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Effects of urban living environments on mental health in adults

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Supplementary Information

Contents

Supplementary Tables

Supplementary Table 1. Urban living environmental variables and categories.

Area	Category	No. of subcategory	No. of variable	Sample size (n)
Traffic	Traffic	1	7	461,291
Air pollution	Air pollution	1	6	461,291
Sound pollution	Sound pollution	1	5	461,291
Greenspace proximity	Natural environment	1	1	497,519
	Greenspace	1	1	440,851
	Domestic garden	1	1	440,851
Water proximity	Domestic water	1	1	440,851
Coastal proximity	Distance from home to coast	1	1	497,519
IMD*	EIMD	1	1	424,419
	SIMD	1	1	424,419
	WIMD	1	1	424,419
Building Class	Building class	1	3	317,095
Terrain	Terrain	2	2	430,832
Destination accessibility	Destination accessibility	9	33	423,886

NDVI	NDVI	2	2	430,832
Landuse density	Landuse density	25	46	424,028
Street network	Street network	5	18	423,562
Total	15	53	128	216,341

EIMD, England Indices of multiple deprivation; SIMD, Scotland Indices of multiple deprivation; WIMD, Wales Indices of multiple deprivation; NDVI, normalized difference vegetation index.

** Each participant only has one IMD score based on their residential locations in England, Scotland and Wales.*

Supplementary Table 2. Detailed urban living environmental variables. (see Excel)

Supplementary Table 3. Detailed description of street accessibility indices

Variable name	Description
Link characteristics: These measures describe the characteristics of individual links in the network	
1. Link Connectivity	The number of link ends that an individual link is connected to at its end points
2. Link Length	Length of the individual link in the network
3. Link Angular Curvature	The cumulative angular change while traversing the full length of a link in degrees
Centrality analysis: These set of measures owe their origin to the graph theory. The associations between urban morphology and the social phenomena dependent on it are essentially captured by indices of relationality in the graphs. The notion of accessibility captured by these measures acts to formally elucidate how network morphology influences individual activity behaviours and drives various socio- economic processes. They indicate the centrality of a vertex within a graph	
1. Mean Angular Distance	In graphical terminology, also called as the closeness centrality/accessibility. It is an indicator of the degree of difficulty, on average, of navigating to all possible destinations within a specified radius from each given link. This is weighted by the link length
2. Network Quantity Penalized for Distance	This is an improved measure of the conventional closeness centrality and takes in to account the effects of network quantity. For each link within a specified radius, it takes the network quantity (defined link length) and divides it by the difficulty of access (angular). This is weighted by the link length.
3. Betweenness	In graphical terminology, also called as the betweenness centrality or path overlap or through-movement potential. It is indicative of how often a given link is used for a journey within a defined radius. Measured as the sum of geodesics that pass through a link for a journey within a defined radius. This has been weighted by origin-destination link length.

4. Two Phase Betweenness — This is betweenness weighted by a two-step floating catchment model. Measured as the sum of geodesics that pass through a link for a journey within a defined radius weighted by the proportion of network quantity accessible from geodesic origin that is represented by geodesic destination
5. Two Phase Destination assignment — This is the total flow to each destination under the two phase betweenness model. In other words, it is similar to the two phase betweenness, but measured for the destination of each geodesic only

Simple radial measures: These measures pertain to the characteristics of the links within a specified network radius.

1. Links — The number of network links within a specified network radius
2. Length — The total network length within a specified network radius
3. Angular Distance — Sum of angular distance of each individual link within a specified radius
4. Weight — Total weight within a specified radius. Weights have been specified with respect unit of network length (in length weighted analysis)
5. Mean Geometric Length — Mean of the angular geodesic Euclidean length within a specified radius. This has been weighted by the origin to destination link length

Network detour analysis: Measure the network severance by comparing the hypothetical crow fly distance to actual network distance. It is an indicator of the extent of deviation of the network from the most direct path.

