Baird et al., 2021 Environmental Research Submission

Title page

Manuscript title:

The Role of Physical Environmental Characteristics and Intellectual Disability in Conduct Problem Trajectories Across Childhood: A Population-Based Cohort Study

Author(s) format:

Baird. A, Papachristou. E, Hassiotis. A, Flouri, E.

Word count: 4642

Author information

Main / corresponding author:

Name: Alister Baird
Highest academic qualification: Master of Science (MSc)
Affiliation: UCL Division of Psychiatry
Address: 6th floor Maple House, 149 Tottenham Court Rd, London, United Kingdom, W1T 7BN
Contact: Alister.baird.19@ucl.ac.uk

Author two:

Name: Dr Efstathios Papachristou
Highest academic qualification: Doctor of Philosophy (PhD)
Affiliation: UCL Institute of Education – Psychology and Human Development
Address: 20 Bedford Way, London, United Kingdom, WC1H 0AL
Contact: efstathios.papachristou@ucl.ac.uk

Author three:

Name: Professor Angela Hassiotis
Highest academic qualification: Doctor of Philosophy (PhD)
Affiliation: UCL Department of Psychiatry
Address: Maple House, 149 Tottenham Court Rd, London, United Kingdom, W1T 7BN
Contact: a.hassiotis@ucl.ac.uk

Author four:

Name: Professor Eirini Flouri
Highest academic qualification: Doctor of Philosophy (PhD)
Affiliation: UCL Institute of Education – Psychology and Human Development
Address: 20 Bedford Way, London, United Kingdom, WC1H 0AL
Contact: e.flouri@ucl.ac.uk

Abstract:

Background:

The paucity of research investigating the role of the physical environment in the developmental progression of conduct problems and the potential moderating effects of intellectual disability (ID) is surprising, given the clinical relevance of elucidating environmental determinants of disruptive behaviours.

Aims:

To use data from a large UK cohort study to assess associations between physical environmental exposures, ID, and conduct problem trajectories.

Method:

The sample included 8,168 Millennium Cohort Study children (1.9% with ID). Multilevel growth curve modelling was used to examine the role of physical environment characteristics in the developmental trajectories of conduct problems after adjustments for ID status.

Results:

Exposure to external environmental domains was not associated with differences in children's conduct problems across development. Alternatively, internal aspects of the household environment: spatial density (b = 0.40, p<.001) and damp problems (b = 0.14, p<.001) were both significantly associated with increased trajectories. Various individual and familial covariates were positively associated with conduct problems over time, including: presence of ID (b = 0.96, p<.001), autism spectrum disorder (b = 1.18, p<.001), male sex (b = 0.26, p<.001), poverty (b = 0.19, p<.001), maternal depression (b = 0.65, p<.001), and non-nuclear family structure (b = 0.35, p<.001). Positive ID status appeared to moderate the effects of internal household spatial density, reporting a non-linear negative association with spatial density and conduct problems across development (b = -1.08, p<.01).

Conclusions

Our findings highlight the potential harmful consequences of poor internal residential conditions on children's development of disruptive behaviours.

Keywords: Intellectual Disability, Conduct Problems, Physical Environment, Millennium Cohort Study, Longitudinal Birth Cohort

Funding

Jointly funded by the UCL Institute of Mental Health (https://www.ucl.ac.uk/mental-health/), the UCL institute of Education (IoE) and the UCL Dept of Civil, Environmental and Geomatic Engineering.

Introduction

Interest in the role of children's early physical environment on neurodevelopmental and socio-cognitive outcomes has increased in recent decades, evidenced by reviews examining its effects on well-being[1,2,3], mental health[4,5], and development[6]. Physical domains explored are diverse, ranging from nature exposure and meteorology, to architectural design. Previous studies have highlighted the valence of physical environmental aspects such as exposure to natural greenspaces[7] and air particulate matter[8] on childhood psychological and neurophysiological outcomes. Considering that conduct problems have been associated with a wide range of negative long-term consequences, ranging from high societal economic costs[9], to reduced life satisfaction and disintegration of social connections[10], it is surprising that there is a paucity of current literature examining the role of the physical environment in the developmental progression of childhood conduct problems. Moreover, it is yet to be examined whether the influence of the physical environment on conduct problem symptom trajectories is more severe for children with intellectual disability (ID) than typically developing children. The global prevalence of ID has been estimated at 1.37%[11], with frequency of reported comorbid challenging behaviors inconsistent, varying between 10-22%[12.13,14,15,16] in population studies, and between 50 – 60% in observation studies[17,18]. Additionally, children with ID have been shown to exhibit significantly more conduct problems than their typically developing peers[19].

Physical environmental characteristics such as air pollution and urbanicity[20,21] have been previously positively associated with conduct problems, whilst exposure to greenspaces has been negatively associated with these problems in both typically developing children[22,23], and children with autism spectrum disorder[24] (ASD). Theories explicating these associations increasingly cite (neuro)physiological paradigms, for example, neuroinflammation via direct exposure to air particulate matter in the brain[25], or nature exposure conveying protection (maintaining homeostasis via regulation of physiological stress and attentional resources) from potentially harmful physical environmental influences[26-29]. Although previous epidemiological work has explored the varied nature of conduct problems in children with cognitive difficulties[30], few systematic reviews examine environmental effects on the trajectories of these behaviours in children with ID and neurodevelopmental disorders (NDDs) more broadly. For these children, escape from external environmental stressors (negative reinforcement) may constitute a significant proportion of the antecedent motivation behind conduct

problems[31]. Additionally, possible limitations in ability to communicate distress and/or regulate their environment, may increase the salience of negative physical environmental characteristics in comparison to typically developing children[14,15]. Considering that the impact of the physical environment may be more potent in early neurodevelopmental stages[32], and that consequences of childhood conduct problems are severe and persistent across the lifespan[33-39], this study has the potential to illuminate the roles of both the external and interior physical environment in the developmental trajectories of conduct problems in children with and without ID.

Method

Sample

The sample was drawn from the Millennium Cohort Study (MCS: https://cls.ucl.ac.uk/cls-studies/millennium-cohort-study/[40]), a UK population-based longitudinal birth cohort study. We used data collected from participants at MCS waves 2, 3, 4 and 5, with children aged, 3, 5, 7, and 11 years, respectively. In total 19,243 families have participated in the MCS to date. The MCS employed a stratified sampling protocol which disproportionally recruited disadvantaged or ethnic minority families (see Plewis[41]). The analytic sample of this study (n = 8,168; 49% male) included children (singletons and first-born twins or triplets) with valid data across all included sweeps (2-5) on cognitive ability and the behavioral outcome measure (conduct problems).

Intellectual disability ascertainment

To identify children with intellectual disability, first we ran principal components analysis (PCA) on standardised cognitive ability assessments available at each wave to derive summary cognitive scores. Such synthesis of multiple well-validated assessments has been shown to produce an adequate metric capturing general cognitive ability[42]. Previous research has adopted PCA to ascertain ID frequency within the MCS[43-48]. These studies predominantly use PCA at sweep 4 (age 7) to identify children with ID, only using scores at sweep 3 (age 5) if children had missing cognitive information at sweep 4, and using parental reports of child special educational needs (SEN) as a proxy for ID, only if cognitive information was not available at any sweep.

Our strategy was divergent in several key regards: We used PCA across cognitive measures at all sweeps (2-5) to classify children, requiring children to score two standard deviations below the mean score for cognitive ability at two or more waves to be classified with ID status. Parental confirmation of SEN statement due to learning disability was also used to provide a positive ID classification for

children across sweeps. Children who received a SEN statement due to being classified as 'gifted', or 'high IQ' were not classified as ID but still included in the analytic sample. Our rationale for using a modified ID ascertainment methodology was the concern that classifying children based on cognitive performance at a singular time point may facilitate miss-identification. Additionally, as we are using cognitive scores as a proxy measure for ID and not direct clinical diagnostic information, we wanted to ensure that classification was accurate and stable over time.

The cognitive assessments used for PCA were: the Bracken School Readiness Assessment-Revised[49] (conceptual knowledge) (BSRA-R) and the BAS-II Naming Vocabulary test[50] (expressive language ability) at MCS wave 2 (child age 3). For MCS wave 3 (child age 5) cognition was assessed using the: BAS Naming Vocabulary, BAS Pattern Construction (spatial problem-solving ability) and BAS Picture Similarities (non-verbal reasoning). For MCS wave 4 (children aged 7) the age standardised pattern construction and word reading scores from the BAS-II were used as well as a shortened version of the Progress in Maths tests[51] (National Foundation for education Research). At wave 5 (child age 11) cognitive ability was assessed with the BAS Verbal Similarities (verbal knowledge and reasoning capability) and the error scores on the spatial working memory (SWM) task (representative of executive functioning[52]) from the Cambridge Neuropsychological Test Automated Battery[53] (CANTAB). Our ascertainment methodology resulted in a prevalence rate for ID of 1.9% (N = 155) in our analytic sample.

Conduct problems

Conduct problems at ages 3, 5, 7, and 11 years were measured using the parent-reported Strengths and Difficulties Questionnaire[54] (SDQ). In MCS, the conduct problems subscale of the SDQ has been shown to have satisfactory internal reliability with Cronbach's alphas ranging from 0.77 and 0.82 for ages 3 – 7 years[55], and 0.68 for children aged 11[56]. In the analytic sample, Cronbach's alpha values ranged from 0.53 to 0.60 across assessments. Importantly, the SDQ has been shown to be comparably valid across populations with and without ID[57,58].

External physical environmental exposures

Greenspace was assessed in the MCS using ward-level greenspace data from the UK, estimated with data from the Generalized Land Use Database[59] (GLUD) and from the Coordination of information on the Environment[60] (CORINE; EEA). Regression models predicted GLUD percentage greenspace per

English ward which was adapted for use on the whole of the UK[61] resulting in a linear greenspace metric reporting the deciles of percentage of greenspace within wards, with higher scores reflective of more greenspace. Information on children's *access to private garden space* was also available. Data on *pathogenic air particulate matter* in the UK was obtained from the Multiple Environmental Deprivation Index (MEDIx) and linked to children's residential addresses. Annual population weighted mean concentrations of nitrogen dioxide (NO_2) were taken between 1999 – 2003 from 2001 UK Census Areas Statistics (CAS) ward with annual means converted into deciles (higher scores representative of increased NO_2) before being linked to MCS waves[62]. Data from the National Office of Statistics (ONS) was used to assess *urbanicity or rurality* of children's residential geography[63] at each included wave.

Interior physical environmental exposures

Home spatial density was measured by extracting parent reported data on the total number of people residing in each household at each wave, divided by the total number of rooms. Parents reported information on *residential damp problems* per wave and this was transformed into a binary variable indicating presence or not of household damp.

