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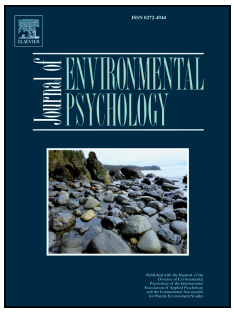

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Title page

The role of the built environment in the trajectories of cognitive ability and mental health across early and middle childhood: Results from a street audit tool in a general-population birth cohort

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The role of the built environment in the trajectories of cognitive ability and mental health across early and middle childhood: Results from a street audit tool in a general-population birth cohort

Abstract

The research exploring the association between the built environment and children's mental health and cognitive abilities has produced mixed results. This may be due to the inconsistency in the approach taken to describe the built environment. This study, using data from the Millennium Cohort Study (MCS), a large general-population birth cohort, considered simultaneously several measures to describe it when the participant child was 3 years old, including neighbourhood disorder (assessed by an MCS interviewer by direct observation of several physical and social aspects of the immediate neighbourhood), area green space, air pollution, urbanicity and neighbourhood socio-economic disadvantage. It then explored its role in the trajectory of mental health (measured with the Strengths and Difficulties Questionnaire-SDQ) and cognitive ability (measured with the British Ability Scales-BAS) across ages 3 to 11 years in 4,454 children of stayer families in England. Using growth curve modelling we found that neighbourhood disorder was associated with emotional symptoms and conduct problems at age 3 and with the trajectory of cognitive ability from ages 3 to 11. These associations were robust to controls for quality of the indoor housing environment and parental mental health and socio-economic status. Neither green space nor air pollution had any effect on our outcomes. Our findings shed light on the importance of specific aspects of the built environment for mental health and cognition

during childhood. They also highlight the value of using direct observation of the immediate neighbourhood.

Keywords: built environment; direct observation; mental health; cognitive ability; neighbourhood disorder; physical environment

Highlights

- Neighbourhood disorder was related to emotional symptoms and conduct problems very early in childhood.
- It was also related to the trajectory of cognitive ability in childhood.
- Direct observation of the physical and social environment of the immediate area was superior to 'objective' measures of the physical and social environment of the neighbourhood.
- Studies on the role of the built environment in children's mental health and cognition should consider using observation of the immediate environment.

1. Introduction

The physical environment presents a unique set of exposures that can directly and indirectly affect the physical and mental health, cognitive performance, and

behaviour of individuals over the course of their lives from the prenatal period to old age (Flouri, Papachristou, & Midouhas, 2019; Gill et al., 2021; Mueller, Flouri, & Kokosi, 2019) (Bijnens, Derom, Thiery, Weyers, & Nawrot, 2020; Choi, Kelley, & Wang, 2018) (Barbarin et al., 2006; Flouri, Papachristou, & Midouhas, 2019; Kohen, Brooks–Gunn, Leventhal, & Hertzman, 2002). The physical environment includes both the natural and the built environment. The built environment is a material and spatial product of human labour that combines physical elements and energy in forms for living, working, and playing (Kaklauskas & Gudauskas, 2016). It has been defined as "the human-made space in which people live, work, and recreate on a day-to-day basis" and it includes neighbourhoods and their particular settings, such as streets, transportation, buildings, homes, worksites, and schools (Roof & Oleru, 2008). The last two decades have witnessed a burgeoning interest in the role of the built environment especially in mental health, particularly in adults and adolescents. For example, neighbourhood disorder, a measure of the built environment which indicates the perceived lack of order of an area, and it is characterised by poorly maintained buildings and dwellings, graffiti, litter, dirt, vandalism and noise, has been associated with depression in adults (Evans, 2003). At the same time, there have been studies producing null findings or even unexpected associations (Evans et al., 2020; Rabinowitz et al., 2020; Reuben et al., 2019).

There are three main reasons that may explain the inconsistency in findings. First, there is a wide variety of approaches typically taken to measure the built environment even on the same spatial scale: (i) resident surveys that give subjective accounts of the perceived environment, (ii) administrative data including those derived by censuses or crime reports, (iii) objective data on physical elements, such as air

quality, noise and greenery, and (iv) direct observation by outside raters. Each of these approaches has advantages and disadvantages (Schaefer-McDaniel, Caughy, O'Campo, & Gearey, 2010), but direct observation is, on balance, considered to offer some unique strengths. That is, even if it is subject to observer bias, it does overcome most of the limitations of resident reports and administrative data (i.e., social desirability, same-source bias, lack of spatial and temporal specificity) (Schaefer-McDaniel et al., 2010). Despite this, most studies in the field have used resident reports and administrative data to measure the built environment. The second likely explanation is the study design. The relationship between the individual and the environment is dynamic as they both change over time. However, most studies to date are cross-sectional rather than longitudinal. The third likely explanation is the inconsistency in the approach taken to manage confounding, with most observational studies controlling for only few basic confounders (Schaefer-McDaniel, 2009). It is especially problematic if area socio-economic deprivation is not included among those confounders given the very strong link between low socio-economic status (SES) and poor built environments.

1.1 The present study

The present study aimed to address all these issues, using data from the Millennium Cohort Study (MCS), a large, general-population longitudinal study. It explored the role of the built environment, measured by direct third-party observation of 'neighbourhood disorder' in the immediate area, in children's mental health and cognitive ability at ages 3, 5, 7 and 11 years, while considering the role of other relevant aspects of the social and physical environment and on different spatial scales [i.e., ward-level and Lower Layer Super Output Area (LSOA)-level; see Measures]. We also adjusted for a wide set of covariates such as gender, exact age, ethnicity and social

class, and controlled for urbanicity/rurality, family structure, maternal depression, and, importantly, quality of the indoor physical environment. Our study therefore used (i) a longitudinal design, (ii) direct observation of the immediate neighbourhood environment, and (iii) a stringent approach to controlling for families' selection into areas and 'objective' measures of the physical and the social environment of the wider neighbourhood.

