Schizophrenia Research, 215*, 223–228. https://doi.org/10.1016/j.schres.2019.10.024

Newbury, J., Arseneault, L., Beevers, S., Kitwiroon, N., Roberts, S., Pariante, C. M., Kelly, F. J., & Fisher, H. L. (2019). Association of air pollution exposure with psychotic experiences during adolescence. *JAMA Psychiatry, 76*(6), 614. https://doi.org/10.1001/jamapsychiatry.2019.0056

Newbury, J., Arseneault, L., Caspi, A., Moffitt, T. E., Odgers, C. L., & Fisher, H. L. (2016). Why are children in urban neighborhoods at increased risk for psychotic symptoms? Findings from a UK longitudinal cohort study. *Schizophrenia Bulletin, 42*(6), 1372–1383. https://doi.org/10.1093/schbul/sbw052

Nierop, M. van, Janssens, M., Bruggeman, R., Cahn, W., Haan, L. de, Kahn, R. S., Meijer, C. J., Myin-Germeys, I., Os, J. van, & Wiersma, D. (2013). Evidence that transition from health to psychotic disorder can be Traced to Semi-Ubiquitous environmental effects operating against background genetic risk. *PLoS One, 8*(11), Article e76690. https://doi.org/10.1371/journal.pone.0076690

Nierop, M. van, Viechtbauer, W., Gunther, N., Zelst, C. van, Graaf, R. de, Have, M. ten, Dorsselaer, S. van, Bak, M., & Winkel, R. van (2014). Childhood trauma is associated with a specific admixture of affective, anxiety, and psychosis symptoms cutting across traditional diagnostic boundaries. *Psychological Medicine, 45*(6), 1277–1288. https://doi.org/10.1017/s0033291714002372

Nowak, D. J., Crane, D. E., & Stevens, J. C. (2006). Air pollution removal by urban trees and shrubs in the United States. *Urban Forestry and Urban Greening, 4*(3–4), 115–123. https://doi.org/10.1016/j.ufug.2006.01.007

O'Donoghue, B., Roche, E., & Lane, A. (2016). Neighbourhood level social deprivation and the risk of psychotic disorders: A systematic review. *Social Psychiatry and Psychiatric Epidemiology, 51*(7), 941–950. https://doi.org/10.1007/s00127-016-1233-4

O'Neill, M. S., Jerrett, M., Kawachi, I., Levy, J. I., Cohen, A. J., Gouveia, N., Wilkinson, P., Fletcher, T., Cifuentes, L., & Schwartz, J. (2003). Health, wealth, and air pollution: Advancing theory and methods. *Environmental Health Perspectives, 111*(16), 1861–1870. https://doi.org/10.1289/ehp.6334

Ochoa, S., Usall, J., Cobo, J., Labad, X., & Kulkarni, J. (2012). Gender Differences in schizophrenia and first-episode psychosis: A comprehensive literature review. *Schizophrenia Research and Treatment, 2012*, 1–9. https://doi.org/10.1155/2012/916198

Ohly, H., White, M. P., Wheeler, B. W., Bethel, A., Ukoumunne, O. C., Nikolaou, V., & Garside, R. (2016). Attention restoration theory: A systematic review of the attention restoration potential of exposure to natural environments. *Journal of Toxicology and Environmental Health, Part A B, 19*(7), 305–343. https://doi.org/10.1080/10937404.2016.1196155

Omer, S., Kirkbride, J. B., Pringle, D. G., Russell, V., O'Callaghan, E., & Waddington, J. L. (2014). Neighbourhood-level socio-environmental factors and incidence of first episode psychosis by place at onset in rural Ireland: The CavanMonaghan First Episode Psychosis Study [CAMFEPS]. *Schizophrenia Research, 152*(1), 152–157. https://doi.org/10.1016/j.schres.2013.11.019