Covariates

Adjustment for a variety of time-invariant and time-varying covariates were made in our analyses. Time-invariant covariates included *ethnicity* (classified as white or non-white due to the granularity of ethnicity captured within the MCS), *sex*, and *autism spectrum disorder (ASD) status*. ASD confirmation was obtained from parental and teacher questionnaires specifying whether the child has a previous ASD diagnosis across at least 2 assessment waves. The time-varying covariates measured at each assessment wave included, *age (in years)*, *poverty* (defined as household income - equivalised for household size - below 60% median national income obtained from the Organisation for Economic Co-operation and Development: OECD), *maternal depression*, and *family structure*. Maternal depression was measured using scores from the Kessler K6 depression scale[64], a 6-item Likert response questionnaire, measuring psychological distress related to symptoms of depression and anxiety. We used previously validated diagnostic cut-off values greater than 13 as representative of serious mental illness (SMI) and depression[64]. Nuclear family structure was defined as the presence of both biological parents in the household.

Statistical analysis

We initially examined whether children in the analytic sample differed from the remaining MCS sample in terms of their sociodemographic characteristics, exposure to external and interior physical environmental exposures, and conduct problem levels. Next, growth curve models (GCM) were fitted as random intercept multilevel models (MLM) to investigate the impact of external (greenspace*,* access to private garden space, air pollution, and urbanicity) and interior (home spatial density and residential damp problems) environmental measures on the developmental trajectories of conduct problems. The MLM had three levels; repeatedly measured data points for individuals (Level1) were treated as being nested within children (Level 2), which were in turn, nested within electoral wards (Level 3). Children's age was measured in years and was centred around the grand mean (6.71 years). Parameterised in this way, the effect of the predictor variables reflect mean differences at approximately age 7 years. We included an additional quadratic term for age in all models to explore the temporal linearity of conduct problems. Missing data in covariates were multiply imputed (MI) using chained equations (MICE) under the assumption that data is missing at random (MAR). Percentages of missing data ranged between 0.02 – 3.38% and a total of 20 datasets were imputed[65].

Our rationale for imputing data for covariates but not ID or our primary outcome was to avoid risking misclassifying typically developing children as intellectually disabled or exhibiting conduct problems, particularly considering the stringency of our non-time varying ID classification (i.e., requiring children to meet cognitive thresholds or parental-reported SEN diagnosis at two or more waves). In an exploratory manner we replicated the main analysis after imputing data for all variables in the model, including ID and SDQ conduct problem scores (N=19,243). In this model ID diagnosis was used as a time-varying variable as it was not possible to reliably impute the original model (B) using the original time-invariant ID diagnosis variable (=>2 waves) across the whole sample. These results (presented in the supplementary material Table S1) were comparable with the analysis presented below (Table 3) which are based on cohort members with complete available information on ID.

The main part of the analyses included two MLM: The first model (Model A) sought to examine the impact of external and interior physical environmental exposures on the trajectories of conduct problems after adjustments for ID status. The second model (Model B) examined the effects of the exposure variables on the outcome after adjustments for the time-varying (maternal psychological distress, socioeconomic disadvantage, family structure) and time-invariant cofounders (sex, ethnicity,

ASD status). For both models we calculated the associated intra-class correlation coefficients (ICC) to estimate the variance in the trajectories that is attributable to the clustering of the variables within higher levels (Levels 2 and 3). For the environmental exposure variables that emerged as significant in the fully adjusted analytic model (B) we estimated their associated E-values. E-values are a recently introduced measure of the hypothetical strength that an unmeasured confounder would need to have with both the exposure and outcome variables, conditional on the measured covariates, to fully explain the association between the exposure and the outcome[66(p.8)]. Additional models including all two-way and three-way interaction terms between ID status, physical environmental measures, and age, were run to assess if the environmental influences on trajectories conduct problems varied dependent on children's ID classification (Supplementary tables S2 – S6). We applied a stringent p-value significance criterion (* = p<0.01) to all models to adjust for multiple comparisons.

Because the MCS sample is disproportionately stratified due to the intentional over-sampling of sub-groups of the population all models were accordingly adjusted by including appropriate stratification variables. Each country had two strata: advantaged and disadvantaged. England had an additional one for areas with high percentage of ethnic minorities. We also adjusted for the clustered MCS sample at electoral ward level but also for attrition and non-response rates by incorporating study-specific weights into our models. All analyses were run in Stata SE 16.1[67].

Results

Bias analysis

First, we explored differences between children in the analytic (N = 8,168) and non-analytic sample (N = 11,075, Table 1). Children in the analytic sample lived in greener, less air polluted neighbourhoods and were more likely to have access to a private garden and to reside in more rural environments. The profile of their indoor home environments also differed, with residential homes being less spatially dense and with fewer damp problems. Significantly higher proportions of the non-analytic sample had income below the 60% medium national level, psychologically distressed mothers, ASD, lower cognitive scores. and lived in non-nuclear family structures.

"INSERT TABLE 1 HERE"

Physical environment and intellectual disability

Next, MLMs were run to examine the impact of physical environmental exposures and ID on trajectories of conduct problems across childhood. Model A included physical environmental exposures and ID status as the only explanatory variables. The ICC estimates suggested that individual child differences (Level 2) explained 51.5% of the variance in conduct problem trajectories, while commonalities of children residing within the same electoral wards (level 3) explained a mere 1.7% of the variation in the outcome. The unstandardised regression estimates of the model are summarised in Table 2. The results showed that children with ID (b = 1.270, SE = 0.176, p<.001), and those residing in houses with higher residential spatial density (b = 0.356, SE = 0.062, p<.001) and with household damp (b = 0.163, SE = 0.033, p<.001) had more conduct problems at around 7 years (the centred intercept). In contrast, none of the exterior environmental characteristics considered were significantly associated with the conduct problem trajectories. The regression estimates of the linear (b = -0.217, SE = 0.005, p<.001) and quadratic (b = 0.052, SE = 0.001, p<.001) age terms indicated that, across childhood, conduct problems decreased in a nonlinear fashion.

"INSERT TABLE 2 HERE".

After adjustments for the covariates (Model B), the ICC values associated with clustering within the second and third level were reduced to 48.2% and 1.3%, respectively, suggesting that a significant amount of variance in conduct problems trajectories was still accounted for by individual-child differences. Table 3 summarises the results of this MLM. Overall, after adjustments for ASD status, ethnicity, sex, family structure, poverty, and maternal depression, children with ID still had more conduct problem scores at around age 7 (b = 0.963, SE = 0.175, p<.001). Presence of damp (b = 0.143, SE = 0.031, p<.001) and high spatial density (b = 0.400, SE = 0.062, p<.001) were significantly associated with elevated levels of conduct problem after adjustments for confounding. As in Model A, we did not find evidence for an impact of greenspace, NO_2 particulate matter, access to private gardens or urbanicity on conduct problem trajectories.

Regarding the effect of covariates, those classified as ASD (b = 1.182, SE = 0.311, p<.001), males (b = 0.263, SE = 0.035, p<.001), those whose mothers were psychologically distressed (b = 0.650, SE =

0.098, *p*<.001) and those living in non-nuclear (b = 0.346, SE = 0.036, *p*<.001) or poorer families (b = 0.190, SE = 0.037, *p*<.001) had, on average, more conduct problems at around 7 years.

We calculated E-values for those environmental exposures that emerged as statistically significant in the fully adjusted model. The association between presence of damp problems and conduct problem trajectories corresponded with an E-value of 1.369 (lower bound of 95% CI = 1.272). As spatial density was measured on a continuous scale, we used three distribution-based cut-offs (Lower quartile, median-split, and upper quartile of the distribution of spatial density in the sample) to reclassify spatial density as a categorical variable with scores above or below the distribution-based thresholds. The respective E-values for the three analyses were 1.404 (lower bound of 95%CI= 1.335), 1.493 (lower bound of 95%CI= 1.433), and 1.426 (lower bound of 95%CI=1.349). E-values in the range of 1.369 to 1.493 have been suggested to indicate magnitudes of unmeasured confounding which are unlikely to affect the associations found[68], suggestive that our model estimates are robust.

"INSERT TABLE 3 HERE".

Interactions between physical environment and intellectual disability

To assess if exposure to physical environmental aspects was differentially associated with conduct problem trajectories for children with or without ID, additional GCM models, each including all 2-way interaction terms and the 3-way interaction term between environmental exposures, ID status and age, were run (results summarised in Tables S2-S6 in the supplementary material). ID did not appear to modify associations between external physical environment exposures and conduct problems. However, the effect of the interaction term between ID and spatial density on conduct problems was statistically significant (b = -1.075, SE = 0.346, *p*<.01), suggesting that positive ID status and increased household spatial density was associated with decreases in conduct problems over time (Table 4).

"INSERT TABLE 4 HERE".

Sensitivity analysis

We investigated this association between spatial density, ID, and conduct problems further by conducting a sensitivity analysis to examine if the ethnicity of children with ID influenced conduct problem trajectories. We found that white ethnicity and increased spatial density interacted significantly to predict elevated SDQ conduct scores (b = 0.419, SE = 0.113, p<.001), however the 3-way interaction including ID did not (b = 0.906, SE = 0.670, p = 0.176), suggesting that whilst ethnicity (white / non-white) interacted with home crowdedness in predicting conduct problem development, ID diagnosis did not appear to moderate this relationship (Supplementary Table 7).

Discussion

The role of physical environmental exposures on children's socioemotional and neurodevelopment is currently not well understood, with previous calls for large scale multilevel interdisciplinary approaches to investigate its impacts being issued[69]. In this study, we used data from UK's largest recent birth cohort to examine associations between various interior and external environmental aspects with conduct problems across childhood. Additionally, the role of ID as a potential moderator of these associations was examined to explore if associations between physical environmental characteristics and conduct problems were more salient for children with ID.

In this sample, external physical environmental domains were not associated with conduct problems, whilst both home crowdedness and damp were both related to increased conduct problem scores across development. In-line with previous literature, multiple socio-economic and familial covariates were also associated with behavioural problems, including: maternal psychological distress[70], poverty[71], living within a non-nuclear family structure[72], ethnicity[73], and male sex[74].

Our lack of significant associations between greenspace and conduct problems is incongruous with literature examining its effects on children's psychobehavioural outcomes. For example, some of the available studies suggest advantageous effects of access to greenspace on children's conduct problems[75-79]. Whilst our findings may be indicative of a true null association between greenspace exposure and child conduct problems, it may also be an artefact of the longitudinal nature of this sample, as previous studies have been primarily cross-sectional. It may also be attributable to inadequacies in the ward-level greenspace data available within the MCS, its reliance on geographical location and inability to assess the quality and frequency of children's greenspace

exposure has been highlighted previously[80]. These are critical components of greenspace contact[81] and their omission may draw into question the validity of this metric. Whilst children's access to private gardens did trend towards reductions in conduct problem trajectories in this study, it did not reach significance. Again, these results are discordant with previous studies which reported beneficial associations between access to private gardens and childhood conduct problems[82,83]. Due to safety concerns, children's opportunity for autonomous play has diminished in recent decades[84-87], potentially limiting their access to neighbourhood greenspaces and making private garden access a more salient measure of greenspace exposure.

