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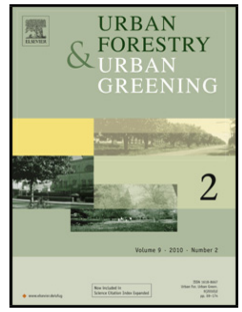

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The role of greenspace deprivation in children's decision-making

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Highlights

- Urban greenery was associated with risk-taking in UK children
- Those in greenspace-deprived urban areas showed more risk-taking
- The link was similar across sexes and robust to adjustment for confounding

Abstract

We explored the role of long-term greenspace deprivation in how children evaluate potential rewards and punishments and use this information to make decisions. We used data from the Millennium Cohort Study (MCS), a large population-based longitudinal birth cohort in the UK. Reward and punishment sensitivity was measured at the age 11 data wave with the Cambridge Gambling Task (CGT). Our sample (N=1,701; 51% male) included children who, as at the age 11 wave, had lived in the same address in urban England since the beginning of MCS and had valid data on the CGT. Our analysis adjusted for families' selection into neighbourhoods, children's pubertal status, sex, ethnicity and cognitive ability but also several important aspects of the home's and the neighbourhood's physical and social environments. Even after full adjustment, children growing up in the least green neighbourhoods showed less aversion to risk (they scored higher on risk-taking), and the association was similar across sexes. However, long-term absence of local greenspace was not significantly associated with other aspects of reward and punishment sensitivity, including risk adjustment, deliberation time or delay aversion, even after minimal adjustment. Long-term greenspace deprivation seems uniquely predictive of fast decision strategies in children.

Keywords: Childhood; gambling task; green space; reward and punishment sensitivity

Introduction

The recent years have witnessed a growing interest in the impact of the built environment, particularly urban greenspace, on emotional and behavioural outcomes in children (Flouri et al., 2014; McCormick, 2017; Tillmann et al., 2018). Little is known however about the role of greenspace exposure in the cognitive antecedents of such child outcomes, notwithstanding the evidence on its role in brain development (Dadvand et al., 2018), cognitive functions (Dadvand, Nieuwenhuijsen, et al., 2015) - especially attention (Dadvand et al., 2017) and working memory (Flouri, Papachristou, et al., 2019) - and self-regulation (Bakir-Demir et al., 2019; Jenkin et al., 2018; Taylor et al., 2002; Weeland et al., 2019). By and large, greenspace exposure is still considered to impact on the cognitive antecedents of emotional and behavioural outcomes in children indirectly. For example, greener areas often have lower levels of traffic-related air pollution (Dadvand, Rivas, et al., 2015) and noise (Gidlöf-Gunnarsson & Öhrström, 2007), are postulated to enrich microbial input from the environment (Rook, 2013), and are thought to facilitate physical activity in children (Bell et al., 2008). In turn, reduced exposure to air pollution and noise, increased physical activity, and enriched microbial input have positive effects on the developing brain (Carlson et al., 2017; Klatte et al. 2013; Lande et al., 2003; Li et al., 2008; Rook, 2013; Sarkar et al., 2018; Sunyer et al. 2015). Our study adds knowledge about the *direct* impact of greenspace exposure on the cognitive antecedents of emotional and behavioural outcomes in childhood, by exploring the role of greenspace exposure in children's reward and punishment sensitivity (Byrd et al., 2018; Lahat et al., 2018; Luman et al., 2012; Rich et al., 2005).

Arguably this link is plausible in children in view of the substantial evidence supporting related ones in adults. For example, several neuroimaging studies have found support for the role of exposure to nature in the brain regions regulating the autonomic and hypothalamic-pituitary-adrenal (HPA) stress response, such that individuals with urban upbringing are more likely to show high neural activity linked to stress processing, in turn causally linked to higher risk of psychiatric disorders (Lederbogen et al., 2011). More recent research has shown that in urban dwellers greenspace exposure is also related to reduced regulatory prefrontal recruitment during processing of aversive social-emotional cues (Tost et al., 2019). Thus, greenspace exposure may compensate for reduced neural regulatory capacity, as suggested by systematic reviews of the epidemiological evidence as well (Fong et al., 2018). Reduced regulatory capacity is a prominent neural trait phenotype for mental health risk found in individuals with trait anxiety (Pezawas et al., 2005), healthy individuals at high risk for depression and anxiety disorders (Opel et al., 2017), and in manifest illness (Opel et al., 2017; Phillips et al., 2003; Stuhrmann et al., 2011). In delineating the cognitive effects of greenspace exposure, research that combines epidemiological and brain structural data on regions probably holds the most promise, but such research is scarce and, typically, cross-sectional. One such study, on older urban dwellers, explored the association between structural brain integrity and amount of forest, urban green, water and wasteland around the home address (Kühn et al., 2017). However, the significant and robust association found between amount of forest surrounding the home address and amygdala integrity is difficult to interpret because of the possibility of reverse causality (i.e., participants may have chosen their geographical surrounding based on their brain structural integrity).