Orrù, G., Pettersson-Yeo, W., Marquand, A. F., Sartori, G., & Mechelli, A. (2012). Using support Vector Machine to identify imaging biomarkers of neurological and psychiatric disease: A critical review. *Neuroscience & Biobehavioral Reviews, 36*(4), 1140–1152. https://doi.org/10.1016/j.neubiorev.2012.01.004

Os, J. van (2002). Cannabis use and psychosis: A longitudinal population-based study. *American Journal of Epidemiology, 156*(4), 319–327. https://doi.org/10.1093/aje/kwf043

Os, J. van, Driessen, G., Gunther, N., & Delespaul, P. (2000). Neighbourhood variation in schizophrenia incidence: Evidence for person-environment interaction. *Schizophrenia Research, 41*(1), 66. https://doi.org/10.1016/s0920-9964(00)90448-1

Os, J. van, Linscott, R. J., Myin-Germeys, I., Delespaul, P., & Krabbendam, L. (2008a). A systematic review and meta-analysis of the psychosis continuum: Evidence for a psychosis pronenesspersistenceimpairment model of psychotic disorder. *Psychological Medicine, 39*(2), 179–195. https://doi.org/10.1017/s0033291708003814

Os, J. van, Rutten, B. P., & Poulton, R. (2008b). Gene-environment interactions in schizophrenia: Review of epidemiological findings and future directions. *Schizophrenia Bulletin, 34*(6), 1066–1082. https://doi.org/10.1093/schbul/sbn117

Paksarian, D., Trabjerg, B. B., Merikangas, K. R., Mors, O., Børglum, A. D., Hougaard, D. M., McGrath, J. J., Pedersen, C. B., Mortensen, P. B., & Agerbo, E. (2017). The role of genetic liability in the association of urbanicity at birth and during upbringing with schizophrenia in Denmark. *Psychological Medicine, 48*(2), 305–314. https://doi.org/10.1017/s0033291717001696

Pedersen, C. B. (2001). Evidence of a dose-response relationship between urbanicity during upbringing and schizophrenia risk. *Archives of General Psychiatry, 58*(11), 1039–1046. https://doi.org/10.1001/archpsyc.58.11.1039

Perälä, J., Suvisaari, J., Saarni, S. I., Kuoppasalmi, K., Isometsä, E., Pirkola, S., Partonen, T., Tuulio-Henriksson, A., Hintikka, J., Kieseppä, T., Härkänen, T., Koskinen, S., & Lönnqvist, J. (2007). Lifetime prevalence of psychotic and bipolar I disorders in a general population. *Archives of General Psychiatry, 64*(1), 19. https://doi.org/10.1001/archpsyc.64.1.19

Polanczyk, G., Moffitt, T. E., Arseneault, L., Cannon, M., Ambler, A., Keefe, R. S. E., Houts, R., Odgers, C. L., & Caspi, A. (2010). Etiological and clinical features of childhood psychotic symptoms. *Archives of General Psychiatry, 67*(4), 328. https://doi.org/10.1001/archgenpsychiatry.2010.14

Powell, N. D., Sloan, E. K., Bailey, M. T., Arevalo, J. M. G., Miller, G. E., Chen, E., Kobor, M. S., Reader, B. F., Sheridan, J. F., & Cole, S. W. (2013). Social stress up-regulates inflammatory gene expression in the leukocyte transcriptome via β-adrenergic induction of myelopoiesis. *Proceedings of the National Academy of Sciences, 110*(41), 16574–16579. https://doi.org/10.1073/pnas.1310655110

Preuß, M., Nieuwenhuijsen, M., Marquez, S., Cirach, M., Dadvand, P., Triguero-Mas, M., Gidlow, C., Grazuleviciene, R., Kruize, H., & Zijlema, W. (2019). Low childhood nature exposure is associated with Worse mental health in adulthood. *International Journal of Environmental Research and Public Health, 16*(10), 1809. https://doi.org/10.3390/ijerph16101809

Putnam-Hornstein, E., Needell, B., King, B., & Johnson-Motoyama, M. (2013). Racial and ethnic disparities: A population-based examination of risk factors for involvement with child protective services. *Child Abuse & Neglect, 37*(1), 33–46. https://doi.org/10.1016/j.chiabu.2012.08.005

R Core Team. (2023). R: A language and environment for statistical computing. https://www.R-project.org/.