Similarly, NO_2 exposure was not correlated with conduct problems in our sample. This mirrors previous findings which found no correlation between NO_2 particulate matter[88] or elemental carbon attributed to traffic pollution (ECAT) on childhood conduct problems. Nonetheless, the available evidence on the associations between air pollution and behavioural outcomes is mixed, with a previous study reporting[20] harmful associations between particulate matter less than 2.5 microns ($PM_{2.5}$) and NO_2 exposure, and increased risk of conduct disorders. This may suggest that cumulative exposure to air pollution grows during childhood, resulting in negative behavioural outcomes manifesting later in development, postliminary to the latest assessment used in our analysis (age 11). Recent research on the effects of ambient air pollution on children with ID - also using the MCS[47] - reported that they are between 17% - 33% more likely to live in areas of high air pollution dependent on the particulate matter exposure measured. Neurotoxicity related to air pollutants has also been linked to the aetiology of NDDs[89,90], and in a recent review of the current epidemiological evidence, Xu, Ha, and Basnet[91] reported the harmful effects of exposure to various air pollutants (H_2S, ozone, PM_{10}, $PM_{2.5}$, and NO_2, among others) on neurodevelopment and psychobehavioural functioning in both adults and children. This is in accordance with recent research linking the presence of ultra-fine air particulate matter in the brain to neuroinflammatory and intrathecal inflammatory responses[92], highlighting valid neurophysiological mechanisms for the aetiology of air pollution in childhood aggression.

We report no association between urbanicity or rurality of residential geography and conduct problems. Previous studies that have examined the relationship between urban/rural residence and aggression outcomes in children, reporting contradictory findings[93-97]. Urban environments have been shown to increase exposure to potentially harmful environmental influences (noise pollution, air

pollution, overcrowding) that may place additional strain on cognitive and self-regulatory processes[99], contributing to the aetiology of violent behaviour[100]. Urban inhabitants also have limited access to greenspaces[101], which have been purported to operate as a protective buffer against harmful environmental exposures[102,103], potentially compounding the negative effects of urban stimuli. It is worth considering if the possible therapeutic efficacy of greenspace exposure may be attributable to reduced exposure to harmful urban environmental stimuli[103] rather than a direct benefit of nature experience itself.

Presence of damp in children's homes was associated with increased SDQ conduct problems scores across development. Previous work using MCS data reported negative effects of children's indoor environment on cognitive and behavioural processes such as self-regulation and conduct problems[104,105,80]. Increased damp can lead to toxic mould and poor air quality[106] to which children are especially vulnerable[107] and which may cause neuroinflammatory and/or neurotoxic responses[108,109]. Financial circumstances and poor interior physical conditions of residential homes are highly correlated[110], it is therefore likely that homes with multiple structural deficits exacerbate there negative effects on children's mental health. Future research should elucidate the direct toxic neurophysiological effects of household damp and mould and attempt to separate these from the influences of comorbid low socioeconomic status that so often accompanies occupation of deficient home environments.

Increased spatial density was associated with decreased conduct problem trajectories in children with a positive ID status. This finding is rather counterintuitive; previous research on spatial density and aggressive behaviour has primarily examined the influence of low-density vs high-density playground or classroom conditions in typically developing children, reporting disparate associations[111-114]. One contemporary study[115] reported that residential overcrowding was correlated with increased teacher reported externalising behaviors. Parents in crowded households have been shown to be less attentive and patient[116], potentially indicative of a habituation effect leading to inaccurate caregiver reported conduct problems. The paucity of research exploring the impact of crowding on onset and/or maintenance of conduct problems in children with ID makes it impossible to embed our findings within the wider literature. This association between spatial density and conduct problems in children with ID may be attributable to several causes: first, this analysis was underpowered due to the relatively small sample of children with ID in this cohort. Second, households with an elevated density of family

members may convey additional benefits to children with ID, for example increased availability of support from proximal family members. Third, due to limited availability of complex spatial density metrics within the MCS, we adopted a one-dimensional measure of parental reported residential crowding, which may fail to capture the whole range of the spatial dynamics in the home. Finally, children with ID may spend a higher proportion of time in indoor environments due to the additional logistical complexity of undertaking activities outside of the home. This is especially relevant given contextual circumstances related to the COVID-19 pandemic pertaining to the additional risks and difficulties of complying to infection control measures[117].

Strengths and limitations

To our knowledge, this is the first study exploring the influences of children's physical environment on conduct problem trajectories whilst examining moderating effects of ID diagnosis. A strength of this work is the large and diverse sample size facilitated by the MCS, even after exclusion of participants due to missing data. The longitudinal nature of this study also allows the examination of conduct problems across children's early neurodevelopmental periods.

Several limitations are also present in the current study, and the results should be interpreted with these caveats in mind. One is the dependence on the accuracy of parental reported SDQ conduct scores, a metric likely to contain inherent biases[22]. Another is the stringency in how we derived our ID classification, which may have resulted in under-ascertainment, however due to inability to certify clinical ID diagnosis this was deemed appropriate, and the resulting ID prevalence in our sample is comparative to previous reported global prevalence rates[11]. It is also worth drawing attention to our bias analysis which evidenced consistent differences between our analytic and non-analytic sample across variables. The lack of diversity in physical environmental aspects that were included in the MCS data collection protocol may be considered a limitation of this work. Ambient road traffic noise for example, has been associated with elevated parent reported conduct problems in children[118,119], therefore the inability to include potential additional confounding physical environmental influences in analysis may limit the external validity of findings.

Conclusion

In conclusion, external physical environmental measures were not associated with childhood trajectories in this population; moreover, classification of ID did not appear to mediate these

relationships. Residential crowdedness and damp problems were both associated with increased conduct problems during development. Investigation of the moderating influence of ID status reported significant interaction effects for home crowding only, reporting a negative non-linear association with children's conduct problems trajectories. A dearth of research on the influence of spatial density on children with ID inhibits extrapolation of this finding, and caution in interpretation is warranted. Additional individual, sociodemographic, and familial covariates such as: ID and ASD diagnosis, maternal psychological distress, poverty, living in a non-nuclear familial structure, and male sex were also significant predictors of increased conduct problems trajectories.

This work highlights the scarcity of contemporary research investigating the influence of physical environmental factors on the pathogenesis and progression of conduct problems in childhood NDDs. Previous work has outlined how NDD populations are disproportionately affected by health inequalities largely attributable to preventable environmental determinants[120]. Despite calls to improve mental ill-health of children over the previous decade[121], systemic study into the harmful effects of children's physical environment, and strategies to mitigate these preventable risks have not been conducted. Understanding the harmful and therapeutic influences of physical environmental domains can inform special educational policy and facilitate additional tools for clinicians and caregivers to alleviate a range of detrimental neurobehavioral outcomes, including conduct problems.

Acknowledgments

The authors are grateful to Marie A. E. Mueller for her advice on statistical aspects of the project.

Author contribution

Alister C. Baird: Original manuscript formation, Statistical analysis, writing.

Angela Hassiotis: Conceptualisation**,** Review and editing, Supervision.

Efstathios Papachristou: Statistical analysis, Supervision, Review and editing.

Eirini Flouri: Conceptualization, Methodology, Supervision, Review and editing.

All authors: Agree to be accountable for all aspects of the work in ensuring that questions related to the accuracy or integrity of any part of the work are appropriately investigated and resolved.

Data availability

The data that support the findings of this study are available from the corresponding author, [A.B.], upon reasonable request and approval from relevant research authorities.

References:

1. Chu A, Thorne A, Guite H. The impact on mental well-being of the urban and physical environment: an assessment of the evidence. *Journal of Public Mental Health*. 2004;3(2): 17-32. Available from: https://doi.org/10.1108/17465729200400010
2. Cooper R, Boyko C, Codinhoto R. The effect of the physical environment on mental wellbeing, In: *Mental capital and wellbeing (*eds CL Cooper, J Field, U Goswami, R Jenkins, BJ Sahakian). Wiley Blackwell. 2010 p.967-1006
3. Guite HF, Clark C, Ackrill G. The impact of the physical and urban environment on mental well-being. *Public health*. 2006;120(12):1117-26. Available from: https://doi.org/10.1016/j.puhe.2006.10.005
4. Clark C, Rowan M, Stansfeld SA, Candy B. A systematic review of the evidence on the effect of the built and physical environment on mental health. *Journal of Public Mental Health*. 2007;6(2):14. Available from: https://doi.org/10.1108/17465729200700011
5. Evans GW. The built environment and mental health. *Journal of urban health*. 2003;80(4):536-55. Available from: https://doi.org/10.1093/jurban/jtg063
6. Evans GW. Child development and the physical environment. *Annu. Rev. Psychol*. 2006;57:423-51. Available from: https://doi.org/10.1146/annurev.psych.57.102904.190057
7. Madzia J, Ryan P, Yolton K, Percy Z, Newman N, LeMasters G, Brokamp C. Residential greenspace association with childhood behavioral outcomes. *The Journal of pediatrics*. 2019;207:233-40. Available from: https://doi.org/10.1016/j.jpeds.2018.10.061
8. Gatzke-Kopp L, Willoughby MT, Warkentien S, Petrie D, Mills-Koonce R, Blair C. Association between environmental tobacco smoke exposure across the first four years of life and manifestation of externalizing behavior problems in school-aged children. *Journal of Child Psychology and Psychiatry*. 2020;61(11):1243-52. Available from: https://doi.org/10.1111/jcpp.13157
9. Foster EM, Jones DE, Conduct Problems Prevention Research Group. The high costs of aggression: Public expenditures resulting from conduct disorder. American Journal of Public Health. 2005;95(10):1767-72. Available from: https://doi.org/10.2105/AJPH.2004.061424
10. White SW, Roberson-Nay R. Anxiety, social deficits, and loneliness in youth with autism spectrum disorders. Journal of autism and developmental disorders. 2009;39(7):1006-13. Available from: https://doi.org/10.1007/s10803-009-0713-8
11. Maulik PK, Mascarenhas MN, Mathers CD, Dua T, Saxena S. Prevalence of intellectual disability: a meta-analysis of population-based studies. *Research in developmental disabilities*. 2011;32(2):419-36. Available from: https://doi.org/10.1016/j.ridd.2010.12.018
12. Emerson E, Kiernan C, Alborz A, Reeves D, Mason H, Swarbrick R, Mason L, Hatton C. The prevalence of challenging behaviors: A total population study. *Research in developmental disabilities*. 2001;22(1):77-93. Available from: https://doi.org/10.1016/S0891-4222(00)00061-5
13. Holden B, Gitlesen JP. A total population study of challenging behaviour in the county of Hedmark, Norway: Prevalence, and risk markers. *Research in developmental disabilities*. 2006;27(4):456-65. Available from: https://doi.org/10.1016/j.ridd.2005.06.001
14. Bowring DL, Totsika V, Hastings RP, Toogood S, Griffith GM. Challenging behaviours in adults with an intellectual disability: A total population study and exploration of risk indices. British Journal of Clinical Psychology. 2017;56(1):16-32. Available from: https://doi.org/10.1111/bjc.12118
15. Lundqvist LO. Prevalence and risk markers of behavior problems among adults with intellectual disabilities: A total population study in Örebro County, Sweden. Research in developmental disabilities. 2013;34(4):1346-56. Available from: https://doi.org/10.1016/j.ridd.2013.01.010
16. Jones S, Cooper SA, Smiley E, Allan L, Williamson A, Morrison J. Prevalence of, and factors associated with, problem behaviors in adults with intellectual disabilities. The Journal of nervous and mental disease. 2008 Sep 1;196(9):678-86.