Findings such as these are usually taken to suggest that greenspace can affect brain structure through positive associations with amygdala integrity, and can mitigate some of the negative effects of exposures to stress-inducing, due to population density and noise, city environments. These positive impacts, related to reward-processing, could also apply to children. In fact, proponents of the biophilia hypothesis, according to which humans have important innate biological connections to nature and respond positively to unthreatening natural environments (Wilson, 1984; Kellert & Wilson, 1993), would likely argue that cognitive benefits for children are larger and transcend abilities. Because of children's 'innate' biophilia, green spaces should be the ideal settings for them to learn by play and exploration, in turn prompting engagement, discovery, creativity, mastery and control, which positively influence different aspects of brain development (Bowler et al. 2010; Kahn & Kellert, 2002). By the same token, the absence of green spaces from their lives should also be felt acutely.

Our study provided a test of this hypothesis. We explored the role of long-term greenspace deprivation in how children evaluate potential rewards and punishments and use this information to make decisions on a gambling task administered at the end of primary school (at age 11 years). We focussed on relative absence of greenspace in view of the recent evidence for threshold effects, such that the population prevalence of mental-health issues is significantly lower beyond minimum limits of neighbourhood vegetation cover (Cox et al., 2017) and that, for children, the risk of future mental illness rises when greenspace deprivation accumulates across development (Engemann et al., 2019). We expected that children growing up in greenspace-deprived urban neighbourhoods would show less aversion to risk and more impulsive choices for two inter-related reasons. First, because exposure to nature lengthens time perception, and lengthening time perception decreases impulsivity (Berry et al., 2015; Rudd et al., 2012). Second, because stress - which should be more likely in greenspace-deprived, and therefore the least biophilic, contexts - affects dopaminergic reward-processing brain regions, by enhancing learning about positive outcomes of choices and impairing learning about negative (Mather & Lighthall, 2012). We also expected that these relationships would survive adjustment for families' selection into neighbourhoods due to socioeconomic status and ethnicity, for children's sex, pubertal status and cognitive ability, but also for private greenery (garden access) and several important aspects of the home's and the neighbourhood's physical and social environments, a unique contribution to the evidence to date. We examined these associations in the participants of the Millennium Cohort Study (MCS), a large population-based longitudinal birth cohort in the UK, who lived in urban areas [i.e., settlements with populations of over 10,000 (Bibby & Shepherd, 2004)]. We excluded rural dwellers because neighbourhood greenspace may be confounded with levels of rurality (White et al., 2013). At the age 11 follow-up, the majority of MCS participants (76.9%) lived in urban areas, indicating that the MCS population is heavily urban. To ensure that we did not introduce bias by allowing for possible changes in quality and type of neighbourhood greenspace due to household moves, we only included children who, as at age 11, had lived in the same address in urban England since the beginning of MCS. We excluded the very few urban stayers in the Celtic countries of the UK because our measure of greenspace was only available for England.

Method

Participants

MCS follows about 19,000 children born in 2000-02 (Joshi & Fitzsimons, 2016), from around 9 months (sweep 1) to around 3, 5, 7, 11 and 14 years (sweeps 2-6). The geography of electoral wards provided the sampling frame for MCS, which was designed to over-represent families living in wards of high child poverty across the UK, wards with high proportions of ethnic minorities in England, and the smaller UK countries (Plewis et al., 2007). The disproportionate representation of these groups ensures that typically hard-to-reach populations are adequately represented and that sample sizes are sufficient for the analysis of ethnic minorities, those from disadvantaged backgrounds and children within each of the UK nations. Within electoral wards, the aim was to recruit 100% of children born in the eligible period. There is a total of 398 wards in MCS, of which 200 are 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. Ethical approval for the MCS was gained from NHS Multi-Centre Ethics Committees, parents gave consent before interviews took place, and cohort children assent (from age 11). At the age 11 sweep, when reward and punishment sensitivity was measured, 13,287 families took part in MCS. This study's analytic sample (N=1,701; 51% male) included children (singletons and first-born twins or triplets) who, as at the age 11 sweep, had lived in the same address in urban England since the beginning of MCS and had valid data on reward and punishment sensitivity. All the children in the analytic sample had data on neighbourhood greenspace.