1. Mean Crow Flight Distance — Mean of the crow flight distance between a link and all the links within a defined radius. This is weighted by the link length
2. Diversion Ratio — Mean of the ratio of actual geodesic length to the crow flight distance for all geodesics within a defined radius. This is weighted by the link length. Indicative of the degree of deviation of the actual paths from the crow flight path

Network shape: Measure of network efficiency in terms of the spatial footprint of the street network in urban space.

1.	Convex Hull Area	Area of the convex hull containing all the origins and destinations within a defined radius. It is an indicator of the network footprint or the spatial spread of the street network in the urban space.
2.	Convex Hull Perimeter	Length of perimeter of the convex hull containing all the origins and destinations within a defined radius. 400,
3.	Convex Hull Maximum Radius	Maximum radius of the convex hull measured as the crow flight distance from the centre of the origin link to the furthest point on the convex hull of a defined radius
4.	Convex Hull Bearing	Compass bearing of the line of maximum radius of convex hull of a defined radius, measured in degrees. It indicates the direction in which one can travel furthest from the origin link, while staying inside the network radius.
5.	Convex Hull Shape Index	Measures the degree of uniformity of the network in all directions. It is measured as the square of the hull perimeter divided by 4π times the hull area. Ranges from 1 in case of a circle to higher values, with higher indicating non-uniformity across all directions.

Supplementary Table 4. Details of 21 psychiatric symptoms in UK biobank

Field ID	Variable name	Question	Answer categories	Sample size	Incidence
1920	Mood swings	Does your mood often go up and down?	1. Yes 2. No 3. Do not know 4. Prefer not to answer	488,298	45.58%
1930	Miserableness	Do you ever feel 'just miserable' for no reason?	1. Yes 2. No 3. Do not know 4. Prefer not to answer	492,219	42.80%
1940	Irritability	Are you an irritable person?	1. Yes 2. No 3. Do not know 4. Prefer not to answer	478,082	28.01%
1950	Sensitivity hurt feelings	Are your feelings easily hurt?	1. Yes 2. No 3. Do not know 4. Prefer not to answer	486,281	55.47%
1960	Fed up feelings	Do you often feel 'fed-up'?	1. Yes 2. No 3. Do not know 4. Prefer not to answer	490,044	40.64%
1970	Nervous feelings	Would you call yourself a nervous person?	1. Yes 2. No 3. Do not know	487,683	23.63%

			4. Prefer not to answer		
1980	Anxious feelings	Are you a worrier?	1. Yes 2. No 3. Do not know 4. Prefer not to answer	487,727	56.51%
1990	Tense /highly strung	Would you call yourself tense or 'highly strung'?	1. Yes 2. No 3. Do not know 4. Prefer not to answer	482,778	17.76%
2000	Worry too long	Do you worry too long after an embarrassing experience?	1. Yes 2. No 3. Do not know 4. Prefer not to answer	480,269	47.71%
2010	Suffering from nerves	Do you suffer from 'nerves'?	1. Yes 2. No 3. Do not know 4. Prefer not to answer	481,980	21.15%
2020	Loneliness and isolation	Do you often feel lonely?	1. Yes 2. No 3. Do not know 4. Prefer not to answer	492,739	18.56%
2030	Guilty feelings	Are you often troubled by feelings of guilt?	1. Yes 2. No 3. Do not know 4. Prefer not to answer	487,212	28.86%

2040	Risk taking	Would you describe yourself as someone who takes risks?	1. Yes 2. No 3. Do not know 4. Prefer not to answer	482,170	26.94%
2050	Depressed mood	Over the past two weeks, how often have you felt down, depressed or hopeless?	1. Not at all 2. Several days 3. More than half the days 4. Nearly every day 5. Do not know 6. Prefer not to answer	478,435	-
2060	Unenthusiasm	Over the past two weeks, how often have you had little interest or pleasure in doing things?	1. Not at all 2. Several days 3. More than half the days 4. Nearly every day 5. Do not know 6. Prefer not to answer	482,800	-
2070	Tenseness	Over the past two weeks, how often have you felt tense, fidgety or restless?	1. Not at all 2. Several days 3. More than half the days 4. Nearly every day 5. Do not know 6. Prefer not to answer	480,413	-
2080	Tiredness	Over the past two weeks, how often have you felt tired or had little energy?	1. Not at all 2. Several days	485,357	-