17. Tenneij NH, Koot HM. Incidence, types and characteristics of aggressive behaviour in treatment facilities for adults with mild intellectual disability and severe challenging behaviour. Journal of Intellectual Disability Research. 2008;52(2):114-24. Available from; https://doi.org/10.1111/j.1365-2788.2007.00968.x

18. Nicholls G, Hastings RP, Grindle C. Prevalence and correlates of challenging behaviour in children and young people in a special school setting. European Journal of Special Needs Education. 2020;35(1):40-54. Available from; https://doi.org/10.1080/08856257.2019.1607659

19. Kaptein S, Jansen DE, Vogels AG, Reijneveld SA. Mental health problems in children with intellectual disability: use of the Strengths and Difficulties Questionnaire. Journal of Intellectual Disability Research. 2008;52(2):125-31. Available from; https://doi.org/10.1111/j.1365-2788.2007.00978.x

20. Roberts S, Arseneault L, Barratt B, Beevers S, Danese A, Odgers CL et al., Exploration of NO2 and PM2. 5 air pollution and mental health problems using high-resolution data in London-based children from a UK longitudinal cohort study. *Psychiatry research*. 2019;272, 8-17. Available from: https://doi.org/10.1016/j.psychres.2018.12.050

21. Evans BE, Buil JM, Burk WJ, Cillessen AH, van Lier PA. Urbanicity is associated with behavioral and emotional problems in elementary school-aged children. *Journal of Child and Family Studies*. 2018;27(7):2193-205. Available from: https://doi.org/10.1007/s10826-018-1062-z

22. Feng X, Astell-Burt T. Residential green space quantity and quality and child well-being: a longitudinal study. *American journal of preventive medicine*. 2017;53(5):616-24. Available from: https://doi.org/10.1016/j.amepre.2017.06.035

23. Younan D, Tuvblad C, Li L, Wu J, Lurmann F, Franklin M et al., Environmental determinants of aggression in adolescents: Role of urban neighborhood greenspace. *Journal of the American academy of child & adolescent psychiatry*. 2016;55(7):591-601. Available from: https://doi.org/10.1016/j.jaac.2016.05.002

24. Barger B, Larson LR, Ogletree S, Torquati J, Rosenberg S, Gaither CJ et al., Tree canopy coverage predicts lower conduct problem severity in children with ASD. *Journal of Mental Health Research in Intellectual Disabilities*. 2020;13(1):43-61. Available from: https://doi.org/10.1080/19315864.2020.1714824

25. D'Angiulli A. The role of neuroinflammation in developmental neurotoxicity, tackling complexity in children's exposures and outcomes. In: Advances in Neurotoxicology 2019 (Vol. 3, pp. 223-257). Academic Press. Available from: https://doi.org/10.1016/bs.ant.2018.10.008

26. Kaplan R, Kaplan S. The experience of nature: A psychological perspective. Cambridge university press; 1989 Jul 28.

27. Ohly H, White MP, Wheeler BW, Bethel A, Ukoumunne OC, Nikolaou V, Garside R. Attention Restoration Theory: A systematic review of the attention restoration potential of exposure to natural environments. Journal of Toxicology and Environmental Health, Part B. 2016;19(7):305-43. Available from: https://doi.org/10.1080/10937404.2016.1196155

28. Berto R. The role of nature in coping with psycho-physiological stress: a literature review on restorativeness. Behavioral sciences. 2014;4(4):394-409. Available from: https://doi.org/10.3390/bs4040394

29. Ulrich RS, Simons RF, Losito BD, Fiorito E, Miles MA, Zelson M. Stress recovery during exposure to natural and urban environments. Journal of environmental psychology. 1991;11(3):201-30. Available from: https://doi.org/10.1016/S0272-4944(05)80184-7

30. Flouri E, Papachristou E, Midouhas E, Joshi H, Ploubidis GB, Lewis G. Early adolescent outcomes of joint developmental trajectories of problem behavior and IQ in childhood. *European child & adolescent psychiatry*. 2018;27(12):1595-605. Available from: https://doi.org/10.1007/s00787-018-1155-7

31. Matson JL, Kozlowski AM, Worley JA, Shoemaker ME, Sipes M, Horovitz M. What is the evidence for environmental causes of challenging behaviors in persons with intellectual disabilities and autism spectrum disorders?. Research in developmental disabilities. 2011 Mar 1;32(2):693-8. Available from: https://doi.org/10.1016/j.ridd.2010.11.012

32. Davey CG, Yücel M, Allen NB. The emergence of depression in adolescence: Development of the prefrontal cortex and the representation of reward. *Neuroscience & Biobehavioral Reviews*. 2008;32(1):1-9. Available from: https://doi.org/10.1016/j.neubiorev.2007.04.016

33. Bradshaw CP, Schaeffer CM, Petras H, Ialongo N. Predicting negative life outcomes from early aggressive–disruptive behavior trajectories: Gender differences in maladaptation across life domains. *Journal of youth and adolescence*. 2010;39(8):953-66. Available from: https://doi.org/10.1007/s10964-009-9442-8

34. Broidy LM, Nagin DS, Tremblay RE et al; Developmental trajectories of childhood disruptive behaviors and adolescent delinquency: a six-site, cross-national study. *Developmental psychology*. 2003;39(2):222. Available from: https://doi.org/10.1037/0012-1649.39.2.222

35. Huesmann LR, Dubow EF, Boxer P. Continuity of aggression from childhood to early adulthood as a predictor of life outcomes: Implications for the adolescent-limited and life-course-persistent models. *Aggressive Behavior: Official Journal of the International Society for Research on Aggression*. 2009;35(2):136-49. Available from: https://doi.org/10.1002/ab.20300

36. Maughan B, Rutter M. Antisocial children grown up. Conduct disorders in childhood and adolescence. *Conduct Disorders in Childhood and Adolescence*. 2001:507-552. Available from: https://doi.org/10.1017/CBO9780511543852.019

37. Raaijmakers MA, Posthumus JA, Van Hout BA, Van Engeland H, Matthys W. Cross-sectional study into the costs and impact on family functioning of 4-year-old children with aggressive behavior. *Prevention Science*. 2011;12(2):192-200. Available from: https://doi.org/10.1007/s11121-011-0204-y

38. Reef J, Diamantopoulou S, van Meurs I, Verhulst FC, van der Ende J. Developmental trajectories of child to adolescent externalizing behavior and adult DSM-IV disorder: results of a 24-year longitudinal study. *Social psychiatry and psychiatric epidemiology*. 2011;46(12):1233-41. Available from: https://doi.org/10.1007/s00127-010-0297-9

39. Romeo R, Knapp M, Scott S. Economic cost of severe antisocial behaviour in children-and who pays it. *The British Journal of Psychiatry*. 2006;188(6):547-53. Available from: https://doi.org/10.1192/bjp.bp.104.007625

40. Connelly R, Platt L. Cohort profile: UK millennium Cohort study (MCS). *International journal of epidemiology*. 2014;43(6):1719-25. Available from: https://doi.org/10.1093/ije/dyu001

41. Plewis I, Calderwood L, Hawkes D, Hughes G, Joshi H. Millennium Cohort Study: technical report on sampling. London: *Centre for Longitudinal Studies*. 2007.

42. Johnson W, Bouchard Jr TJ, Krueger RF, McGue M, Gottesman II. Just one g: Consistent results from three test batteries. *Intelligence*. 2004;32(1):95-107. Available from: https://doi.org/10.1016/S0160-2896(03)00062-X

43. Totsika V, Hastings RP, Emerson E, Hatton C. Early years parenting mediates early adversity effects on problem behaviors in intellectual disability. Child development. 2020 May;91(3):e649-64.

44. Emerson E, Robertson J, Baines S, Hatton C. Vaccine coverage among children with and without intellectual disabilities in the UK: cross sectional study. BMC public health. 2019 Dec;19(1):1-7.

45. Emerson E, Hatton C, Robertson J, Baines S. Exposure to second hand tobacco smoke at home and child smoking at age 11 among British children with and without intellectual disability. Journal of Intellectual Disability Research. 2016 Mar;60(3):274-81.

46. Emerson E, Blacher J, Einfeld S, Hatton C, Robertson J, Stancliffe RJ. Environmental risk factors associated with the persistence of conduct difficulties in children with intellectual

disabilities and autistic spectrum disorders. Research in Developmental Disabilities. 2014 Dec 1;35(12):3508-17.