Measures

Reward and punishment sensitivity

This was measured with the Cambridge Neuropsychological Test Automated Battery (CANTAB) Cambridge Gambling Task (CGT; Cambridge Cognition, 2006) at age 11 (sweep 5). The CGT is a measure of decision-making and risk-taking behaviour to obtain rewards (i.e., explicit risk contingencies; Manes et al., 2002). It has been used extensively, but, typically, in small samples. To our knowledge, no other general-population birth cohort study has ever used this or other gambling tasks during childhood assessments. During the task, participants are asked to guess the location of a hidden token on a computer screen, and then gamble a proportion of their points on their decision. Participants are presented with a row of ten boxes (red and blue) across the top of the screen and are told that the computer has hidden a "token" behind one of them. They have to choose a) which colour of box they believe the token is hidden behind (red or blue), and b) the number of points they want to gamble on their colour choice. The proportion of red to blue boxes (box ratio) varies during the task pseudo-randomly to assess the influence of statistical risk (probability) on decision-making. Participants start the task with 100 points and select a proportion of these points to bet on their decision (between 5% and 95%). A circle in the centre of the screen displays the current bet value, which either increases or decreases incrementally. Participants press the button when it shows the proportion of their score they would like to bet. These points are either added to, or subtracted from, their total score, depending on their decision and where the token was actually hidden. Before the formal experiment, participants are instructed with a practice phase to make sure they understand the rules. The task produces six outcome measures: 1) Risk-taking, the mean proportion of points bet on trials where the most probable colour was selected. Higher scores reflect higher reward-sensitivity (or lower punishment-sensitivity); 2) Quality of decision-making, the mean proportion of trials where the most probable colour was selected; 3) Deliberation time, the mean time (in milliseconds) taken to make a box colour selection; 4) Risk adjustment, the extent to which betting behaviour is moderated by probability. It reflects the tendency to stake higher bets on high-probability compared to low-probability trials; 5) Delay aversion, the time participants are prepared to wait in order to place a higher or lower bet; 6) Overall proportion bet, the mean proportion of points gambled across all trials. We excluded the overall proportion bet variable from the analysis as it was highly correlated (r > .9) with risk-taking. The remaining five measures are typically largely independent from each other and assess different aspects of decision-making tendency (Flouri, Moulton, et al., 2019).

Neighbourhood greenspace

Neighbourhood greenspace was measured using the 2001 Generalised Land Use Database (GLUD; Office of the Deputy Prime Minister, 2005). The GLUD classifies land use at high geographical resolution across England into nine categories: greenspace, domestic gardens, fresh water, domestic buildings, nondomestic buildings, roads, paths, railways, and other (largely hard standing). GLUD offers an indicator of the percentage of greenspace per Lower layer Super Output Area (LSOA) in England, covering both public and private green spaces larger than 5m2 (excluding domestic gardens). An LSOA is a standard geospatial statistical unit for England and Wales, built from smaller Census Output Areas, and typically includes about 600 homes and 1,500 residents. GLUD provides an overall “greenness” indicator for each LSOA given it captures even very small green spaces. In MCS, the percentages of neighbourhood greenspace have been converted to deciles. To assess the effect of long-term absence of local greenspace, we created for this study a dichotomous variable measuring whether the child lived in an LSOA in the lowest decile of greenspace or not. In our analytic sample, 15.7% of families lived in areas with the lowest decile of greenspace and 2.1% in areas with the highest decile of greenspace. Those in deciles 2-9 comprised, respectively, 17.4%, 12.5%, 9.9%, 8.6%, 10.3%, 8.4%, 10.7%, and 4.3% of the sample (all unweighted %).