2. Methods

2.1 Study sample

We used data from the Millennium Cohort Study (MCS) (www.cls.ioe.ac.uk/mcs), a longitudinal survey of over 19,000 children born in the UK between September 2000 and January 2002. The MCS sample is disproportionately stratified, firstly by country, and then type of electoral ward. The sample design over-represented families living in areas of high child poverty, areas with high proportions of ethnic minority populations across England, and the three smaller UK countries. There was a total of 398 wards in MCS, of which 200 were in England. Most of the information in MCS was collected through interviews with, and self-completion questionnaires from, the main respondent (overwhelmingly the mother) in the child's home. There have been seven sweeps of data collection to date. MCS children were around 9 months old at Sweep 1, and 3, 5, 7, 11, 14 and 17 years old at sweeps 2-7, respectively. We used data from sweeps 2 to 5 (when children were aged 3 to 11 years) in our study. The neighbourhood assessment form was completed in MCS when the participant child was aged 3. Our analytic sample included children (singleton and, in case of multiple births, the first-born twin or triplet) who did not change address since age 3 (n=4,454) in England. [We focused on England because green space at LSOA-

level (see Measures) that we wanted to consider alongside the other measures of the environment was only available in England.] Ethical approval for the MCS was gained from NHS Multi-Centre Ethics Committees, parents gave consent before interviews took place, and at age 11 cohort children gave their assent.

2.2 Measures

2.2.1 Mental health (emotional and behavioural problems) at ages 3, 5, 7 and 11 years

Emotional and behavioural problems were measured at ages 3, 5, 7 and 11 with the parent-reported Strengths and Difficulties Questionnaire [SDQ (Goodman, 1997)]. The SDQ is a short, reliable and widely-used behavioural screening tool. It consists of 20 items (grouped in 4 scales) of difficulties. Each item is scored on a 3-point scale of 0 (*not true*), 1 (*somewhat true*), and 2 (*certainly true*). The scales (of 5 items each) are: emotional symptoms, conduct problems, hyperactivity/inattention and peer problems. Scores for each scale may range 0-10.

2.2.2 Cognitive ability at ages 3, 5, 7 and 11 years

In MCS, cognitive ability was assessed from age 3 to age 11 with several scales at each time-point. At age 3, there were two cognitive assessments, the Bracken School Readiness Assessment-Revised, which measures children's 'readiness' for formal education by testing their knowledge and understanding of basic concepts, and the second edition of the British Ability Scales (BAS) (Elliot, Smith, & McCulloch, 1996) for Naming Vocabulary, which measures expressive language. At age 5, ability was assessed with three scales: BAS Naming Vocabulary, BAS Pattern Construction (measuring spatial problem-solving) and BAS Picture Similarities (measuring non-verbal reasoning). At age 7, it was measured with BAS Pattern Construction, BAS Word Reading (measuring educational knowledge of reading) and the National

Foundation for Educational Research Progress in Maths. At age 11, it was measured with BAS Verbal Similarities, which assesses verbal reasoning and verbal knowledge. When multiple cognitive assessments were available (i.e., at ages 3, 5 and 7), a cognitive ability score for each time-point was calculated using the scores derived from a principal components analysis (PCA) of these (age-adjusted) assessments. Each component score was then transformed into a standardized IQ score with a mean of 100 and a standard deviation of 15. Multiple well-validated assessments are thought to be able to capture a higher-level intelligence ('g') factor which is not dependent on the use of specific mental ability tasks. For age 11, when only one BAS measure was available in MCS, we transformed the age-adjusted ability score into a standardized IQ score. This is an approach taken by previous studies using MCS to track the trajectory of children's cognitive ability across this period (Flouri, Papachristou, Midouhas, et al., 2019).

2.2.3 Neighbourhood disorder

The interviewers of MCS completed an assessment of the immediate neighbourhood built environment of the cohort families at sweep 2 (age 3) with a checklist of 11 items recording: 1) conditions of the buildings in the neighbourhood ("well kept", "fair", "poor", "badly deteriorated"), 2) presence of security blinds ("none", "some", "most"), 3) presence of traffic calming measures ("yes", "no"), 4) levels of traffic volume ("no", "light", "moderate", "heavy"), 5) burnt-out cars in the street ("yes", "no"), 6) presence of litter in the street or on the pavement ("almost none", "some", "about everywhere"), 7) level of dog mess on the pavement ("none", "some", "a lot"), 8) presence of graffiti on walls or on public spaces ("no", "a little", " a lot"), 9) any evidence of vandalism ("yes", "no"), 10) presence of people arguing or fighting in the street ("no-one seen", "none observed behaving in hostile ways", "yes, one or

two arguing", "at least one group of three of more"), and 11) own feelings in the street ("very comfortable - can imagine living/shopping here", "comfortable – a safe and friendly place", "fairly safe and comfortable", "uncomfortable living/shopping here", "felt like an outsider looked on suspiciously", "felt afraid for my personal safety"). We used a PCA to combine these 11 items into a single index of the immediate area's built environment. Higher scores represented worse neighbourhood conditions, thus greater 'neighbourhood disorder'.

2.2.4 *Covariates*

We controlled for variables (measured at baseline, i.e., at cohort child's age 3 years, unless otherwise specified) that had been previously associated with both exposure and outcomes: *Neighbourhood green space* was measured using the 2001 Generalised Land Use Database (GLUD; Office of the Deputy Prime Minister, 2005), which indexes the proportion of green space per LSOA in England. In MCS, green space data were converted into deciles ranging from 1 ('most deprived' or 'least green') to 10 ('least deprived' or 'most green'). *Neighbourhood air pollution* was measured using estimates of particulate matter smaller than 10 μm (PM10) concentrations at ward-level from the Multiple Environmental Deprivation Index (MEDIx; https://cresh.org.uk/cresh-themes/environmental-deprivation/medix-and-medclass/).