Rapp, M. A., Kluge, U., Penka, S., Vardar, A., Aichberger, M. C., Mundt, A. P., Schouler-Ocak, M., Mösko, M., Butler, J., Meyer-Lindenberg, A., & Heinz, A. (2015). When local poverty is more important than your income: Mental health in minorities in inner cities. *World Psychiatry, 14*(2), 249–250. https://doi.org/10.1002/wps.20221

Reeves, L. E., Anglin, D. M., Heimberg, R. G., Gibson, L. E., Fineberg, A. M., Maxwell, S. D., Kerns, C. M., & Ellman, L. M. (2014). Anxiety mediates the association between cannabis use and attenuated positive psychotic symptoms. *Psychiatry Research, 218*(1–2), 180–186. https://doi.org/10.1016/j.psychres.2014.03.040

Richardson, L., Hameed, Y., Perez, J., Jones, P. B., & Kirkbride, J. B. (2018). Association of environment with the risk of developing psychotic disorders in rural populations. *JAMA Psychiatry, 75*(1), 75. https://doi.org/10.1001/jamapsychiatry.2017.3582

Ritchie, H., & Roser, M. (2018). Urbanization. *Our World in Data*. https://ourworldindata.org/urbanization.

Ronald, A. (2015). Recent quantitative genetic research on psychotic experiences: New approaches to old questions. *Current Opinion in Behavioral Sciences, 2*, 81–88. https://doi.org/10.1016/j.cobeha.2014.10.001

Rook, G. A. (2013). Regulation of the immune system by biodiversity from the natural environment: An ecosystem service essential to health. *Proceedings of the National Academy of Sciences, 110*(46), 18360–18367. https://doi.org/10.1073/pnas.1313731110

Rook, G. A. W., Lowry, C. A., & Raison, C. L. (2013). Microbial 'Old Friends', immunoregulation and stress resilience. *Evolution, Medicine, and Public Health, 2013* (1), 46–64. https://doi.org/10.1093/emph/eot004

Saraceno, B., & Barbui, C. (1997). Poverty and mental illness. *Canadian Journal of Psychiatry, 42*(3), 285–290. https://doi.org/10.1177/070674379704200306

Sariaslan, A., Fazel, S., D'Onofrio, B. M., Långström, N., Larsson, H., Bergen, S. E., Kuja-Halkola, R., & Lichtenstein, P. (2016). Schizophrenia and subsequent neighborhood deprivation: Revisiting the social drift hypothesis using population, twin and molecular genetic data. *Translational Psychiatry, 6*(5). https://doi.org/10.1038/tp.2016.62. e796–e796.

Sariaslan, A., Larsson, H., D'Onofrio, B., Långström, N., Fazel, S., & Lichtenstein, P. (2014). Does population density and neighborhood deprivation predict schizophrenia? A Nationwide Swedish Family-based study of 2.4 Million individuals. *Schizophrenia Bulletin, 41*(2), 494–502. https://doi.org/10.1093/schbul/sbu105

Schäfer, I., & Fisher, H. L. (2011). Childhood trauma and psychosis - what is the evidence? *Dialogues in Clinical Neuroscience, 13*(3), 360–365. https://doi.org/10.31887/dcns.2011.13.2/ischaefer

Selten, J.-P., Booij, J., Buwalda, B., & Meyer-Lindenberg, A. (2017). Biological mechanisms Whereby social exclusion may contribute to the Etiology of psychosis: A narrative review. *Schizophrenia Bulletin, sbw180*. https://doi.org/10.1093/schbul/sbw180

Selten, J.-P., & Cantor-Graae, E. (2005). Social defeat: Risk factor for schizophrenia? *British Journal of Psychiatry, 187*(2), 101–102. https://doi.org/10.1192/bjp.187.2.101