Home physical environment

The home physical environment was measured by observation at ages 3 (sweep 2) and 5 (sweep 3) years (Oloye & Flouri, 2021). We created an overall measure of it using the scores from a principal components analysis (PCA) of the items about home traffic, background noise, interruptions, darkness, cleanliness and clutter, as recorded by the MCS interviewer during a home visit. There were 8 items at age 3 years about the home: 1) dark; 2) reasonably clean; 3) reasonably uncluttered; 4) noise from TV; 5) background conversation; 6) anyone entering or leaving the home; 7) interruption by another child; 8) interruption by another adult. At age 5 there were 3 items: 1) noise from TV; 2) background conversation; 3) background noise from other children. PCAs were performed separately for age 3 and age 5 and the averaged standardised score of the two sweeps' PCA scores was used in the analysis. Another three parent-reported home environment items were used independently in the analysis as the closest available home-level equivalents of our neighbourhood indicators of socio-economic disadvantage and greenspace, respectively: whether the child was exposed to second-hand smoke in the home ('yes', 'no') for any of the first three sweeps (9 months old, age 3 and age 5), lived in an overcrowded (>1 person per room) home ('yes', 'no') at sweep 1 (9 months old), and had access to a domestic garden ('yes', 'no').

Neighbourhood physical and social environment

The neighbourhood physical environment was measured by a standardised score from a PCA of 11 items about the neighbourhood, as recorded by the MCS interviewer during the home visit at age 3: 1) level of building conditions ("well kept", "fair", "poor", "badly deteriorated"), 2) security blinds ("none", "some", "most"), 3) traffic calming ("yes", "no"), 4) levels of traffic volume ("no", "light", "moderate", "heavy"), 5) burnt-out cars on the street ("yes", "no"), 6) litter on the street or pavement ("almost none", "some", "about everywhere") 7) dog mess on the pavement ("none", "some", "a lot"), 8) graffiti on walls or on public spaces ("no", "a little", " a lot"), 9) any evidence of vandalism ("yes", "no"), 10) arguing or fighting on 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) how did you feel 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"). The neighbourhood social environment was approximated by the MCS sampling 'stratum' (in our case, 'England-Advantaged', 'England-Disadvantaged', '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.

Covariates

We controlled for individual- and family-level characteristics related to families' selection into neighbourhoods and children's reward and punishment sensitivity. The individual covariates included sex, age at the assessment on the CGT, pubertal status (at least some signs of puberty vs. no signs) and ethnicity (white, black, Indian, Pakistani/Bangladeshi, mixed and other). General cognitive ability (IQ) was also controlled for. This was measured at age 5 (sweep 3) using the scores from a PCA of the three subscales of British Ability Scales (BAS; Elliott et al., 1996), available at MCS at that sweep: Naming Vocabulary (measuring expressive language), Pattern Construction (measuring spatial problem-solving), and Picture Similarities (measuring non-verbal reasoning) (Flouri, Moulton, et al., 2019). The family-level covariates included family socio-economic status, which we approximated by maternal education and family poverty. Maternal education was measured with a dummy variable indicating whether the mother had a university degree as at sweep 5 (end of the study period), and family poverty was measured with a dummy variable indicating whether or not the family's income was below the poverty line at sweep 5, when CGT was measured. As an additional test, we adjusted for sweep 5 internalising and externalising problems (indexing mental health problems in the general child population), associated with both neighbourhood conditions and children's reward and punishment sensitivity. These were assessed with the main respondent's report of the Strengths and Difficulties Questionnaire (Goodman, 1997), which indexes children's levels of emotional symptoms, peer problems, conduct problems and hyperactivity. Internalising problems (Cronbach's α = 0.60) comprised emotional symptoms and peer problems, and externalising problems (Cronbach's α = 0.70) comprised conduct problems and hyperactivity.

Analytic strategy

We fitted three multiple linear regression models for each of the five CGT measures we considered. We specified the first (a minimally adjusted) model to explore the role of neighbourhood greenspace while taking steps to account for selection and avoid committing the ecological fallacy (the error of attributing the characteristics of a population to an individual). That model therefore controlled for access to domestic garden, area deprivation, maternal education, and pubertal status and sex. In the second model, we added neighbourhood physical environment, home physical environment, overcrowding and second-hand smoke, poverty, ethnicity, IQ and exact age. The last model was a sensitivity analysis whereby we additionally adjusted for internalising and externalising problems.