The *indoor housing environment* was measured by home observation. During a home visit, the MCS interviewer completed a checklist of items about home traffic, background noise from TV or conversations, interruptions by adults or children, darkness, cleanliness, clutter, presence of open fires, level of damp/condensation and presence of second-hand smoke. We used a PCA to combine into a single index these 11 items describing the indoor physical environment. Higher scores represented worse indoor conditions, thus poorer indoor environment. The broader neighbourhood's

social environment was approximated by the MCS sampling 'stratum' (in our case, 'England-Advantaged', 'England-Disadvantaged', and 'England-Ethnic Minority'), in turn indexing the area's socio-economic deprivation. The '*Ethnic minority*' stratum comprises wards in England which, in the 1991 Census, had an ethnic minority indicator of at least 30%. That is, at least 30% of their total population fell into the two categories 'Black' (Black Caribbean, Black African and Black Other) or 'Asian' (Indian, Pakistani and Bangladeshi). The '*Disadvantaged'* stratum includes wards, other than those in the 'Ethnic minority' stratum, which fell into the upper quartile (poorest 25% of wards) of the ward-based Child Poverty Index (CPI). Finally, the *'Advantaged'* stratum includes wards, other than those falling into the 'Ethnic minority' stratum, which were not in the top quartile of the CPI. We also controlled our models for *family structure* (two natural parents at home or not), *family poverty* (below the poverty line or not), *urbanicity* (living in an urban area, i.e., a settlement with a population greater than 10,000 or not), *maternal education* [whether or not the mother had attained a university degree (asked at the end of our study period, at child's age 11 years)], *overcrowding* (>1 person per room, 'yes', 'no'), *access to a domestic garden* ('yes', 'no'), *home ownership* ('yes', 'no'), *exact age* in years, *maternal mental health*, assessed with the 6-item Kessler scale (Kessler, Barker, Colpe, & et al., 2003) of psychological distress, *ethnicity* (white, Indian, Pakistani/Bangladeshi, black, mixed, and other) and *gender*.

2.3 Statistical analysis

We first explored the differences between the analytic sample (*n*= 4,454) and the non-analytic sample (*n*= 14,790) on the study variables. Continuous variables were compared using one-way analysis of variance tests and categorical variables using chi-

square tests. Next, we inspected the correlations between the study variables. Given the focus on neighbourhood disorder we also describe in detail the PCA for our construct of it. The percentage of missingness in the study variables ranged from 0.2% to 15.6%, and, to handle it, we used multiple imputation by chained equations (MICE) (20 imputed datasets). To predict missing data, we used all variables selected for analysis models. During the imputation process the MCS sampling stratum was controlled to account for the disproportionate stratification of the MCS survey design. Finally, in order to model the associations between neighbourhood disorder and trajectories of emotional/behavioural problems and cognitive ability across ages 3 to 11 years we fitted two-level growth curve models. This allowed us to avoid the underestimation of standard errors due to the hierarchical nature of our data (Goldstein, 2011) by having repeated measures (at ages 3, 5, 7, and 11) of scores (Level 1) nested in children (Level 2). [A third level, area, was tested too but was eventually dropped for parsimony.] The intercept was set at baseline (age 3). To allow for changes in emotional/behavioural problems and cognitive ability across time to vary between children, we specified a random slope on the child's age. We had a fixed effect for age as well as age^2 to account for the non-linear shape of the average trajectory of some scores. All analyses were performed in *Stata 16*.

3. Results

3.1 Descriptive analysis

Among the 17,706 MCS children with information on neighbourhood disorder at age 3, 12,224 were living in England and among them 7,770 changed their address across ages 5 to 11. Thus, our analytic sample was 4,454 children. Table 1 shows the descriptive statistics and the differences between the analytic and non-analytic samples.

The children in the non-analytic sample had on average greater emotional and behavioural problems and lower cognitive ability across all ages. They also had higher scores on neighbourhood disorder, poor indoor environment and maternal depression, and were more likely to live in single-parent families, be below the poverty line, have non university educated mothers, and live in overcrowded homes. Their homes were also less likely to be owned by their parents and more likely to be in the less green and more polluted neighbourhoods. As expected, given that our sample was families in England, the non-analytic sample had a greater proportion of white children and lower proportions of minority ethnic children. Correlations among our study variables were weak to moderate, ranging from 0.04 to 0.66 (Table 2).

3.2 PCA

The PCA on the eleven items from the interviewer's observation confirmed the presence of a general underlying factor of neighbourhood disorder. The Kaiser-Meyer-Olkin (KMO) test value was 0.83 indicating that the sampling was adequate. The loadings of the items on the factor were as follows: building conditions 0.40, presence of security blinds 0.32, presence of traffic calming measures -0.17, level of traffic volume 0.10, burnt-out cars in the street -0.07, presence of litter in the street or on the pavement 0.40, level of dog mess on the pavement 0.25, presence of graffiti on walls or on public spaces 0.37, any evidence of vandalism 0.29, presence of people arguing or fighting in the street 0.21, and the interviewer's feeling in the street 0.42. Table S1 in the supplementary material shows the descriptive statistics of all the items of neighbourhood disorder.

3.3 Growth curve models

In our partially adjusted models [adjusted for neighbourhood green space, air pollution, urbanicity and neighbourhood social environment (i.e., MCS stratum)] we found that greater neighbourhood disorder was predictive of higher scores on all four types of emotional and behavioural problems at age 3 and of lower cognitive ability scores across ages 3 to 11 (Table 3). In our fully adjusted models, neighbourhood disorder remained a significant predictor of emotional symptoms at baseline (i.e., our intercept, age 3), conduct problems at baseline and lower cognitive ability across ages 3 to 11 (Table 3). In the complete case analysis, greater neighbourhood disorder was also predictive of lower cognitive ability across ages 3 to 11 years even after full adjustment (Table S2), but there were no effects on emotional and behavioural problems.

To illustrate some of these differences in our outcomes for children exposed to different levels of neighbourhood disorder, we plotted the predicted values for the trajectories of conduct problems, emotional symptoms and cognitive ability, based on the adjusted model results, for two illustrative cases of children in areas of high and low neighbourhood disorder (Figures 1-3). In this example, high neighbourhood disorder was the mean score of those belonging to the top decile of the neighbourhood disorder variable distribution (4.19) and low neighbourhood disorder was the mean score of those belonging to the bottom decile of the neighbourhood disorder variable distribution (-0.33).

4. Discussion

To our knowledge, this is the first study to explore the association between the built environment and children's trajectories of cognition and mental health from the preschool period until the end of primary school, by using several measures of the built

environment and controlling for many relevant covariates. We found, in a large sample of almost 5,000 children in the general population that we drew from MCS, that the immediate built environment, assessed through direct third-party observation of degree of 'neighbourhood disorder', was associated with mental health and cognitive functioning across childhood. This association was robust to adjustment for indoor housing conditions and several 'objective' measures (e.g., based on administrative records and geocoded data) of the physical and social environment of the broader area as well as important confounders including parental SES and mental health. Neighbourhood disorder is broadly taken to refer to observed or perceived physical and social features of neighbourhoods that may signal the breakdown of order and social control, and that can undermine the quality of life. In our study, it was assessed by MCS interviewers who reported the presence in the immediate local area of features such as dog mess, litter, graffiti, hostile arguing on the street, vandalised cars and run-down buildings, during a home visit when the cohort child was aged about 3 years.