47. Emerson E, Robertson J, Hatton C, Baines S. Risk of exposure to air pollution among British children with and without intellectual disabilities. Journal of Intellectual Disability Research. 2019;63(2):161-7. Available from: https://doi.org/10.1111/jir.12561
48. Emerson E, Robertson J, Baines S, Hatton C. Obesity in British children with and without intellectual disability: cohort study. BMC Public Health. 2016 Dec;16(1):1-0.
49. Bracken BA. Bracken Basic Concept Scale Revised: Examiner's Manual. *The Psychological Corporation*; 1998.
50. Elliott CD, Smith P, McCulloch K. British ability scales II: technical manual. NferNelson; 1997.
51. Connelly R. Interpreting test scores (Millennium Cohort Study Data Note No. 2013/1). London, *UK: Centre for Longitudinal Studies*. 2013.
52. Atkinson M. Millennium cohort study interpreting the Cantab cognitive measures. *London, UK: Centre for Longitudinal Studies*. 2015.
53. Robbins TW, James M, Owen AM, Sahakian BJ, McInnes L, Rabbitt P. Cambridge Neuropsychological Test Automated Battery (CANTAB): a factor analytic study of a large sample of normal elderly volunteers. *Dementia and Geriatric Cognitive Disorders*. 1994;5(5):266-81. Available from: https://doi.org/10.1159/000106735
54. Goodman R. The Strengths and Difficulties Questionnaire: a research note. *Journal of child psychology and psychiatry*. 1997;38(5):581-6. Available from: https://doi.org/10.1111/j.1469-7610.1997.tb01545.x
55. Croft S, Stride C, Maughan B, Rowe R. Validity of the strengths and difficulties questionnaire in preschool-aged children. *Pediatrics*. 2015;135(5):e1210-9. Available from: https://doi.org/10.1542/peds.2014-2920
56. Flouri E, Midouhas E, Ruddy A, Moulton V. The role of socio-economic disadvantage in the development of comorbid emotional and conduct problems in children with ADHD. *European child & adolescent psychiatry*. 2017;26(6):723-32. Available from: https://doi.org/10.1007/s00787-017-0940-z
57. Rice LJ, Emerson E, Gray KM et al; Concurrence of the strengths and difficulties questionnaire and developmental behaviour checklist among children with an intellectual disability. *Journal of Intellectual Disability Research*. 2018;62(2):150-5. Available from: https://doi.org/10.1111/jir.12426
58. Murray CA, Hastings RP, Totsika V. Clinical utility of the parent-reported Strengths and Difficulties Questionnaire as a screen for emotional and behavioural difficulties in children and adolescents with intellectual disability. *The British Journal of Psychiatry*. 2020:1-3. Available from: https://doi.org/10.1192/bjp.2020.224
59. Office of the Deputy Prime Minister. *Generalised land use database statistics for England*. London: ODPM Publications. 2001.
60. EEA. *Corine land cover 2000 coastline*. 2006. Available from: http://www.eea.europa.eu/data-and-maps/data/corine-land-cover-2000-coastline/#tab-gis-data [Accessed May 24 2021].
61. Loaekeimidi S, Midouhas E, Church D. Data Note: Green space data at Lower layer Super Output LSOA-level (England) and ward-level (UK), linked to MCS1-MCS5. *Centre for Longitudinal Studies*. 2017. Available from: http://doc.ukdataservice.ac.uk/doc/8154/mrdoc/pdf/data_note_mcs_green_space_data.pdf [Accessed on May 24 2021].
62. Church D, Midouhas E. MCS Data Note: MEDIX air pollution data at ward level, linked to MCS1 and MCS2. *Centre for Longitudinal Studies*. 2017. Available from: http://doc.ukdataservice.ac.uk/doc/8153/mrdoc/pdf/data_note_mcs_medix_air_pollution_data.pdf [Accessed on May 25 2021]

63. Johnson J. Millennium Cohort Study: Geographic Identifiers in MCS. *London: Centre for Longitudinal Studies.* 2009. Available from: https://cls.ucl.ac.uk/wp-content/uploads/2017/07/MCS-Geographical-Identifiers.pdf [Accessed on May 25 2021]
64. Kessler RC, Andrews G, Colpe LJ et al: Short screening scales to monitor population prevalences and trends in non-specific psychological distress. *Psychological medicine*. 2002;32(6):959. Available from: https://doi.org/10.1017/S0033291702006074
65. Enders, C. K. *Applied missing data analysis. Methodology in the social sciences*. Guilford Press. 2010.
66. VanderWeele TJ, Ding P. Sensitivity analysis in observational research: introducing the E-value. Annals of internal medicine. 2017;167(4):268-74. Available from: https://doi.org/10.7326/M16-2607
67. StataCorp. *Stata Statistical Software: Release 16*. College Station, TX: StataCorp LLC. 2019.
68. Blum MR, Tan YJ, Ioannidis JP. Use of E-values for addressing confounding in observational studies—an empirical assessment of the literature. International journal of epidemiology. 2020;49(5):1482-94. Available from: https://doi.org/10.1093/ije/dyz261
69. Ferguson KT, Cassells RC, MacAllister JW, Evans GW. The physical environment and child development: An international review. *International Journal of Psychology*. 2013;48(4):437-68. Available from: https://doi.org/10.1080/00207594.2013.804190
70. Kingston D, Tough S, Whitfield H. Prenatal and postpartum maternal psychological distress and infant development: a systematic review. *Child Psychiatry & Human Development*. 2012 Oct;43(5):683-714. Available from: https://doi.org/10.1007/s10578-012-0291-4
71. Flouri E, Midouhas E, Charman T, Sarmadi Z. Poverty and the growth of emotional and conduct problems in children with autism with and without comorbid ADHD. *Journal of autism and developmental disorders*. 2015 Sep;45(9):2928-38. Available from: https://doi.org/10.1007/s10803-015-2456-z
72. Aasen Nilsen S, Breivik K, Wold B, Bøe T. Divorce and family structure in Norway: Associations with adolescent mental health. *Journal of Divorce & Remarriage*. 2018;59(3):175-94. Available from: https://doi.org/10.1080/10502556.2017.1402655
73. Gutman LM. Do conduct problem pathways differ for Black and minority ethnic children in the UK? An examination of trajectories from early childhood to adolescence. *Journal of youth and adolescence*. 2019;48(10):1967-79. Available from: https://doi.org/10.1007/s10964-019-01116-w
74. Demmer DH, Hooley M, Sheen J, McGillivray JA, Lum JA. Sex differences in the prevalence of oppositional defiant disorder during middle childhood: a meta-analysis. *Journal of abnormal child psychology*. 2017;45(2):313-25. Available from: https://doi.org/10.1007/s10802-016-0170-8
75. Amoly E, Dadvand P, Forns J, López-Vicente M, Basagaña X, Julvez J et al., Green and blue spaces and behavioral development in Barcelona schoolchildren: the BREATHE project. Environmental health perspectives. 2014;122(12):1351-8. Available from: https://doi.org/10.1289/ehp.1408215
76. Barger B, Larson LR, Ogletree S et al; Tree Canopy Coverage Predicts Lower Conduct Problem Severity in Children with ASD. *Journal of Mental Health Research in Intellectual Disabilities*. 2020;13(1):43-61. Available from: https://doi.org/10.1080/19315864.2020.1714824
77. Liao J, Yang S, Xia W et al; Associations of exposure to green space with problem behaviours in preschool-aged children. *International journal of epidemiology*. 2020;49(3):944-53. Available from: https://doi.org/10.1093/ije/dyz243
78. Madzia J, Ryan P, Yolton K, Percy Z, Newman N, LeMasters G et al., Residential greenspace association with childhood behavioral outcomes. *The Journal of pediatrics*. 2019;207:233-40. Available from: https://doi.org/10.1016/j.jpeds.2018.10.061
79. Younan D, Tuvblad C, Li L, Wu J, Lurmann F, Franklin M et al., Environmental determinants of aggression in adolescents: Role of urban neighborhood greenspace. *Journal of the*

American academy of child & adolescent psychiatry. 2016;55(7):591-601. Available from: https://doi.org/10.1016/j.jaac.2016.05.002

80. Mueller MA, Flouri E. Neighbourhood greenspace and children's trajectories of self-regulation: Findings from the UK Millennium Cohort Study. *Journal of Environmental Psychology*. 2020;71:101472. Available from: https://doi.org/10.1016/j.jenvp.2020.101472
81. Conniff A, Craig T. A methodological approach to understanding the wellbeing and restorative benefits associated with greenspace. *Urban Forestry & Urban Greening*. 2016;19:103-9. Available from: https://doi.org/10.1016/j.ufug.2016.06.019
82. Flouri E, Midouhas E, Joshi H. The role of urban neighbourhood green space in children's emotional and behavioural resilience. *Journal of environmental psychology*. 2014;40:179-86. Available from: https://doi.org/10.1016/j.jenvp.2014.06.007
83. Richardson EA, Pearce J, Shortt NK, Mitchell R. The role of public and private natural space in children's social, emotional and behavioural development in Scotland: A longitudinal study. *Environmental research*. 2017;158:729-36. Available from: https://doi.org/10.1016/j.envres.2017.07.038
84. Kalish M, Banco L, Burke G, Lapidus G. Outdoor play: A survey of parent's perceptions of their child's safety. *Journal of Trauma and Acute Care Surgery*. 2010;69(4):S218-22. Available from: 10.1097/TA.0b013e3181f1eaf0
85. O'Brien J, Smith J. Childhood transformed? Risk perceptions and the decline of free play. *British Journal of Occupational Therapy*, 2002;*65*(3),123–128. Available from: https://doi.org/10.1177/030802260206500304
86. Stillianesis S, Spencer G, Villeneuve M, Sterman J, Bundy A, Wyver S et al., Parents' perspectives on managing risk in play for children with developmental disabilities. *Disability & Society*. 2021:1-9. Available from: https://doi.org/10.1080/09687599.2021.1874298
87. Valentine G, McKendrck J. Children's outdoor play: Exploring parental concerns about children's safety and the changing nature of childhood. *Geoforum*, 1997;*28*(2), 219–235. Available from: https://doi.org/10.1016/S0016-7185(97)00010-9
88. Mueller MA, Flouri E, Kokosi T. The role of the physical environment in adolescent mental health. *Health & place*. 2019;58:102153. Available from: https://doi.org/10.1016/j.healthplace.2019.102153
89. Costa LG, Cole TB, Coburn J, Chang YC, Dao K, Roqué PJ. Neurotoxicity of traffic-related air pollution. *Neurotoxicology*. 2017;59:133-9. Available from: https://doi.org/10.1016/j.neuro.2015.11.008
90. McGuinn LA, Windham GC, Kalkbrenner AE, Bradley C, Di Q, Croen LA et al., Early life exposure to air pollution and autism spectrum disorder: findings from a multisite case–control study. *Epidemiology*. 2020;31(1):103. Available from: 10.1097/EDE.0000000000001109
91. Xu X, Ha SU, Basnet R. A review of epidemiological research on adverse neurological effects of exposure to ambient air pollution. *Frontiers in public health*. 2016;4:157. Available from: https://doi.org/10.3389/fpubh.2016.00157
92. Calderón-Garcidueñas L, Kulesza RJ, Doty RL, D'Angiulli A, Torres-Jardón R. Megacities air pollution problems: Mexico City Metropolitan Area critical issues on the central nervous system pediatric impact. *Environmental research*. 2015;137:157-69. Available from: https://doi.org/10.1016/j.envres.2014.12.012
93. Evans BE, Buil JM, Burk WJ, Cillessen AH, van Lier PA. Urbanicity is associated with behavioral and emotional problems in elementary school-aged children. *Journal of Child and Family Studies.* 2018;27(7):2193-205. Available from: https://doi.org/10.1007/s10826-018-1062-z
94. Handal PJ, Hopper S. Relationship of sex, social class and rural/urban locale to preschoolers' AML scores. *Psychological reports*. 1985;57(3):707-13. Available from: https://doi.org/10.2466/pr0.1985.57.3.707

95. Hope TL, Bierman KL. Patterns of Home and School Behavior Problems in Rural and Urban Settings. *Journal of School Psychology*, 1998;*36*(1), 45–58. Available from: https://doi.org/10.1016/S0022-4405(97)00049-6

96. Sheridan SM, Koziol NA, Clarke BL, Rispoli KM, Coutts MJ. The influence of rurality and parental affect on kindergarten children's social and behavioral functioning. *Early Education and Development.* 2014;25(7):1057-82. Available from: https://doi.org/10.1080/10409289.2014.896682

97. Wongtongkam N, Ward PR, Day A, Winefield AH. The Relationship Between Exposure to Violence and Anger in Thai Adolescents. *Journal of Interpersonal Violence*, 2016;*31*(13), 2291–2301. Available from: https://doi.org/10.1177/0886260515575610