Selten, J.-P., & Cantor-Graae, E. (2007). Hypothesis: Social defeat is a risk factor for schizophrenia? *British Journal of Psychiatry, 191*(S51), s9–s12. https://doi.org/10.1192/bjp.191.51.s9

Selten, J.-P., Ven, E. van der, Rutten, B. P. F., & Cantor-Graae, E. (2013). The social defeat hypothesis of schizophrenia: An Update. *Schizophrenia Bulletin, 39*(6), 1180–1186. https://doi.org/10.1093/schbul/sbt134

Selten, J.-P., Ven, E. van der, & Termorshuizen, F. (2019). Migration and psychosis: A meta-analysis of incidence studies. *Psychological Medicine, 50*(2), 303–313. https://doi.org/10.1017/s0033291719000035

Semple, D. M., McIntosh, A. M., & Lawrie, S. M. (2005). Cannabis as a risk factor for psychosis: Systematic review. *Journal of Psychopharmacology, 19*(2), 187–194. https://doi.org/10.1177/0269881105049040

Shanahan, D. F., Bush, R., Gaston, K. J., Lin, B. B., Dean, J., Barber, E., & Fuller, R. A. (2016). Health benefits from nature experiences Depend on dose. *Scientific Reports, 6* (1). https://doi.org/10.1038/srep28551

Shevlin, M., Murphy, J., Read, J., Mallett, J., Adamson, G., & Houston, J. E. (2010). Childhood adversity and hallucinations: A community-based study using the national comorbidity survey Replication. *Social Psychiatry and Psychiatric Epidemiology, 46*(12), 1203–1210. https://doi.org/10.1007/s00127-010-0296-x

Shiyko, M. P., Burkhalter, J., Li, R., & Park, B. J. (2014). Modeling nonlinear time-dependent treatment effects: An application of the generalized time-varying effect model (TVEM). *Journal of Consulting and Clinical Psychology, 82*(5), 760–772. https://doi.org/10.1037/a0035267

Solmi, F., Lewis, G., Zammit, S., & Kirkbride, J. B. (2019). Neighborhood characteristics at birth and positive and negative psychotic symptoms in adolescence: Findings from the ALSPAC birth cohort. *Schizophrenia Bulletin, 46*(3), 581–591. https://doi.org/10.1093/schbul/sbz049

Stain, H. J., Galletly, C. A., Clark, S., Wilson, J., Killen, E. A., Anthes, L., Campbell, L. E., Hanlon, M.-C., & Harvey, C. (2012). Understanding the social costs of psychosis: The experience of adults affected by psychosis identified within the second Australian national survey of psychosis. *Australian and New Zealand Journal of Psychiatry, 46*(9), 879–889. https://doi.org/10.1177/0004867412449060

Steinheuser, V., Ackermann, K., Schönfeld, P., & Schwabe, L. (2014). Stress and the city. *Psychosomatic Medicine, 76*(9), 678–685. https://doi.org/10.1097/psy.0000000000000113

Stilo, S. A., Gayer-Anderson, C., Beards, S., Hubbard, K., Onyejiaka, A., Keraite, A., Borges, S., Mondelli, V., Dazzan, P., Pariante, C., Di Forti, M., Murray, R. M., & Morgan, C. (2016). Further evidence of a cumulative effect of social disadvantage on risk of psychosis. *Psychological Medicine, 47*(5), 913–924. https://doi.org/10.1017/s0033291716002993

Sudimac, S., Sale, V., & Kühn, S. (2022). How nature nurtures: Amygdala activity decreases as the result of a one-hour walk in nature. https://doi.org/10.31234/osf.io/tucy7.