In particular, we found that greater neighbourhood disorder was associated with: (i) higher levels of emotional symptoms at the starting point (intercept) of their trajectory at age 3, (ii) higher levels of conduct problems at age 3 and (iii) lower cognitive ability across ages 3 to 11. These associations were robust to controls for 'objective' measures of the physical and social environment of the broader area (air pollution, green space, urbanicity, socio-economic disadvantage) as well as the indoor physical environment, and after adjustment for family-level variables related to selection into areas such as ethnicity, mental health, education, family structure and SES (Rollings, Wells, Evans, Bednarz, & Yang, 2017). We also found that greater neighbourhood disorder was associated with higher levels of peer problems and hyperactivity at age 3 when controlling for the 'objective' measures of the broader

area's environment but not after adjustment for the family-level covariates. Our results are in line with previous findings of studies with adolescents showing that those from neighbourhoods of poor quality, often defined by the amount of litter on the street, buildings in disrepair, graffiti, and vandalism, are at a higher risk for poor cognition, depression and anxiety as well as dangerous alcohol, tobacco, and drug use (Evans, 2003). Our study demonstrates that these local area features are related to the mental health of children as young as three-years-old and to the trajectory of general cognitive ability across the primary school years.

It would be important for future studies to test our findings and, if replicated, test pathways of influence. There has been much interest, for instance, in the observation that the built environment can be a source of stress (Halpern, 2014). As such, its effects on the resident population's mental health and cognition can be direct, for example by influencing environmental quality, or indirect, by influencing behaviours that impact disease transmission and health and brain development and function (Cooper, Burton, & Cooper, 2014; Szalma & Hancock, 2011). Here, related evidence from Canada has also shown that the longitudinal association between adverse childhood experiences and emotional and behavioural problems in adolescence is ameliorated in children who grow up in more socially cohesive neighbourhoods (Kingsbury, Clayborne, Colman, & Kirkbride, 2020). Together, the available evidence suggests that both the built and social environments can impact emotional and behavioural issues in childhood and adolescence. Our findings are particularly intriguing because they demonstrate that the role of the built environment can be evidenced as early as the preschool period, when, crucially, direct exposures to the built environment outside the home are limited and controlled.

Importantly, our findings also help to explain some of the inconsistencies in the previous evidence about the role of the physical environment in child cognition and mental health. They clearly demonstrate that the physical environment of the neighbourhood is important for these outcomes, but they also suggest that only very specific aspects of it, mostly pertaining to level of safety and calmness and state of maintenance and upkeep, carry the most weight.

Our findings echo others' that it is essential to tackle the underlying environmental justice issues, and to distribute healthy, safe, nurturing environments across the population (Pinter-Wollman, Jelić, & Wells, 2018) in order to reduce mental health disparities and cognitive skill inequalities in childhood. They also suggest that a neighbourhood's s physical attributes especially those relating to physical upkeep - strongly linked to adult outcomes - may need to be systematically examined in future research examining the role of the built environment in children (Hur & Nasar, 2014).

Our study has many strengths. First, it considered simultaneously objective measures, and from various sources, of the physical and social environment. Second, it modelled these exposures on different scales: neighbourhood disorder applied to the immediate (most proximal) environment (the MCS interviewer was asked to report on the condition of 'the street' and 'the pavement'), green space was measured at the level of LSOA (a small, Census geography unit of around 1,500 residents), and air pollution and socio-economic deprivation were measured at the level of ward (an electoral area unit of around 5,500 residents). Third, it used longitudinal data from a large general-population study.

However, it also comes with some limitations. First, given the observational nature of the data, causality cannot be inferred. Second, we did not include any residents' perceptions of their environment (e.g., self reports or other residents'

reports). Third, the neighbourhood disorder measure that we used was available only at baseline (i.e., when the cohort child was aged about 3 years) and thus it cannot capture changes in the neighbourhood over time. To a large extent however we dealt with this by including in the sample only families who did not change address from that point until the end of the study period (when the cohort child was aged about 11 years at the end of primary school). Fourth, although we considered several key covariates in our statistical models, we cannot rule out confounding or misclassification entirely. Finally, our study sample includes children in one UK country, England, whose families did not change address for eight years, which somewhat limits the generalisability of findings. These limitations notwithstanding our study goes some way to clarifying the relation between the physical and social environment and child cognition and mental health in the general population. It also highlights the usefulness of using direct observation of the immediate built environment for the prediction of these outcomes.

Declarations

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Conflicts of interest/Competing interests: The authors report no biomedical financial interests or potential conflicts of interest.

Availability of data and material: We used data from the Millennium Cohort Study, which are publicly available and can be downloaded from the UK data service website (https://ukdataservice.ac.uk/).

Code availability: Not applicable

Ethics approval: The Millennium Cohort Study (MCS) received the ethics approval from the National Health Service (NHS) Research Ethics Committee (REC) system.

Consent to participate: In MCS written consent has been sought from parents for their participation and the participation of their child(ren). Written consent has also been sought for gathering information from health, education and economic records and from teachers.

Consent for publication: Written informed consent for publication was obtained from all the authors.

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Table 1.

Bias analysis of study variables between the analytic and the non-analytic sample