98. Evans GW, Kim P. Childhood poverty, chronic stress, self-regulation and coping. *Child Development Perspectives*, 2013;7,43-48. Available from: https://doi.org/10.1111/cdep.12013

99. World Bank. Violence in the city: Understanding and supporting community responses to urban violence. 2011. Available from: https://doi.org/10.1596/27454

100. Sikorska D, Łaszkiewicz E, Krauze K, Sikorski P. The role of informal green spaces in reducing inequalities in urban green space availability to children and seniors. *Environmental Science & Policy*. 2020;108:144-54. Available from: https://doi.org/10.1016/j.envsci.2020.03.007

101. Dzhambov A, Dimitrova D. Urban green spaces′ effectiveness as a psychological buffer for the negative health impact of noise pollution: A systematic review. *Noise and Health*, 2014;16(70), 157–165. Available from: 10.4103/1463-1741.134916

102. Li M, Van Renterghem T, Kang J, Verheyen K, Botteldooren D. Sound absorption by tree bark. *Applied Acoustics*, 2020;165. Available from: https://doi.org/10.1016/j.apacoust.2020.107328

103. Jenkin R, Frampton I, White MP, Pahl S. The relationship between exposure to natural and urban environments and children's self-regulation. *Landscape Research*, 2018;*43*(3), 315–328. Available from: https://doi.org/10.1080/01426397.2017.1316365

104. Midouhas E, Kokosi T, Flouri E. The quality of air outside and inside the home: associations with emotional and behavioural problem scores in early childhood. *BMC Public Health*, 2019;*19*(1), 1–10. Available from: https://doi.org/10.1186/s12889-019-6733-1

105. Oloye HT, Flouri E. The role of the indoor home environment in children's self-regulation. *Children and Youth Services Review*, 2021;*121*. Available from: https://doi.org/10.1016/j.childyouth.2020.105761

106. Singh J. Toxic moulds and indoor air quality. *Indoor and Built Environment*, 2005;*14*(3–4), 229–234. Available from: https://doi.org/10.1177/1420326X05054015

107. Vanos JK. Children's health and vulnerability in outdoor microclimates: A comprehensive review. *Environment International*, 2015;*76*, 1–15. Available from: https://doi.org/10.1016/j.envint.2014.11.016

108. Brockmeyer S, D'Angiulli A. How air pollution alters brain development: The role of neuroinflammation. *Translational Neuroscience*, 2016;7,24–30. doi: 10.1515/tnsci-2016-0005

109. Calderón-Garcidueñas L, Leray E, Heydarpour P, Torres-Jardón R, Reis J. Air pollution, a rising environmental risk factor for cognition, neuroinflammation and neurodegeneration: The clinical impact on children and beyond. *Revue Neurologique*, 2016;*172*(1), 69–80. Available from: https://doi.org/10.1016/j.neurol.2015.10.008

110. Singh A, Daniel L, Baker E, Bentley R. Housing disadvantage and poor mental health: a systematic review. *American Journal of Preventive Medicine*, 2019;57(2), 262–272. Available from: https://doi.org/10.1016/j.amepre.2019.03.018

111. Ginsburg HJ, Pollman VA, Wauson MS, Hope ML.Variation of aggressive interaction among male elementary school children as a function of changes in spatial density. *Environmental Psychology and Nonverbal Behavior*, 1977;*2*(2), 67–75. Available from: https://doi.org/10.1007/BF01145822

112. Loo C, Kennelly D. Social density: Its effects on behaviors and perceptions of preschoolers. *Environmental Psychology and Nonverbal Behavior*, 2017;*3*(3), 131–146. Available from: https://doi.org/10.1007/BF01142588

113. Loo C, Smetana J. The effects of crowding on the behavior and perception of 10-year-old boys. *Environmental Psychology and Nonverbal Behavior*, 1978;*2*(4), 226–249. Available from: https://doi.org/10.1007/BF01173771

114. Neill SRSJ. Preschool Design and Child Behaviour. *Journal of Child Psychology and Psychiatry*, 1982;*23*(3), 309–318. Available from: https://doi.org/10.1111/j.1469-7610.1982.tb00075.x

115. Supplee LH, Unikel EB, Shaw DS. Physical environmental adversity and the protective role of maternal monitoring in relation to early child conduct problems. *Journal of Applied Developmental Psychology*, 2007;*28*(2),166–183. Available from: https://doi.org/10.1016/j.appdev.2006.12.001

116. Evans GW, Saltzman H, Cooperman JL. Housing quality and children's socioemotional health. *Environment and Behavior*, 2001b;33(3),389– 399. Available from: https://doi.org/10.1177/00139160121973043

117. Paulauskaite L, Farris O, Spencer HM, EPICC-ID group, Hassiotis A. My son can't socially distance or wear a mask: how families of preschool children with severe developmental delays and challenging behavior experienced the COVID-19 Pandemic*. Journal of Mental Health Research in Intellectual Disabilities*. 2021;14(2):225-36. Available from: https://doi.org/10.1080/19315864.2021.1874578

118. Crombie R, Clark C, Stansfeld SA. Environmental noise exposure, early biological risk and mental health in nine to ten year old children: a cross-sectional field study. *Environmental Health*. 2011;*10*(1),1-8. Available from: https://doi.org/10.1186/1476-069X-10-39

119. Stansfeld SA, Clark C, Cameron RM, Alfred T, Head J, Haines MM et al., Aircraft and road traffic noise exposure and children's mental health. *Journal of Environmental Psychology*. 2009;29(2):203-7. Available from: https://doi.org/10.1016/j.jenvp.2009.01.002

120. Allerton LA, Welch V, Emerson E. Health inequalities experienced by children and young people with intellectual disabilities: a review of literature from the United Kingdom. *Journal of Intellectual Disabilities*. 2011;15(4):269-78. Available from: https://doi.org/10.1177/1744629511430772

121. Marmot M. Fair society, healthy lives: the Marmot Review: strategic review of health inequalities in England post-2010. 2010. ISBN 9780956487001. Available from: https://www.instituteofhealthequity.org/resources-reports/fair-society-healthy-lives-the-marmot-review/fair-society-healthy-lives-full-report-pdf.pdf

Table and figures document

Baird et al., 2021

Table1: Bias analysis

Table 1
Bias analysis between analytic and non-analytic samples.

	Analytic sample (n = 8168)		Non-analytic sample (n = 11,075)		Test
Continuous variables	n	M (SD)	n	M (SD)	F
SDQ conduct scores Sweep 2	8168	2.70 (2.01)	6602	2.99 (2.13)	75.05**
SDQ conduct scores Sweep 3	8168	1.40 (1.42)	6577	1.67 (1.61)	121.82**
SDQ conduct scores Sweep 4	8168	1.27 (1.47)	5304	1.59 (1.65)	132.99**
SDQ conduct scores Sweep 5	8168	1.29 (1.50)	4630	1.56 (1.69)	87.22**
Cognitive scores Sweep 2	8168	0.202 (1.204)	5389	-0.307 (1.279)	551.79**
Cognitive scores Sweep 3	8168	0.256 (1.197)	6695	-0.312 (1.344)	741.37**
Cognitive scores Sweep 4	8148	0.205 (1.310)	5124	-0.325 (1.398)	488.45**
Cognitive scores Sweep 5	8147	0.082 (1.006)	4329	-0.155 (1.065)	151.47**
Greenspace Sweep 2	8167	4.49 (2.67)	7422	4.07 (2.67)	206.44**
Greenspace Sweep 3	8167	4.78 (2.69)	7078	4.15 (2.70)	206.46**
Greenspace Sweep 4	8166	4.84 (2.69)	5689	4.17 (2.73)	202.55**
Greenspace Sweep 5	8164	4.91 (2.69)	5116	4.15 (2.72)	249.94**
Air pollution (NO_2) Sweep 2	8167	6.15 (2.91)	7422	6.77 (3.06)	166.79**
Air pollution (NO_2) Sweep 3	8167	6.66 (3.08)	7078	6.66 (3.08)	132.34**
Air pollution (NO_2) Sweep 4	8166	6.05 (2.91)	5689	6.65 (3.09)	132.66**
Air pollution (NO_2) Sweep 5	8164	5.99 (2.90)	5116	6.79 (3.06)	227.77**

Household spatial density Sweep 2	8166	0.72 (0.24)	7255	0.82 (0.32)	448.91**
Household spatial density Sweep 3	8157	0.73 (0.24)	6967	0.82 (0.31)	449.96**
Household spatial density Sweep 4	8154	0.74 (0.26)	5573	0.85 (0.32)	467.08**
Household spatial density Sweep 5	8120	0.88 (0.28)	4814	1.02 (0.35)	594.22**
Child Age (years) Sweep 2	8168	3.17 (0.19)	7422	3.20 (0.30)	55.81**
Child Age (years) Sweep 3	8168	5.28 (0.24)	7077	5.30 (0.26)	24.68**
Child Age (years) Sweep 4	8168	7.22 (0.24)	5676	7.26 (0.27)	87.82**
Child Age (years) Sweep 5	8168	11.16 (0.32)	5119	11.19 (0.34)	27.37**
Categorical variables	n	%	n	%	Chi^2
Access to private garden Sweep 2	8107	94.99	7198	89.25	176.85**
Access to private garden Sweep 3	8096	95.81	6051	90.38	167.82**
Access to private garden Sweep 4	8095	95.96	4497	90.95	132.24**
Access to private garden Sweep 5	8083	96.67	3736	91.70	135.45**
Urban residence Sweep 2	8167	77.01	7422	81.92	57.28**
Urban residence Sweep 3	8167	75.84	7078	81.63	75.43**
Urban residence Sweep 4	8166	75.25	5689	81.28	70.39**
Urban residence Sweep 5	8164	74.31	5116	81.43	90.10**
Household damp problems Sweep 2	8168	12.82	7279	16.06	32.91**
Household damp problems Sweep 3	8165	11.87	6989	14.48	22.61**
Household damp problems Sweep 4	8166	13.38	5596	16.24	21.83**
Household damp problems Sweep 5	8142	16.20	4872	18.45	10.94**
Below poverty line Sweep 2	8151	25.09	7248	41.96	493.47**
Below poverty line Sweep 3	8164	25.12	6971	44.33	618.27**
Below poverty line Sweep 4	8165	22.79	5672	40.57	502.82**
Below poverty line Sweep 5	8168	16.12	5119	38.97	877.89**
Maternal psychological distress Sweep 2	7670	2.71	5920	4.53	32.57**
Maternal psychological distress Sweep 3	8070	2.86	6262	4.50	27.51**
Maternal psychological distress Sweep 4	8097	3.11	5066	4.46	16.20**
Maternal psychological distress Sweep 5	7732	4.45	3973	8.38	74.48**
Atypical family structure Sweep 2	8153	15.80	7323	25.00	203.16**
Atypical family structure Sweep 3	8164	20.22	7071	30.39	209.29**

Atypical family structure Sweep 4	8164	23.80	5683	33.71	163.86**
Atypical family structure Sweep 5	8164	30.56	5115	39.47	111.29**
Male	8168	48.98	11075	53.18	33.18**
Autism Spectrum Disorder	7958	0.44	7539	1.25	30.55**
Ethnicity White	8168	90.45	11050	75.61	698.22**
England-Advantaged	2698	33.03	2130	19.23	476.25**
England-Disadvantaged	1971	24.13	2834	25.59	5.34*
England-Ethnic Minority	557	6.82	2034	18.37	537.89**
Wales-Advantaged	381	4.66	451	4.07	3.99*
Wales-Disadvantaged	792	9.70	1136	10.26	1.64
Scotland-Advantaged	562	6.44	619	5.59	6.08*
Scotland-Disadvantaged	407	4.98	784	7.08	35.57**
Northern Ireland-Advantaged	350	4.29	373	3.37	10.93**
Northern Ireland-Disadvantaged	486	5.95	714	6.45	1.99

Note. *p < .05, **p < .01

Table 2: Model A (Minimally adjusted)

Table 2: Model A (minimally adjusted GCM predicting SDQ conduct scores, *N* = 8168).