Although our hypothesis was that long-term greenspace *deprivation* (i.e., continuously living in the lowest decile of greenspace) is key, we explored in a supplementary analysis other thresholds (i.e., living in the bottom 2 deciles or not, living in the bottom 3 deciles or not, living in the bottom 4 deciles or not, and living in the bottom 5 deciles or top 5 deciles). In all models, we used study-specific weights to account for the probability of nonresponse and attrition. As explained, there were no missing data on greenspace or the outcome variables. Missing data on the covariates were imputed using multiple imputation by chained equations, on the assumption that they were missing at random (Raghunathan et al., 2001). We generated 20 imputed datasets and used Rubin's combination rules to consolidate the obtained individual estimates into a single set of multiply imputed estimates (Rubin, 1987). All models were fitted in STATA 16.

Results

Descriptive statistics and bivariate analysis (unweighted data)

The amount of missing data was low for neighbourhood physical environment, access to domestic garden, second-hand smoke, maternal education, IQ and externalising/internalising problems, ranging from 0% to 5%. Home physical environment and pubertal status had relatively higher proportions of missing values, at 10.9% and 6.6%, respectively. The other covariates did not have missing values. Table 1 shows the sample's characteristics by quantity of neighbourhood greenspace. As expected, compared to the least green urban areas, urban areas with more greenspace tended be cleaner, safer and relatively more advantaged, and families in such areas were more likely to be white and less likely to experience income poverty, overcrowding or poor home environments. However, there was no difference between the two area 'types' in children's scores on IQ, CGT or internalising/externalising problems. Correlations among the covariates in the analytic sample were low to moderate, as expected (Table S1).

Regression models

For risk-taking, the effect of long-term greenspace deprivation was significant and robust to adjustment. As shown in Table 2, less availability of local greenspace was related to more risk-taking in model 1 (b=0.025, SE=0.011, p=0.022). In model 2, after full adjustment, low greenspace availability (b=0.022, SE=0.011, p=0.036) and poor home physical environment (b=0.027, SE=0.013, p=0.044) were positively associated with risk-taking. In model 3, the effect of home physical environment lost significance after further adjusting for externalising and internalising problems (b=0.024, SE=0.013, p=0.066), but the effect of low greenspace availability remained significant (b=0.021, SE=0.010, p=0.043). The results indicate that children living in the least green areas show higher sensitivity to reward (or lower sensitivity to punishment). The positive association on the other hand between poor home environments (i.e., living in a dark, cluttered, disorganised and noisy home) and children's risk-taking became nonsignificant when controlling for internalising and externalising problems. Indian children showed more risk-taking compared to white children, consistently across models. As expected, boys scored higher on risk-taking than girls, but the interaction term between greenspace and sex was non-significant (results not shown), suggesting that the association between long-term absence of local greenspace and risk-taking was similar across sexes. Also consistent with our expectations, externalising and internalising problems were, respectively, positively and negatively associated with risk-taking.

On the other hand, long-term absence of local greenspace was not significantly associated with risk adjustment, deliberation time or delay aversion even after minimal adjustment (Tables 3, 5 and 6, respectively). Poorer neighbourhood physical environments, however, were associated with worse risk adjustment even after full adjustment (model 2: b=-0.153, SE=0.077, p=0.048), though not after additional controls for externalising and internalising problems (model 3: b=-0.145, SE=0.077, p=0.062). As expected, children scored higher on risk adjustment if they had higher IQ, if they had fewer externalising problems and if they lived with university-educated mothers. For deliberation time, children with access to domestic gardens had longer deliberation time, even after full adjustment (b=310, SE=94.3, p=0.001) and controls for externalising and internalising problems (b=303, SE=95.5, p=0.002). Longer deliberation time was also positively associated with internalising problems and area disadvantage. By contrast, deliberation time was shorter in children with higher IQ, those from 'other' ethnic groups, those living in poverty and those with university-educated mothers. None of the individual, neighbourhood or home-level variables predicted delay aversion. As with risk-taking, the interaction term between greenspace and sex was not significant (results not shown) for risk adjustment, deliberation time or delay aversion, either.