	Analytic sample (n=4,454)		Non-analytic sample (n= 14,790)		Test
	Continuous variables				
	N	*M(SD)*	*N*	*M(SD)*	*F*
SDQ Emotional symptoms, age 3	4,079	1.32 (1.47)	10,664	1.40 (1.53)	**7.90****
SDQ Conduct problems, age 3	4,086	2.68 (2.00)	10.684	2.88 (2.09)	**27.26****
SDQ Hyperactivity/inattention, age 3	4,055	3.82 (2.29)	10,577	3.96 (2.39)	**10.25****
SDQ Peer problems, age 3	4,065	1.51 (1.59)	10,581	1.57 (1.59)	**4.32***
SDQ Emotional symptoms, age 5	4,309	1.37 (1.59)	10,417	1.40 (1.60)	1.61
SDQ Conduct problems, age 5	4,314	1.41 (1.42)	10,431	1.56 (1.55)	**31.69****
SDQ Hyperactivity/inattention, age 5	4,288	3.17 (2.30)	10,371	3.37 (2.41)	**21.26****
SDQ Peer problems, age 5	4,306	1.10 (1.41)	10,410	1.20 (1.47)	**16.94****
SDQ Emotional symptoms, age 5	4,316	1.49 (1.72)	9,127	1.55 (1.79)	3.22
SDQ Conduct problems, age 7	4,327	1.29 (1.44)	9,145	1.44 (1.59)	**28.44****
SDQ Hyperactivity/inattention, age 7	4,306	3.23 (2.45)	9,116	3.44 (2.55)	**19.90****
SDQ Peer problems, age 7	4,319	1.22 (1.55)	9,133	1.24 (1.56)	0.53
SDQ Emotional symptoms, age 11	4,289	1.80 (1.96)	8,506	1.90 (2.01)	**7.45****
SDQ Conduct problems, age 11	4,289	1.29 (1.49)	8,509	1.43 (1.61)	**22.51****
SDQ Hyperactivity/inattention, age 11	4,282	2.96 (2.39)	8,489	3.20 (2.51)	**26.47****
SDQ Peer problems, age11	4,291	1.32 (1.66)	8,511	1.40 (1.70)	**5.00***
Cognitive ability score, age 3	3,773	100.87 (15.30)	9,784	99.66 (14.86)	**17.75****
Cognitive ability score, age 5	4,390	101.22 (14.58)	10,473	99.48 (15.14)	**41.92****
Cognitive ability score, age 7	4,362	101.76 (14.61)	8,910	99.13 (15.10)	**90.93****
Cognitive ability score, age 11	4,384	100.57 (14.96)	8,610	99.70 (15.00)	**9.60****
Maternal Kessler score, age 3	3,757	3.05 (3.35)	9,833	3.36 (3.90)	**19.11****
Neighbourhood disorder, age 3	4,295	-0.31(1.60)	13,018	0.10 (2.00)	**151.16****
Poor indoor environment, age 3	3,967	-0.14 (1.36)	9,750	0.06 (1.55)	**55.33****
	Categorical variables				
	N	**%**	**N**	**%**	**Chi^2**
Female	2,156	50.0	5,477	48.5	2.69
Single-parent family, age 3	508	11.8	2,217	19.8	**136.13****
Below poverty line, age 3	1,141	26.6	3,945	35.4	**108.21****
Home-owner parents, age 3	3,147	73.4	6,712	60.1	**236.42****
Living in an urban area, age 3	3,644	84.7	6,718	83.7	1.88
Maternal university degree (by age 11)	1,869	41.9	3,330	39.6	**6.77****
Overcrowding, age 3	367	8.5	1,247	11.1	**22.57****

Access to domestic garden, age 3	4,152	93.4	13,143	89.2	68.04
Ethnicity					
White	3,309	80.7	9,373	87.2	**101.47****
Indian	174	4.3	206	1.9	**64.41****
Pakistani/Bangladeshi	333	8.1	612	5.7	**29.30****
Black	163	4.0	296	2.8	**14.76****
Mixed	38	0.9	96	0.9	**0.03****
Other	83	2.0	162	1.5	**4.88***
England advantaged stratum	2,093	46.9	2,735	18.5	n/a
England disadvantaged stratum	1,615	36.2	3,190	21.6	n/a
England ethnic stratum	746	16.7	1,845	12.5	n/a
Green space: most deprived decile	852	19.7	1,884	16.7	**267.47****
Air pollution: most deprived decile	1,227	28.4	2,215	19.6	**290.12****

Note: $p<.01$** $p<.05$*

Table 2.

Pearson's correlations of the main study variables in the analytic sample (n=4,454)

	SDQ E, age 3	SDQ C, age 3	SDQ H, age 3	SDQ P, age 3	SDQ E, age 5	SDQ C, age 5	SDQ H, age 5	SDQ P, age 5	SDQ E, age 7	SDQ C, age 7	SDQ H, age 7	SDQ P, age 7	SDQ E, age 11	SDQ C, age 11	SDQ H, age 11	SDQ P, age 11
SDQ E, age 3	1															
SDQ C, age 3	0.27**	1														
SDQ H, age 3	0.22**	0.47**	1													
SDQ P, age 3	0.32**	0.24**	0.23**	1												
SDQ E, age 5	0.43**	0.21**	0.14**	0.29**	1											
SDQ C, age 5	0.17**	0.48**	0.32**	0.17**	0.29**	1										
SDQ H, age 5	0.16**	0.34**	0.55**	0.20**	0.24**	0.50**	1									
SDQ P, age 5	0.24**	0.18**	0.18**	0.39**	0.37**	0.26**	0.27**	1								
SDQ E, age 7	0.36**	0.23**	0.17**	0.26**	0.49**	0.26**	0.23**	0.30**	1							
SDQ C, age 7	0.17**	0.43**	0.32**	0.17**	0.20**	0.58**	0.42**	0.21**	0.35**	1						
SDQ H, age 7	0.14**	0.33**	0.49**	0.18**	0.17**	0.41**	0.66**	0.25**	0.27**	0.54**	1					
SDQ	0.20**	0.20**	0.19**	0.36**	0.26**	0.25**	0.25**	0.53**	0.40**	0.34**	0.31**	1				