Fixed effects	Coefficient (SE)	95% CI
Age	-0.217 (0.005)**	[-0.226, -0.208]
Age^2	0.052 (0.001)**	[0.049, 0.054]
Intellectual disability	1.270 (0.176)**	[0.925, 1.614]
Greenspace (ward decile)	-0.003 (0.009)	[-0.021, 0.015]
Air pollution (NO_2)	-0.021 (0.010)	[-0.040, -0.002]
Access to private garden	-0.236 (0.146)	[-0.523, 0.051]
Urban residence	0.107 (0.057)	[-0.005, 0.219]
Home spatial density	0.356 (0.062)**	[0.234, 0.477]
Damp / condensation	0.163 (0.033)**	[0.098, 0.227]
Constant	1.148 (0.191)**	[0.774, 1.523]
Random effects	**Estimate (SE)**	**95% CI**
Level 3 (ward-level)		
Intercept variance	0.218 (0.025)	[0 .174, 0.273]
Level 2 (Child level)		
Slope (age) variance	0.140 (0.005)	[0.131, 0.149]
Intercept variance	1.120 (0.019)	[1.083, 1.159]
Intercept-slope variance	-0.329 (0.036)	[-0.398, -0.256]

Note. Age was measured in years and grand mean centered (6.71 yrs).
For fixed effects: *p<.01, **p<.001

Table 3: Model B (Fully adjusted)

Table 3: Model B (fully adjusted GCM predicting SDQ conduct scores, *N* = 8168).

Fixed effects	Coefficient (SE)	95% CI
Age	-0.224 (.005)**	[-0.234, -0.215]
Age^2	0.052 (.001)**	[0.049, 0.054]
Intellectual disability	0.963 (.175)**	[0.620, 1.307]
Greenspace (ward decile)	-0.000 (0.009)	[-0.018, 0.017]
Air pollution (NO_2)	-0.014 (0.009)	[-0.031, 0.004]
Access to private garden	-0.164 (0.130)	[-0.419, 0.091]
Urban residence	0.071 (0.056)	[-0.039, 0.181]
Home spatial density	0.400 (0.062)**	[0.277, 0.523]
Damp / condensation	0.143 (0.031)**	[0.083, 0.203]
Maternal psychological distress	0.650 (0.098)**	[0.458, 0.842]
Below poverty line	0.190 (0.037)**	[0.117, 0.262]
Atypical family structure	0.346 (0.036)**	[0.275, 0.416]
Male	0.263 (0.035)**	[0.195, 0.331]
Autism Spectrum Disorder	1.182 (0.311)**	[0.572, 1.793]
White ethnicity	0.170 (0.068)	[0.036, 0.304]
Constant	0.605 (0.181)*	[0.251, 0.959]
Random effects	**Estimate (SE)**	**95% CI**
Level 3 (ward-level)		
Intercept variance	0.176 (0.022)	[0.138, 0.224]
Level 2 (Child level)		
Slope (age) variance	0.139 (0.005)	[0.131, 0.148]
Intercept variance	1.058 (0.018)	[1.024, 1.094]
Intercept-slope variance	-0.356 (0.034)	[-0.420, -0.288]

Note. Age was measured in years and grand mean centered (6.71 yrs).
For fixed effects: *p<.01, **p<.001

Table 4: spatial density x intellectual disability interaction model

Table 4: Spatial density x ID diagnosis growth curve interaction model predicting SDQ conduct scores (N = 8168).

Fixed effects	Coefficient (SE)	95% CI
Age	-0.195 (0.010)**	[-0.215, -0.170]
Age^2	0.053 (0.001)**	[0.050, 0.055]
ID diagnosis	1.882 (0.340)**	[1.118, 2.646]
Greenspace (ward decile)	-0.000, (0.009)	[-0.017, 0.017]
Air pollution (NO_2)	-0.013 (0.009)	[-0.031, 0.004]
ID diagnosis x spatial density x Age	-0.055 (0.063)	[-0.178, 0.068]
Spatial density x Age	-0.040 (0.012)*	[-0.063, -0.017]
ID diagnosis x Age	0.123 (0.061)	[0.006, 0.251]
ID diagnosis x Spatial density	-1.075 (0.346)*	[-1.753, -0.397]
Urban residence	0.072 (0.056)	[-0.038, 0.182]
Access to private garden	-0.153 (0.130)	[-0.408, 0.102]
Home spatial density	0.460 (0.063)**	[0.257, 0.495]
Damp / condensation	0.145 (0.031)**	[0.085. 0.205]
Maternal psychological distress	0.654 (0.098)**	[0.461, 0.846]
Below poverty line	0.192 (0.037)**	[0.119, 0.264]
Atypical family structure	0.348 (0.036)**	[0.278, 0.419]
Male	0.263 (0.035)**	[0.195, 0.331]
Autism Spectrum Disorder	1.156 (0.312)**	[0.543, 1.768]
White ethnicity	0.165 (0.069)*	[0.031, 0.299]
Constant	0.549 (0.182)*	[0.193, 0.905]
Random effects	**Estimate (SE)**	**95% CI**
Level 3 (ward-level)		
Intercept variance	0.178 (0.022)	[0.139, 0.225]
Level 2 (Child level)		
Slope (age) variance	0.138 (0.005)	[0.129, 0.147]
Intercept variance	1.058 (0.018)	[1.023, 1.093]
Intercept-slope variance	-0.351 (0.034)	[-0.417, -0.283]

Note. Age was measured in years and grand mean centered (6.71 yrs).
For fixed effects: *p<.01, **p<.001

Supplementary Table 1: Sensitivity analysis: ID as time-invariant (non-analytic sample)

Table 1: Fully adjusted model across whole non-analytic sample (*N* = 19,243).

Fixed effects	Coefficient (SE)	95% CI
Age	-0.247 (0.005)**	[-0.256, -0.238]
Age^2	0.053 (0.001)**	[0.051, 0.056]
ID diagnosis	0.514 (0.064)**	[0.389, 0.638]
Greenspace (ward decile)	-0.010 (0.008)	[-0.025, 0.005]
Air pollution (NO^2)	-0.018 (0.009)	[-0.036, 0.001]
Damp	0.147 (0.028)**	[0.093, 0.201]
Urban	0.074 (0.046)	[-0.017, 0.165]
Access to garden	-0.133 (0.086)	[-0.302, 0.036]
Home spatial density	0.289 (0.046)**	[0.199, 0.380]
Maternal psychological distress	0.731 (0.068)**	[0.597, 0.864]
Below poverty line	0.273 (0.030)**	[0.216, 0.331]
Atypical family structure	0.088 (0.020)**	[0.049, 0.126]
Male	0.301 (0.027)**	[0.248. 0.355]
ASD	0.829 (0.157)**	[0.522, 1.137]
White ethnicity	0.143 (0.066)	[0.014, 0.273]
Constant	0.839 (0.141)**	[0.563, 1.116]
Random effects	**Estimate (SE)**	**95% CI**
Level 3 (ward-level)		
Intercept variance	0.197 (0.021)	[0.160, 0.244]
Level 2 (Child level)		
Slope (age) variance	0.145 (0.004)	[0.137, 0.154]
Intercept variance	1.132 (0.016)	[1.102, 1.163]
Intercept-slope variance	-0.336 (0.030)	[-0.393, -0.276]

Note. Age was measured in years and grand mean centered (6.71 yrs).
For fixed effects: *p<.01, **p<.001

S2 – S6:

Supplementary Table 2: Greenspace interaction model

Table 2: Fully adjusted greenspace model predicting SDQ conduct scores (N = 8168).

Fixed effects	Coefficient (SE)	95% CI
Age	-0.238 (0.008)**	[-0.253, -0.223]
Age^2	0.052 (0.001)**	[0.049, 0.054]
ID diagnosis	0.780 (0.327)	[0.140, 1.421]
Greenspace (ward decile)	-0.002 (0.009)	[-0.020, 0.015]
ID diagnosis x Greenspace x Age	0.007 (0.010)	[-0.013, 0.027]
Greenspace x Age	0.003 (0.001)	[0.000, 0.005]
ID diagnosis x Age	0.004 (0.050)	[-0.094, 0.102]
ID diagnosis x Greenspace	0.034 (0.059)	[-0.081, 0.150]
Air pollution (NO^2)	-0.014 (0.009)	[-0.031, 0.004]
Damp	0.144 (0.031)**	[0.084, 0.205]
Urban	0.073 (0.056)	[-0.037, 0.183]
Access to garden	-0.162 (0.131)	[-0.418, 0.094]
Home spatial density	0.401 (0.063)**	[0.279, 0.525]
Maternal psychological distress	0.650 (0.098)**	[0.457, 0.842]
Below poverty line	0.190 (0.037)**	[0.118, 0.263]
Atypical family structure	0.346 (0.040)**	[0.275, 0.416]
Male	0.263 (0.035)**	[0.195, 0.331]
ASD	1.193 (0.312)**	[0.581, 1.804]
White ethnicity	0.169 (0.069)	[0.033, 0.302]
Constant	0.614 (0.180)*	[0.261, 0.970]
Random effects	**Estimate (SE)**	**95% CI**
Level 3 (ward-level)		
Intercept variance	0.177 (0.022)	[0.139, 0.224]
Level 2 (Child level)		
Slope (age) variance	0.139 (0.005)	[0.130, 0.148]
Intercept variance	1.058 (0.018)	[1.024, 1.094]
Intercept-slope variance	-0.355 (0.034)	[-0.420, -0.287]

Note. Age was measured in years and grand mean centered (6.71 yrs).
For fixed effects: *p<.01, **p<.001

Supplementary Table 3: NO_2 interaction model

Table 3: Fully adjusted greenspace model predicting SDQ conduct scores (N = 8168).