The results of the models on quality of decision-making were unexpected (Table 4). Low availability of local greenspace and access to domestic garden were, respectively, positively and negatively related to quality of decision-making in model 2 (b=0.024, SE=0.010, p=0.015; b=-0.035, SE=0.018, p=0.049, respectively) and model 3 (b=0.024, SE=0.010, p=0.016; b=-0.035, SE=0.018, p=0.047, respectively), although they were both non-significant in the minimally adjusted model (b=0.020, SE=0.010, p=0.052; b=-0.014, SE=0.018, p=0.427, respectively). As expected, children with university-educated mothers and those with higher IQ scored higher on quality of decision-making. As was also the case with the other CGT variables, the interaction term between greenspace and sex was not significant (results not shown). Black, compared to white, children scored lower. We suspected that the discrepancy in the effects of both public and private greenspace was caused by collinearity due to ethnic differences in both children's deliberation time on the CGT and families' housing and selective sorting into areas in urban England (Nygaard, 2011). Therefore, we built another two models from models 2 and 3 excluding ethnicity (Table S2, models 4 and 5, respectively). As expected, neither low availability of local greenspace nor access to domestic garden was significant in model 4 (b=0.019, SE=0.010, p=0.052; b=-0.023, SE=0.018, p=0.201, respectively) or model 5 (b=0.018, SE=0.010, p=0.057; b=-0.023, SE=0.018, p=0.206, respectively).

Supplementary analysis

Although our hypothesis that long-term greenspace *deprivation* (i.e., continuously living in the lowest decile of greenspace) was confirmed for risk-taking, we explored in a sensitivity analysis other thresholds (i.e., living in the bottom 2 deciles or not, living in the bottom 3 deciles or not, living in the bottom 4 deciles or not, and living in the bottom 5 deciles or top 5 deciles). The results from our investigation of how these other thresholds (i.e., 20%, 30%, 40% and 50%) behaved for risk-taking are presented in Supplementary Tables S3-S6. As can be seen, no other operationalization of greenspace was related to risk-taking, even after minimal adjustment, suggesting that the 10% threshold was indeed optimal. We do acknowledge, however, that this could also indicate that the relationship is weak and only detectable at the most extreme end of the distribution of greenspace deprivation.

Discussion

Reward processing is especially useful for understanding motivation, in turn associated with many health, educational and socio-economic outcomes (Eccles, Wigfield, & Schiefele, 1998). This study investigated the association between long-term greenspace deprivation and children's reward processing, measured with a gambling task. Specifically, it explored whether reward and punishment sensitivity, measured using the Cambridge Gambling Task (CGT) around the beginning of adolescence (age 11), was associated with growing up in a greenspace-deprived neighbourhood since birth, in a large urban sample of stayer families in England. We expected that children growing up in the least green urban areas would show less aversion to risk, less adjustment to risk, lower quality of decision-making and more delay aversion than other urban children.

We found some support for our hypothesis. Even after adjusting for physical and social aspects of both homes and neighbourhoods but also important individual characteristics, such as sex, ethnicity, pubertal status and IQ, children in the least green urban areas showed higher sensitivity to reward (they scored higher on risk-taking) than other urban children. Low greenspace availability and poor home physical environment (i.e., living in a dark, cluttered, disorganised and noisy home) were both positively associated with risk-taking but the effect of latter lost significance after further adjusting for externalising and internalising problems. Although the effect of long-term greenspace deprivation on children's risk-taking was small it is substantively important. It suggests that limited availability in urban areas of natural or semi-natural areas, partially or completely covered by vegetation, that provide habitat for wildlife and can be used for recreation (such as parks, woodlands and allotments) is related to the process of choice under risk in children, an important antecedent of mental health (Halahakoon et al., 2020) but also a host of other outcomes, both short and long-term (Schultz, 2006).