			3. More than half the days 4. Nearly every day 5. Do not know 6. Prefer not to answer		
2090	Seen a doctor (GP)	Have you ever seen a general practitioner (GP) for nerves, anxiety, tension or depression?	1. Yes 2. No 3. Do not know 4. Prefer not to answer	501,704	33.78%
2100	Seen a psychiatrist	Have you ever seen a psychiatrist for nerves, anxiety, tension or depression?	1. Yes 2. No 3. Do not know 4. Prefer not to answer	501,704	11.49%
6145	Grief and stress	In the last 2 years have you experienced any of the following?	1. Serious illness, injury or assault to yourself 2. Serious illness, injury or assault of a close relative 3. Death of a close relative 4. Death of a spouse or partner 5. Marital separation/divorce 6. Financial difficulties 7. None of the above 8. Prefer not to answer	497,926	-

20127	Neuroticism score	The score was generated by summarizing the number of Yes answers across these twelve neurotic behaviour domains into a single integer score for each participant (0 to 12): 1. Does your mood often go up and down? 2. Do you ever feel 'just miserable' for no reason? 3. Are you an irritable person? 4. Are your feelings easily hurt? 5. Do you often feel 'fed-up'? 6. Would you call yourself a nervous person? 7. Are you a worrier? 8. Would you call yourself tense or 'highly strung'? 9. Do you worry too long after an embarrassing experience? 10. Do you suffer from 'nerves'? 11. Do you often feel lonely? 12. Are you often troubled by feelings of guilt?	For each question, participants could answer: 1. Yes 2. No 3. Do not know 4. Prefer not to answer	401,652	-

Supplementary Table 5. Weight of urban living environment category and psychiatric symptoms in sCCA-regression analysis (see Excel)

Supplementary Table 6. Multiple comparisons of canonical correlation *r* value in each resampling of training dataset.

Category	Mean	Mean difference	95% CI	95% CI	$P_{two\text{-}sided}$
100% vs. 10%	0.2156	-0.009357	-0.01088	-0.007837	***<0.0001***
100% vs. 20%	0.2120	-0.005734	-0.007255	-0.004214	***<0.0001***
100% vs. 30%	0.2094	-0.003153	-0.004673	-0.001632	***<0.0001***
100% vs. 40%	0.2082	-0.001956	-0.003477	-0.0004359	***0.0037***
100% vs. 50%	0.2074	-0.001175	-0.002695	0.0003456	0.2320
100% vs. 60%	0.2071	-0.0008983	-0.002419	0.0006221	0.5591
100% vs. 70%	0.2072	-0.0009570	-0.002477	0.0005635	0.4768
100% vs. 80%	0.2070	-0.0007446	-0.002265	0.0007758	0.7790
100% vs. 90%	0.2065	-0.0002455	-0.001766	0.001275	0.9994
100% vs. 110%	0.2061	0.0001150	-0.001406	0.001635	0.9997
100% vs. 120%	0.2065	-0.0002426	-0.001763	0.001278	0.9994
100% vs. 130%	0.2060	0.0002525	-0.001268	0.001773	0.9993
100% vs. 140%	0.2062	2.210e-006	-0.001518	0.001523	>0.9999
100% vs. 150%	0.2062	-2.253e-005	-0.001543	0.001498	>0.9999

$P_{two\text{-}sided}$ value in bold and italics were shown as statistically different between groups. Each $P_{two\text{-}sided}$ value was adjusted to account for multiple comparisons.

Supplementary Table 7. Statistics in ten folds cross-validation in sCCA analysis.