P, age 7																
SDQ E, age 11	0.27**	0.20**	0.16**	0.22**	0.38**	0.23**	0.22**	0.23**	0.47**	0.27**	0.24**	0.27**	1			
SDQ C, age 11	0.15**	0.36**	0.27**	0.14**	0.20**	0.48**	0.36**	0.18**	0.23**	0.56**	0.39**	0.23**	0.37**	1		
SDQ H, age 11	0.13**	0.30**	0.41**	0.16**	0.15**	0.38**	0.55**	0.23**	0.20**	0.44**	0.64**	0.27**	0.36**	0.53**	1	
SDQ P, age 11	0.17**	0.17**	0.18**	0.29**	0.22**	0.22**	0.27**	0.39**	0.26**	0.26**	0.28**	0.48**	0.46**	0.34**	0.36**	1
IQ, age 3	-0.18**	-0.22**	-0.22**	-0.17**	-0.16**	-0.19**	-0.24**	-0.21**	-0.16**	-0.20**	-0.22**	-0.20**	-0.13**	-0.19**	-0.21**	-0.17**
IQ, age 5	-0.14**	-0.15**	-0.20**	-0.13**	-0.15**	-0.16**	-0.24**	-0.17**	-0.16**	-0.17**	-0.23**	-0.18**	-0.13**	-0.15**	-0.22**	-0.14**
IQ, age 7	-0.13**	-0.18**	-0.22**	-0.12**	-0.15**	-0.19**	-0.27**	-0.14**	-0.20**	-0.21**	-0.29**	-0.19**	-0.20**	-0.20**	-0.29**	-0.19**
IQ, age 11	-0.14**	-0.13**	-0.16**	-0.11**	-0.14**	-0.15**	-0.17**	-0.13**	-0.16**	-0.17**	-0.16**	-0.14**	-0.17**	-0.16**	-0.19**	-0.13**
Neighbourhood disorder	0.13**	0.13**	0.08**	0.11**	0.11**	0.13**	0.13**	0.15**	0.11**	0.13**	0.10**	0.15**	0.08**	0.14**	0.13**	0.13
Green space	-0.07**	-0.07**	-0.06**	-0.08**	-0.07**	-0.06**	-0.07**	-0.12**	-0.07**	-0.05**	-0.07**	-0.11**	-0.03*	-0.04**	-0.04**	-0.06**
Air Pollution	0.06**	0.03*	0.04**	0.07**	0.05**	0.02	0.05**	0.09**	0.05**	0.01	0.04**	0.09**	0.01	0.02**	0.02	0.04**
England advantaged stratum	-0.13**	0.13**	-0.10**	-0.14**	-0.11**	-0.11**	-0.12**	-0.16**	-0.09**	-0.12**	-0.10**	-0.15**	-0.08**	-0.11**	-0.09	-0.11
England disadvantaged stratum	0.04**	0.11**	0.05**	0.03*	0.04**	0.09**	0.08**	0.05**	0.03*	0.08**	0.06**	0.04**	0.06**	0.09**	0.07**	0.06**
England ethnic stratum	0.12**	0.04**	0.07**	0.15**	0.10**	0.03*	0.06**	0.16**	0.09**	0.05**	0.06**	0.15**	0.02	0.03*	0.03*	0.07**
Poor indoor environment	0.06**	0.14**	0.06**	0.06**	0.05**	0.10**	0.08**	0.08**	0.06**	0.09**	0.05**	0.07**	0.05**	0.10**	0.07**	0.08**

Maternal Kessler score	0.24**	0.26**	0.19**	0.20**	0.21**	0.19**	0.19**	0.19**	0.20**	0.18**	0.17**	0.19**	0.21**	0.17**	0.17**	0.17**
Below poverty line	0.19**	0.17**	0.15**	0.17**	0.14**	0.19**	0.15**	0.18**	0.17**	0.18**	0.13**	0.19**	0.11**	0.16**	0.12**	0.16**
Home owner parents	-0.14**	-0.17**	-0.14**	-0.13**	-0.11**	-0.16**	-0.16**	-0.18**	-0.15**	-0.17**	-0.15**	-0.18**	-0.11**	-0.18**	-0.14**	-0.18**
Living in an urban area	0.05**	0.07**	0.04**	0.03	0.04**	0.05**	0.06**	0.08**	0.04**	0.04**	0.04**	0.07**	0.02	0.03*	0.04**	0.05**
Maternal university degree	-0.11**	-0.12**	-0.15**	-0.11**	-0.08**	-0.12**	-0.15**	-0.10**	-0.09**	-0.13**	-0.13**	-0.09**	-0.08**	-0.12**	-0.14**	-0.09**
Overcrowding	0.06**	0.05**	0.03*	0.10**	0.06**	0.06**	0.04**	0.10**	0.04**	0.04**	0.03*	0.10**	0.02	0.06**	0.04**	0.05**
Access to domestic garden	-0.03*	-0.00	0.00	-0.06**	-0.03*	-0.02	-0.02	-0.05**	-0.03*	-0.02	-0.00	-0.06**	-0.00	-0.01	-0.01	-0.04**
Female	-0.00	-0.05**	-0.11**	-0.06**	0.01	-0.08**	-0.13**	-0.06**	0.00	-0.09**	-0.15**	-0.05**	0.04**	-0.08**	-0.17**	-0.03
Single Parent family	0.09**	0.11**	0.09**	0.06**	0.05**	0.12**	0.11**	0.08**	0.09**	0.11**	0.08**	0.12**	0.07**	0.11**	0.08	0.10**
Ethnicity, white	-0.15**	-0.03*	-0.07**	-0.18**	-0.11**	-0.03	-0.06**	-0.18**	-0.08**	-0.03*	-0.04**	-0.17**	0.00	-0.00	0.00	-0.06**
Ethnicity, Indian	0.04**	0.00	0.02	0.05**	0.02	0.00	0.01	0.06**	0.00	-0.00	0.00	0.05**	-0.04**	-0.02	0.00	-0.00
Ethnicity, Pakistani/ Bangladeshi	0.16**	0.07**	0.10**	0.18**	0.13**	0.05**	0.06**	0.16**	0.09**	0.06**	0.07**	0.16**	0.03*	0.03*	0.00	0.06**
Ethnicity, black	0.00	-0.02	-0.02	0.02	0.02	-0.00	0.01	0.03*	0.02	-0.00	-0.01	0.04**	-0.00	-0.00	-0.00	0.00
Ethnicity, mixed	0.00	0.00	0.01	0.03*	0.01	0.01	0.00	0.03*	0.03*	0.01	0.00	0.04**	0.00	-0.00	0.01	0.02
Ethnicity, other	0.03*	-0.02	0.00	0.03*	-0.00	-0.01	-0.00	0.03	0.00	-0.01	0.00	0.01	-0.01	-0.00	-0.01	0.03*

	IQ, age 3	IQ, age 5	IQ, age 7	IQ, age 11	Neigh. disord.	Green space	Air Poll.	Poor Indoor env.	Urban area	Engl. Adv.	Engl. dis	Engl. Eth.
IQ, age 3	1											
IQ, age 5	0.54**	1										
IQ, age 7	0.47**	0.62**	1									
IQ, age 11	0.32**	0.40**	0.40**	1								