Our study also has some limitations. First, it is correlational, and so it remains unclear if the association between living in areas with little greenspace and increased reward sensitivity is causal and not due to unmeasured confounding. For instance, we did not consider the role of other contexts whose characteristics are associated with both urban neighbourhoods' greenspace and children's risk-taking, such as schools and peer groups. However, to a large extent their effects were partialled out by our accounting for selective sorting into areas (and therefore schools and, by extension, peer groups). Second, our measure of greenspace used data from 2001 to characterise quantity of greenspace a decade later. Although our sample of urban stayer families did not of course change neighbourhood across the study period, aspects of neighbourhoods - even contextual aspects, such as greenspace - can change over time. However, there is evidence that in the UK area deprivation and other area characteristics do not change substantially over 10 years in recent history (Gambaro et al., 2016; Kontopantelis et al., 2018). Third, we had no data on the quality of greenspace and different types of greenness which may be more relevant than percentage of green cover for the outcomes we considered. Fourth, we had no data on access and use of green spaces. Fifth, there is a significant risk of misclassification. We did not consider the greenspace available in adjacent areas, which children, especially those living near LSOA boundaries, could also access. In fact, for children about to enter puberty, residential LSOAs (very small geographical units, especially in urban areas where our sample lived) may not be the most relevant physical context. Adolescents are likely exposed to many neighbourhoods, such as those of their schools and peer groups but we were not able to link data on those locations to individual children in our sample. Thus, we could not fully capture our sample's actual everyday spatial behaviour and therefore more precise exposure to greenspace. Sixth, our sample was selective as it comprised only urban families with young children who did not change address for a decade, a somewhat atypical population. Finally, there are the limitations of the CGT. Risk-taking conflates the seeking of reward and the avoidance of punishment. Reduced betting, even when the odds of winning are high, might occur because participants are less motivated by reward or because they want to avoid loss (punishment), and this cannot be disentangled in this task.

Nonetheless, our study has significant strengths, including the use of data from a large and nationally representative cohort, the longitudinal recording of exposure to greenspace and the measurement of reward and punishment sensitivity in a critical period, early adolescence. Its findings contribute to our understanding of the 'net' role of greenspace in children's decision-making, which is itself related to many important life outcomes. We suggest that future studies should use more fine-grained measures of locality and greenery to assess more precisely the proximity of families to green sites, and to account for the influence of neighbouring green space, not just green space in children's immediate neighbourhoods. This would be possible with the use of geographic information systems (GIS). Utilising data on the quality of green sites in a GIS framework may also capture access to high quality green spaces. Future studies should also consider that children entering puberty may not only be exposed to the immediate neighbourhood where they live.

Conclusions

We showed that children living in the least green urban neighbourhoods in the UK showed 'faster' strategies than other urban children. The association was not large but was robust to stringent adjustment for confounders. If the association we established between long-term greenspace deprivation and child risk-taking is causal it suggests that the built environment can impact on decision-making among children as young as 11 years old, in turn setting in motion the course for a range of important health, socio-economic and educational outcomes.

author statement

Eirini Flouri: Conceptualization, Methodology, Supervision, Project Administration, Funding Acquisition, Writing. **Dongying Ji**: Software, Formal Analysis. **Jonathan Roiser**: Writing- Reviewing and Editing.

conflict of interest

The authors declare they have no conflict of interest

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Table 1. Analytic sample characteristics (unweighted data)

		All participants n=1701 (100%)	In low neighbourhood greenspace (bottom decile) n=267 (16%)	In other neighbourhood greenspace (other deciles) n=1434 (84%)	*p*-value
Continuous variables, M(SD)					
CGT	Risk-taking	.53 (.16)	.55 (.16)	.53 (.17)	.119
	Risk adjustment	.75 (1.06)	.73 (1.09)	.75 (1.06)	.713
	Quality of decision-making	.82 (.17)	.83 (.16)	.82 (.17)	.212
	Delay aversion	.29 (.24)	.30 (.25)	.29 (.23)	.779
	Deliberation time (milliseconds)	3292.60 (1353.46)	3226.92 (1353.46)	3304.83 (1301.66)	.388
Internalising problems		2.96 (2.95)	2.83 (2.73)	2.99 (2.98)	.426
Externalising problems		4.10 (3.26)	3.95 (3.03)	4.13 (3.30)	.437
Age		11.12 (.33)	11.11 (.31)	11.13 (.33)	.379
IQ		101.57 (14.40)	100.45 (15.44)	101.78 (14.19)	.168
Poor home physical environment		.99 (.37)	1.03 (.38)	.98 (.36)	.029
Poor neighbourhood physical environment		.93 (.39)	1.02 (.41)	.91 (.39)	.000
Categorical variables, n (%)					
Female		838 (49%)	137 (51%)	701 (49%)	.466
Pubertal signs		936 (60%)	152 (64%)	784 (58%)	.112
Stratum	Advantaged	850 (50%)	97 (36%)	753 (53%)	.000
	Disadvantaged	573 (34%)	77 (29%)	496 (35%)	
	Ethnic	278 (16%)	93 (35%)	185 (13%)	
Ethnicity	White	1311 (77%)	147 (55%)	1164 (81%)	.000
	Mixed	54 (3%)	9 (3%)	45 (3%)	
	Indian	102 (6%)	30 (11%)	72 (5%)	
	Pakistani and Bangladeshi	121 (7%)	52 (19%)	69 (5%)	
	Black or Black British	76 (4%)	20 (7%)	56 (4%)	
	Other ethnic group	37 (2%)	9 (3%)	28 (2%)	
Mother is university-educated		351 (21%)	69 (26%)	282 (20%)	.023
Below the poverty line		265 (16%)	58 (22%)	207 (14%)	.003
Access to garden		1566 (92%)	247 (93%)	1319 (92%)	.796
Second-hand smoke		311 (18%)	42 (16%)	269 (19%)	.238
Overcrowding		198 (12%)	44 (16%)	154 (11%)	.007