Fixed effects	Coefficient (SE)	95% CI
Age	-0.219 (0.007)**	[-0.234, -0.205]
Age^2	0.052 (0.001)**	[0.049, 0.054]
ID diagnosis	0.892 (0.303)*	[0.299, 1.485]
Greenspace (ward decile)	-0.000 (0.009)	[-0.018, 0.017]
Air pollution (NO^2)	-0.013 (0.009)	[-0.031, 0.005]
ID diagnosis x Air pollution (NO^2) x Age	0.009 (0.009)	[-0.008, 0.026]
Air pollution (NO^2) x Age	-0.001 (0.001)	[-0.003, 0.001]
ID diagnosis x Age	-0.027 (0.058)	[-0.142, 0.087]
ID diagnosis x Air pollution (NO^2)	0.006 (0.044)	[-0.081, 0.093]
Damp	0.144 (0.031)**	[0.084, 0.204]
Urban	0.072 (0.056)	[-0.038, 0.182]
Access to garden	-0.164 (0.130)	[-0.419, 0.091]
Home spatial density	0.400 (0.063)**	[0.276, 0.522]
Maternal psychological distress	0.651 (0.098)**	[0.459, 0.848]
Below poverty line	0.190 (0.037)**	[0.118, 0.263]
Atypical family structure	0.346 (0.036)**	[0.275, 0.417]
Male	0.263 (0.035)**	[0.195, 0.331]
ASD	1.175 (0.313)**	[0.561, 1.789]
White ethnicity	0.170 (0.068)	[0.037, 0.304]
Constant	0.602 (0.181)	[0.247, 0.967]
Random effects	**Estimate (SE)**	**95% CI**
Level 3 (ward-level)		
Intercept variance	0.176 (0.022)	[0.138, 224]
Level 2 (Child level)		
Slope (age) variance	0.139 (0.005)	[0.131, 0.148]
Intercept variance	1.058 (0.018)	[1.024, 1.094]
Intercept-slope variance	-0.356 (0.034)	[-0.420, -0.288]

Note. Age was measured in years and grand mean centered (6.71 yrs).
For fixed effects: *p<.01, **p<.001

Supplementary Table 4: Garden access interaction model

Table 4: Fully adjusted greenspace model predicting SDQ conduct scores (N = 8168).

Fixed effects	Coefficient (SE)	95% CI
Age	-0.241 (0.017)**	[-0.274, -0.207]
Age^2	0.052 (0.001)**	[0.049, 0.054]
ID diagnosis	0.825 (0.496)	[-0.148, 1.798]
Greenspace (ward decile)	-0.000 (0.009)	[-0.148, 1.798]
Air pollution (NO^2)	-0.014 (0.009)	[-0.031, 0.004]
ID diagnosis x Access to garden x Age	-0.085 (0.117)	[-0.315, 0.145]
Access to garden x Age	0.016 (0.017)	[-0.016, 0.049]
ID diagnosis x Age	0.115 (0.114)	[-0.108, 0.339]
ID diagnosis x Access to garden	0.113 (0.493)	[-0.853, 1.079]
Access to garden	-0.168 (0.134)	[-0.430, 0.094]
Damp	0.144 (0.031)	[0.084, 0.205]
Urban	0.072 (0.056)	[-0.038, 0.182]
Home spatial density	0.400 (0.063)	[0.276, 0.523]
Maternal psychological distress	0.651 (0.068)**	[0.458, 0.844]
Below poverty line	0.189 (0.037)**	[0.116, 0.262]
Atypical family structure	0.346 (0.036)**	[0.276, 0.417]
Male	0.263 (0.035)**	[0.195, 0.331]
ASD	1.183 (0.311)**	[0.574, 1.793]
White ethnicity	0.170 (0.068)	[0.036, 0.304]
Constant	0.611 (0.182)*	[0.255, 0.968]
Random effects	**Estimate (SE)**	**95% CI**
Level 3 (ward-level)		
Intercept variance	0.176 (0.022)	[0.138, 0.224]
Level 2 (Child level)		
Slope (age) variance	0.139 (0.005)	[0.131, 0.148]
Intercept variance	1.058 (0.018)	[1.024, 1.094]
Intercept-slope variance	-0.355 (0.034)	[-0.420, -0.287]

Note. Age was measured in years and grand mean centered (6.71 yrs).
For fixed effects: *p<.01, **p<.001

Supplementary Table 5: Urbanicity and Rurality interaction model

Table 5: Fully adjusted greenspace model predicting SDQ conduct scores (N = 8168).

Fixed effects	Coefficient (SE)	95% CI
Age	-0.218 (0.007)**	[-0.231, -0.205]
Age^2	0.052 (0.001)**	[0.049, 0.054]
ID diagnosis	1.230 (0.361)*	[0.523, 1.938]
Greenspace (ward decile)	-0.000 (0.009)	[-0.018, 0.017]
Air pollution (NO^2)	-0.013 (0.009)	[-0.031, 0.004]
ID diagnosis x Urban x Age	0.032 (0.074)	[-0.113, 0.178]
Urban x Age	-0.009 (0.008)	[-0.024, 0.006]
ID diagnosis x Age	0.007 (0.066)	[-0.123, 0.136]
ID diagnosis x Urban	-0.368 (0.386)	[-1.125, 0.390]
Urban	0.083 (0.057)	[-0.028, 0.194]
Damp	0.144 (0.031)**	[0.084, 0.204]
Access to garden	-0.163 (0.131)	[-0.419, 0.093]
Home spatial density	0.400 (0.063)**	[0.277, 0.523]
Maternal psychological distress	0.651 (0.098)**	[0.458, 0.843]
Below poverty line	0.190 (0.037)**	[0.117, 0.263]
Atypical family structure	0.345 (0.036)**	[0.275, 0.416]
Male	0.263 (0.035)**	[0.195, 0.331]
ASD	1.205 (0.313)**	[0.592, 1.818]
White ethnicity	0.169 (0.069)	[0.035, 0.303]
Constant	0.596 (0.183)*	[0.238, 0.953]
Random effects	**Estimate (SE)**	**95% CI**
Level 3 (ward-level)		
Intercept variance	0.177 (0.022)	[0.139, 0.224]
Level 2 (Child level)		
Slope (age) variance	0.139 (0.005)	[0.130, 0.148]
Intercept variance	1.058 (0.018)	[1.024, 1.094]
Intercept-slope variance	-0.356 (0.034)	[-0.420, -0.288]

Note. Age was measured in years and grand mean centered (6.71 yrs).
For fixed effects: *p<.01, **p<.001

Supplementary Table 6: Damp interaction model

Table 6: Fully adjusted damp interaction model predicting SDQ conduct scores (N = 8168).

Fixed effects	Coefficient (SE)	95% CI
Age	-0.225 (0.005)**	[-0.235, -0.216]
Age^2	0.052 (0.001)**	[0.049, 0.054]
ID diagnosis	1.013 (0.177)**	[0.666, 1.361]
Greenspace (ward decile)	-0.000 (0.009)	[-0.018, 0.017]
Air pollution (NO^2)	-0.014 (0.009)	[-0.031, 0.004]
ID diagnosis x Damp x Age	-0.060 (0.077)	[-0.211, 0.091]
Damp x Age	0.002 (0.011)	[-0.019, 0.022]
ID diagnosis x Age	0.040 (0.029)	[-0.016, 0.096]
ID diagnosis x Damp	-0.531 (0.246)	[-1.014, -0.048]
Damp	0.154 (0.033)**	[0.090, 0.218]
Urban	0.071 (0.056)	[-0.039, 0.180]
Access to garden	-0.166 (0.130)	[-0.421, 0.089]
Home spatial density	0.399 (0.063)**	[0.278, 0.522]
Maternal psychological distress	0.650 (0.098)**	[0.458, 0.843]
Below poverty line	0.191 (0.037)**	[0.163, 0.303]
Atypical family structure	0.345 (0.036)**	[0.274, 0.416]
Male	0.263 (0.035)**	[0.195, 0.331]
ASD	1.196 (0.313)**	[0.583, 1.810]
White ethnicity	0.171 (0.068)	[0.037, 0.304]
Constant	0.607 (0,180)*	[0.254, 0.960]
Random effects	**Estimate (SE)**	**95% CI**
Level 3 (ward-level)		
Intercept variance	0.176 (0.022)	[0.138, 0.224]
Level 2 (Child level)		
Slope (age) variance	0.139 (0.005)	[0.130, 0.148]
Intercept variance	1.058 (0.018)	[1.023, 1.093]
Intercept-slope variance	-0.357 (0.034)	[-0.421, -0.289]

Note. Age was measured in years and grand mean centered (6.71 yrs).
For fixed effects: *p<.01, **p<.001

Supplementary Table 7: Sensitivity analysis: ethnicity x spatial density x Intellectual disability

Table 7: ethnicity x spatial density x intellectual disability sensitivity analysis (N = 8168).

Fixed effects	Coefficient (SE)	95% CI
Age	-0.225 (0.005)**	[-0.234, -0.215]
Age^2	0.052 (0.001) **	[0.049, 0.054]
ID diagnosis	2.656 (0.754)**	[1.178, 4.134]
Greenspace (ward decile)	0.000 (0.008)	[-0.017, 0.017]
Air pollution (NO^2)	-0.013 (0.009)	[-0.030, 0.005]
ID diagnosis x ethnicity x spatial density	0.906 (0.670)	[-0.407, 2.219]
Ethnicity x spatial density	0.419 (0.113)**	[0.197, 0.641]
ID diagnosis x ethnicity	-1.061 (0.841)	[-2.710, 0.587]
ID diagnosis x spatial density	-1.623 (0.580)*	[-2.760, -0.486]
Damp	0.143 (0.031)**	[0.083, 0.203]
Urban	0.067 (0.056)	[-0.042, 0.176]
Access to garden	-0.166 (0.130)	[-0.420, 0.089]
Home spatial density	0.0751 (0.102)	[-0.124, 0.274]
Maternal psychological distress	0.653 (0.098)**	[0.461, 0.845]
Below poverty line	0.190 (0.037)**	[0.118, 0.263]
Atypical family structure	0.343 (0.036)**	[0.272, 0.414]
Male	0.262 (0.035)**	[0.194, 0.330]
ASD	1.173 (0.312)**	[0.561, 1.786]
White ethnicity	-0.199 (0.122)	[-0.438, 0.041]
Constant	0.903 (0.202)**	[0.508, 1.299]
Random effects	**Estimate (SE)**	**95% CI**
Level 3 (ward-level)		
Intercept variance	0.173 (0.022)	[0.136, 0.222]
Level 2 (Child level)		
Slope (age) variance	0.139 (0.005)	[0.130, 0.148]
Intercept variance	1.056 (0.018)	[1.022, 1.092]
Intercept-slope variance	-0.357 (0.034)	[-0.422, -0.289]

Note. Age was measured in years and grand mean centered (6.71 yrs).
For fixed effects: *p<.01, **p<.001