Sudlow, C., Gallacher, J., Allen, N., Beral, V., Burton, P., Danesh, J., Downey, P., Elliott, P., Green, J., Landray, M., Liu, B., Matthews, P., Ong, G., Pell, J., Silman, A., Young, A., Sprosen, T., Peakman, T., & Collins, R. (2015). UK Biobank: An open access resource for identifying the Causes of a Wide range of complex Diseases of middle and old age. *PLoS Medicine, 12*(3), Article e1001779. https://doi.org/10.1371/journal.pmed.1001779

Sundquist, K., Frank, G., & Sundquist, J. (2004). Urbanisation and incidence of psychosis and depression. *British Journal of Psychiatry, 184*(4), 293–298. https://doi.org/10.1192/bjp.184.4.293

Temesgen, W. A., Chien, W. T., & Bressington, D. (2018). Conceptualizations of subjective recovery from recent onset psychosis and its associated factors: A systematic review. *Early Intervention in Psychiatry, 13*(2), 181–193. https://doi.org/10.1111/eip.12698

Tibshirani, R. (1996). Regression shrinkage and selection via the Lasso. *Journal of the Royal Statistical Society: Series B, 58*(1), 267–288. https://doi.org/10.1111/j.2517-6161.1996.tb02080.x

Tortelli, A., Nakamura, A., Suprani, F., Schürhoff, F., Van der Waerden, J., Szöke, A., Tarricone, I., & Pignon, B. (2018). Subclinical psychosis in adult migrants and ethnic minorities: Systematic review and meta-analysis. *BJPsych Open, 4*(6), 510–518. https://doi.org/10.1192/bjo.2018.68

Trotta, A., Murray, R. M., & Fisher, H. L. (2015). The impact of childhood adversity on the persistence of psychotic symptoms: A systematic review and meta-analysis. *Psychological Medicine, 45*(12), 2481–2498. https://doi.org/10.1017/s0033291715000574

Turley, D., Drake, R., Killackey, E., & Yung, A. R. (2019). Perceived stress and psychosis: The effect of perceived stress on psychotic-like experiences in a community sample of adolescents. *Early Intervention in Psychiatry, 13*(6), 1465–1469. https://doi.org/10.1111/eip.12795

Twohig-Bennett, C., & Jones, A. (2018). The health benefits of the great outdoors: A systematic review and meta-analysis of greenspace exposure and health outcomes. *Environmental Research, 166*, 628–637. https://doi.org/10.1016/j.envres.2018.06.030

Ulrich, R. S. (1983). *Aesthetic and affective response to natural environment*. Springer US. https://doi.org/10.1007/978-1-4613-3539-9_4

Ulrich, R. S., Simons, R. F., Losito, B. D., Fiorito, E., Miles, M. A., & Zelson, M. (1991). Stress recovery during exposure to natural and urban environments. *Journal of Environmental Psychology, 11*(3), 201–230. https://doi.org/10.1016/s0272-4944(05)80184-7

Völker, S., & Kistemann, T. (2011). The impact of blue space on human health and well-being Salutogenetic health effects of inland surface waters: A review. *International Journal of Hygiene and Environmental Health, 214*(6), 449–460. https://doi.org/10.1016/j.ijheh.2011.05.001

Van den Berg, A. E. (2017). From green space to green prescriptions: Challenges and opportunities for research and practice. *Frontiers in Psychology, 8*. https://doi.org/10.3389/fpsyg.2017.00268

van den Berg, A. E., Maas, J., Verheij, R. A., & Groenewegen, P. P. (2010). Green space as a buffer between stressful life events and health. *Social Science & Medicine, 70*(8), 1203–1210. https://doi.org/10.1016/j.socscimed.2010.01.002

van den Berg, M., Wendel-Vos, W., Poppel, M. van, Kemper, H., Mechelen, W. van, & Maas, J. (2015). Health benefits of green spaces in the living environment: A systematic review of epidemiological studies. *Urban Forestry and Urban Greening, 14* (4), 806–816. https://doi.org/10.1016/j.ufug.2015.07.008