Neighbourhood disorder	-0.29**	-0.22**	-0.20**	-0.13**	1							
Green space	0.21**	0.14**	0.09**	0.02	-0.32**	1						
Air Pollution	-0.17**	-0.12**	-0.05**	-0.02	0.25**	-0.61**	1					
Poor indoor environment	-0.18**	-0.13**	-0.13**	-0.08**	0.22**	-0.09**	0.08**	1				
Living in an urban area	-0.15**	-0.11**	-0.05**	-0.00	0.24**	-0.68**	0.48**	0.05**	1			
England advantaged stratum	0.25**	0.19**	0.16**	0.10**	-0.38**	0.39**	-0.27**	-0.11**	-0.29**	1		
England disadvantaged stratum	-0.03*	-0.03*	-0.08**	-0.01	0.14**	-0.09**	0.00	0.05**	0.17**	-0.71**	1	
England ethnic stratum	-0.30**	-0.21**	-0.10**	-0.11**	0.33**	-0.40**	0.35**	0.08**	0.17**	-0.42**	-0.33**	1
Maternal Kessler score	-0.12**	-0.07**	-0.09**	-0.05**	0.13**	-0.09**	0.07**	0.06**	0.06**	-0.10**	0.03*	0.10**
Below poverty line	-0.38**	-0.28**	-0.26**	-0.20**	0.41**	-0.21**	0.12**	0.17**	0.14**	-0.31**	0.09**	0.29**
Home owner parents	0.27**	0.20**	0.23**	0.16**	-0.39**	0.15**	-0.08**	-0.17**	-0.10**	0.24**	-0.11**	-0.17**
Maternal university degree	0.21**	0.20**	0.20**	0.17**	-0.16**	0.05**	-0.02	-0.10**	-0.07**	0.13**	-0.11**	-0.03*
Overcrowding	-0.22**	-0.15**	-0.13**	-0.11**	0.27**	-0.17**	0.13**	0.19**	0.08**	-0.20**	0.00	0.26**
Access to domestic garden	0.13**	0.07**	0.04**	0.02	-0.26**	0.17**	-0.12**	-0.06**	-0.08**	0.18**	-0.03*	-0.19**
Female	0.09**	0.06**	0.02	-0.05**	0.00	0.00	-0.00	-0.01	0.00	-0.00	-0.00	0.01
Single parent family	-0.14**	-0.09**	-0.12**	-0.06**	0.18**	-0.08**	0.03*	0.05**	0.07**	-0.12**	0.08**	0.06**
Ethnicity, white	0.35**	0.28**	0.13**	0.10**	-0.33**	0.40**	-0.39**	-0.08**	-0.19**	0.34**	0.14**	-0.65**
Ethnicity, Indian	-0.07**	-0.03*	0.03*	0.04**	0.06**	-0.15**	0.17**	0.01	0.07**	-0.13**	-0.08**	0.29**
Ethnicity, Pakistani/ Bangladeshi	-0.34**	-0.25**	-0.15**	-0.18**	0.27**	-0.24**	0.22**	0.07**	0.12**	-0.25**	-0.10**	0.48**

Ethnicity, black	-0.10**	-0.10**	-0.07**	0.02	0.16**	-0.19**	0.18**	0.05**	0.08**	-0.13**	-0.01	0.21**
Ethnicity, mixed	-0.03*	-0.04**	-0.03*	-0.02	0.04**	-0.05**	0.06**	0.00	0.02	-0.02	-0.00	0.04**
Ethnicity, other	-0.06**	-0.06**	0.00	-0.01	0.05**	-0.11**	0.11**	0.00	0.05**	-0.08**	-0.03*	0.15**

Note: SDQ E= Strengths and Difficulties Questionnaire Emotional symptoms; SDQ C= Strengths and Difficulties Questionnaire Conduct problems; SDQ H= Strengths and Difficulties Questionnaire Hyperactivity/Inattention; SDQ P= Strengths and Difficulties Questionnaire Peer problems. Green Space= Green space at LSOA-level (from most deprived to least deprived) in deciles; Air pollution= PM10 concentration at ward-level (from least deprived to most deprived), in deciles

* $p<0.05$
** $p< 0.01$

Table 3.

Fixed and random effect estimates of the main study variables on outcomes for partially adjusted and fully adjusted models in imputed cases (n=4,454)

	Emotional symptoms		Conduct problems		Hyperactivity/ Inattention		Peer Problems		Cognitive ability	
	Coeff.	S.E.	Coeff.	S.E.	Coeff.	S.E.	Coeff.	S.E.	Coeff.	S.E.
Fixed effects	Model 1 (partially adjusted)									
Neigh. disorder on intercept	0.08**	0.01	0.10**	0.00	0.07**	0.02	0.05**	0.01	-2.19**	0.14
Age	0.06**	0.00	-0.14**	0.00	-0.09**	0.00	-0.01**	0.00	-0.02	0.03
Neigh. disorder on slope	-0.00	0.00	-0.00	0.00	0.00	0.00	0.00	0.00	0.15**	0.01
Green space	-0.00	0.01	-0.00	0.01	-0.00	0.01	-0.00	0.01	-0.07	0.10
Air pollution	0.00	0.01	-0.01	0.01	-0.01	0.01	0.00	0.0	-0.05	0.09
Urbanicity	-0.01	0.07	0.05	0.06	0.05	0.11	-0.02	0.06	-0.52	0.62
England disadvan.	0.19**	0.06	0.29**	0.04	0.35**	0.06	0.25**	0.03	-2.33**	0.38
England ethnic stratum	0.45**	0.13	0.21**	0.06	0.45**	0.09	0.61**	0.05	-6.69**	.57
Random effects										
Level 2 (child) Intercept	0. 74	0.02	0. 74	0.02	1.54	0.02	0. 79	0.01	8.55	0.16
Level 2 (child) Slope	0. 11	0.00	0. 09	0.01	0.10	0.00	0. 07	0.00	0.45	0.05
Level 1 (occasion) Intercept	1.29	0.00	1.29	0.00	1.61	0.01	1.21	0.00	11.10	0.07
Fixed effects	Model 2 (fully adjusted)									
	Emotional symptoms		Conduct problems		Hyperactivity/ Inattention		Peer Problems		Cognitive ability	
	Coeff.	S.E.	Coeff.	S.E.	Coeff.	S.E.	Coeff.	S.E.	Coeff.	S.E.
Neigh. disorder on intercept	0.03*	0.01	0.04*	0.00	0.00	0.02	-0.00	0.01	-1.41**	0.14
Age	0.06**	0.00	-0.14**	0.00	-0.09**	0.00	-0.01**	0.00	-0.01	0.03
Neigh. disorder on slope	-0.00	0.00	-0.00	0.00	-0.00	0.00	0.00	0.00	0.15**	0.01
Green space	0.00	0.01	-0.00	0.01	-0.00	0.01	-0.00	0.01	-0.11	0.10