	Training dataset	Test dataset
First correlate	0.204 (9.47×10^{-4})	0.201 (0.009)
Second correlate	0.111 (5.90×10^{-4})	0.104 (0.005)
Third correlate	0.054 (6.82×10^{-4})	0.037 (0.009)

Data are shown as mean (standard deviation) of canonical correlation r value across ten folds.

Supplementary Table 8. sCCA analysis between urban living environment and psychiatric symptoms in males and females, separately

	Training dataset		Test dataset		
	r	**Two-sided P_{perm}**	***r***	**Two-sided P_{perm}**	P_{FDR}
Females					
First correlate	0.205	***P<0.001***	0.196	***P<0.001***	***P<0.001***
Second correlate	0.118	***P<0.001***	0.101	***P<0.001***	***P<0.001***
Third correlate	0.059	***P<0.001***	0.043	0.179	0.277
Males					
First correlate	0.206	***P<0.001***	0.188	***P<0.001***	***P<0.001***
Second correlate	0.107	***P<0.001***	0.086	***P<0.001***	***P<0.001***
Third correlate	0.062	***P<0.001***	0.035	***P<0.001***	***0.002***

Supplementary Table 9. 3,436 significant GWAS associations between SNPs and affective symptoms group after Bonferroni correction of *Pc*<0.05 (see Excel)

Supplementary Table 10. 29 significant GWAS associations between SNPs and anxiety symptoms group after Bonferroni correction of *Pc*<0.05 (see Excel)

Supplementary Table 11. 10 significant GWAS associations between SNPs and emotional instability symptoms group after Bonferroni correction of *Pc*<0.05 (see Excel)

Supplementary Table 12. Gene-set enrichment analysis in gene ontology of affective, anxiety and emotional instability symptom groups associated genes after Bonferroni correction of *Pc*<0.05 (see Excel)

Supplementary Table 13. Replications of gene scores associated with psychiatric symptom groups in UKB-NI dataset (see Excel)

Supplementary Table 14. Weights for brain volumes simultaneously associated with urban living environment profiles and psychiatric symptoms groups in msCCA-regression.

Mental health	Brain area	Weight
Affective symptom group	Right Frontal Pole	-0.239
	Left Superior Frontal Gyrus	-0.457
	Right Superior Frontal Gyrus	-0.429
	Right Occipital Fusiform Gyrus	-0.242
	Right Crus I Cerebellum	-0.319
	Right Crus II Cerebellum	-0.287
	Right VIIb Cerebellum	-0.332
	Left VIIb Cerebellum	-0.256
	Right VIIIa Cerebellum	-0.438
	Left VIIIa Cerebellum	-0.296
	Right VIIIb Cerebellum	-0.328
	Left Amygdala	-0.278
	Right Ventral Striatum	-0.246
Anxiety symptom group	Left Inferior Frontal Gyrus	-0.250
	Left Juxtapositional Lobule Cortex	-0.287
	Right V Cerebellum	-0.301
	Left VI Cerebellum	-0.278
	Right Crus I Cerebellum	-0.351
	Left Crus I Cerebellum	-0.289
	Left VIIIa Cerebellum	-0.274
	Right VIIIa Cerebellum	-0.396
	Left VIIIb Cerebellum	-0.300
	Right VIIIb Cerebellum	-0.291
	Right Amygdala	-0.277
Emotional instability symptom group	Left Frontal Pole	-0.339

Right Frontal Pole	-0.344
Left Insular Cortex	-0.276
Right Insular Cortex	-0.262
Left Precentral Gyrus	-0.391
Right Precentral Gyrus	-0.321
Left Postcentral Gyrus	-0.268
Left Lateral Occipital Cortex	-0.275
Left Central Opercular Cortex	-0.270
Right Frontal Orbital Cortex	-0.270
Left Amygdala	-0.278
Right Amygdala	-0.292
Left Crus I Cerebellum	-0.269

Supplementary Table 15. Moderated mediation statistics in genes scores, urban environmental profile, brain component and psychiatric symptoms groups after bootstrapping (see Excel)

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