Varese, F., Smeets, F., Drukker, M., Lieverse, R., Lataster, T., Viechtbauer, W., Read, J., Os, J. van, & Bentall, R. P. (2012). Childhood adversities increase the risk of psychosis: A meta-analysis of Patient-control, prospective- and cross-sectional cohort studies. *Schizophrenia Bulletin, 38*(4), 661–671. https://doi.org/10.1093/schbul/sbs050

Vassos, E., Pedersen, C. B., Murray, R. M., Collier, D. A., & Lewis, C. M. (2012). Meta-analysis of the association of urbanicity with schizophrenia. *Schizophrenia Bulletin, 38*(6), 1118–1123. https://doi.org/10.1093/schbul/sbs096

Veling, W., & Adriaanse, M. (2013). Psychotic-like experiences and cumulative social disadvantage in a multi-ethnic population-based adolescent sample. *Schizophrenia Bulletin, 39*, 80–81.

Veling, W., Susser, E., Selten, J.-P., & Hoek, H. W. (2014). Social disorganization of neighborhoods and incidence of psychotic disorders: A 7-year first-contact incidence study. *Psychological Medicine, 45*(9), 1789–1798. https://doi.org/10.1017/s0033291714002682

Wang, C., Wang, Q., Li, X., Zhang, Y., Wei, W., Deng, W., Guo, W., He, L., Tang, W., Chen, T., & Li, T. (2019). Rural birth/upbringing and childhood adversities are associated with psychotic experiences in university students in China. *Schizophrenia Research, 209*, 105–112. https://doi.org/10.1016/j.schres.2019.05.009

Ward Thompson, C., Roe, J., Aspinall, P., Mitchell, R., Clow, A., & Miller, D. (2012). More green space is linked to less stress in deprived communities: Evidence from salivary cortisol patterns. *Landscape and Urban Planning, 105*(3), 221–229. https://doi.org/10.1016/j.landurbplan.2011.12.015

Weich, S., Blanchard, M., Prince, M., Burton, E., Erens, B., & Sproston, K. (2002). Mental health and the built environment: Cross sectional survey of individual and contextual risk factors for depression. *British Journal of Psychiatry, 180*(5), 428–433. https://doi.org/10.1192/bjp.180.5.428

Winkel, R. van, Stefanis, N. C., & Myin-Germeys, I. (2008). Psychosocial stress and psychosis. A review of the neurobiological mechanisms and the evidence for gene-stress interaction. *Schizophrenia Bulletin, 34*(6), 1095–1105. https://doi.org/10.1093/schbul/sbn101

Yuii, K., Suzuki, M., & Kurachi, M. (2007). Stress Sensitization in schizophrenia. *Annals of the New York Academy of Sciences, 1113*(1), 276–290. https://doi.org/10.1196/annals.1391.013

Zammit, S., Kounali, D., Cannon, M., David, A. S., Gunnell, D., Heron, J., Jones, P. B., Lewis, S., Sullivan, S., Wolke, D., & Lewis, G. (2013). Psychotic experiences and psychotic disorders at age 18 in relation to psychotic experiences at age 12 in a longitudinal population-based cohort study. *American Journal of Psychiatry, 170*(7), 742–750. https://doi.org/10.1176/appi.ajp.2013.12060768

Zammit, S., Lewis, G., Rasbash, J., Dalman, C., Gustafsson, J.-E., & Allebeck, P. (2010). Individuals, Schools, and neighborhood. *Archives of General Psychiatry, 67*(9), 914. https://doi.org/10.1001/archgenpsychiatry.2010.101

Zavos, H. M. S., Freeman, D., Haworth, C. M. A., McGuire, P., Plomin, R., Cardno, A. G., & Ronald, A. (2014). Consistent Etiology of severe, frequent psychotic experiences and Milder, less frequent manifestations. *JAMA Psychiatry, 71*(9), 1049. https://doi.org/10.1001/jamapsychiatry.2014.994

Zubin, J., & Spring, B. (1977). Vulnerability: A new view of schizophrenia. *Journal of Abnormal Psychology, 86*(2), 103–126. https://doi.org/10.1037/0021-843x.86.2.103