Air pollution	0.00	0.00	-0.01	0.00	0.00	0.01	0.00	0.00	-0.09	0.08
Urbanicity	-0.02	0.06	0.04	0.06	0.01	0.10	-0.02	0.06	-0.43	0.59
England disadvan.	0.12**	0.04	0.20**	0.04	0.22**	0.06	0.17**	0.03	-1.13**	0.36
England ethnic	0.21**	0.07	0.07	0.07	0.26*	0.10	0.33**	0.06	-3.04**	0.63
Random effects										
Level 2 (child) Intercept	0.65	0.02	0.90	0.01	1.41	0.02	0.72	0.01	7.51	0.17
Level 2 (child) Slope	0.11	0.00	2.27	1.21	0.10	0.00	0.07	0.00	0.50	0.04
Level 1 (occasion) Intercept	1.29	0.00	1.29	0.00	1.61	0.01	1.21	0.00	11.09	0.07

Note: Coeff.= (Unstandardised) regression coefficient; S.E.=Standard error; Neigh. disorder = Neighbourhood disorder; Urbanicity= living in an urban area; England disadvant.= England disadvantaged stratum

[1] Model 1 (partially adjusted) includes: Neighbourhood disorder+ Green space+ Air pollution+ Urbanicity+ England disadvantaged stratum+ England ethnic stratum

[2] Model 2 (fully adjusted) includes: Model 1+ maternal Kessler score+ poor indoor environment+ sex+ family structure+ poverty line status+ maternal education+ overcrowding+ access to domestic garden+ ethnicity

** p<.01; * p<.05

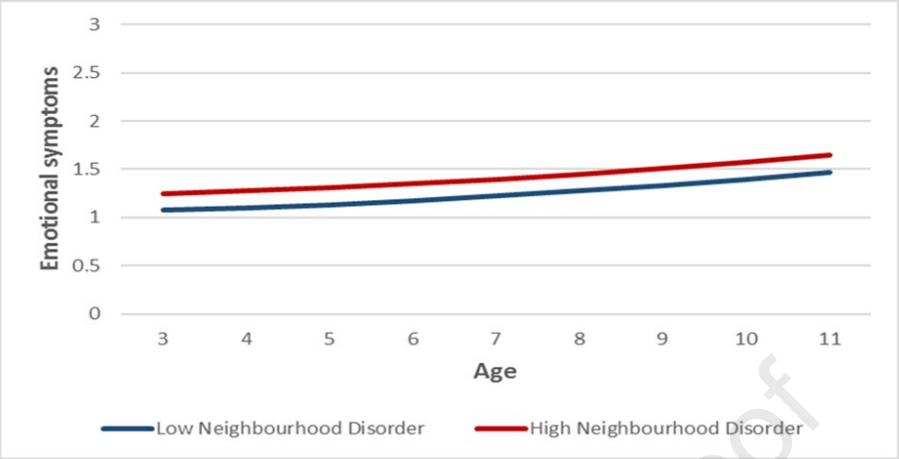

Figure 1. Predicted emotional symptoms trajectories by neighbourhood disorder level (high vs low

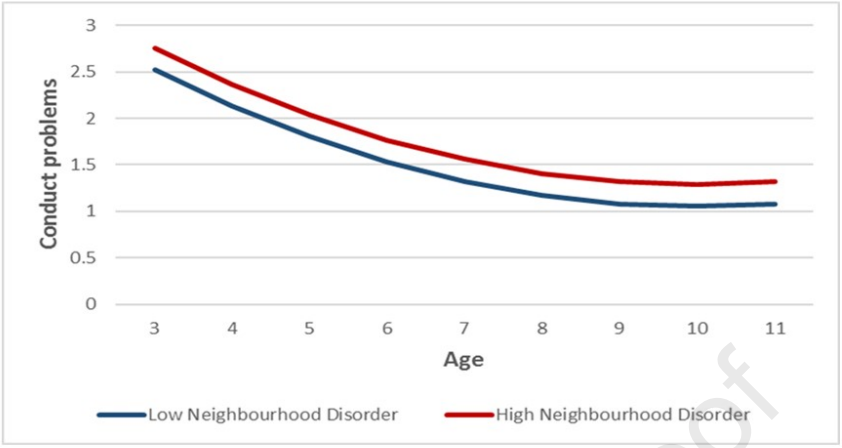

Figure 2. Predicted conduct problems trajectories by neighbourhood disorder level (high vs low).

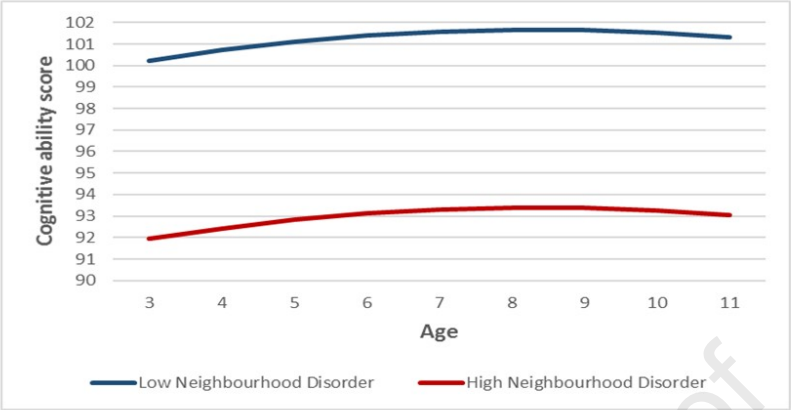

Figure 3. Predicted cognitive ability trajectories by neighbourhood disorder level (high vs low). Estimated effect on the slope.

Author statement

Marta Francesconi: Took part in the design process of the study, undertook the statistical analyses and took part in the writing process of the manuscript.

James B. Kirkbride: Took part in the design process of the study and in the revision process of the manuscript.

Eirini Flouri: Took part in the design process of the study, in the writing process of the manuscript and supervised the statistical analyses.

All authors contributed to and have approved the final manuscript.