Note. Note. p-values of t-tests for continuous variables and chi-square tests for categorical variables.

Table 2. Multiple linear regression model results for risk-taking (N=1,701)

	Model 1		Model 2		Model 3	
	Coef. [95% CI]	S.E.	Coef. [95% CI]	S.E.	Coef. [95% CI]	S.E.
Greenspace: bottom decile	**.025*[.004, .046]**	**.011**	**.022*[.002, .043]**	**.011**	**.021*[.001, .041]**	**.010**
Access to garden	-.027 [-.070, .016]	.022	-.029 [-.073, .014]	.022	-.026 [-.067, .015]	.021
Overcrowding			.001 [-.033, .034]	.017	.003 [-.030, .036]	.017
Second-hand smoke			.012 [-.013, .037]	.013	.010 [-.014, .035]	.013
Poor home physical environment			**.027*[.001, .053]**	**.013**	.024 [-.002, .050]	.013
Poor neighbourhood physical environment			.004 [-.021, .029]	.013	.003 [-.022, .028]	.013
Age			-.004 [-.030, .021]	.013	.000 [-.022, .025]	.013
Pubertal signs	.002 [-.021, .025]	.012	-.000 [-.024, .024]	.012	.001 [-.022, .024]	.012
Female	-.094***[-.111,-.078]	.008	-.094***[-.111,-.077]	.009	-.089***[-.106,-.072]	.009
Below the poverty line			-.007 [-.043, .029]	.018	-.012 [-.048, .025]	.018
Mother university-educated	-.008 [-.029, .014]	.011	-.002 [-.023, .020]	.011	.004 [-.018, .027]	.011
IQ			-.000 [-.001, .000]	.000	-.000 [-.001, .001]	.000
Stratum (ref England-Advantaged)						
England - Disadvantaged	.013 [-.013, .037]	.013	.007 [-.018, .032]	.013	.007 [-.018, .031]	.012
England - Ethnic	.024 [-.007, .054]	.016	-.003 [-.042, .036]	.020	-.002 [-.042, .038]	.020
Ethnicity (ref 'White')						
Mixed			.016 [-.031, .064]	.024	.022 [-.024, .068]	.023
Indian			.071**[.031, .112]	.020	.072**[.030, .114]	.021
Pakistani/Bangladeshi			.021 [-.034, .077]	.028	.030 [-.026, .086]	.028
Black/Black British			-.010 [-.045, .025]	.018	-.002 [-.037, .033]	.018
Other			.021 [-.028, .070]	.025	.032 [-.021, .085]	.027
Internalising problems					-.005**[-.008,-.001]	.002
Externalising problems					.008***[.006, .011]	.001
Constant	.689***[.638, .740]	.026	.739***[.428, 1.05]	.157	.631***[.331, .931]	.152

*p<.05; **p<.01; ***p<.001

Table 3. Multiple linear regression model results for risk adjustment (N=1,701)

	Model 1		Model 2		Model 3	
	Coef. [95% CI]	S.E.	Coef. [95% CI]	S.E.	Coef. [95% CI]	S.E.
Greenspace: bottom decile	-.024 [-.166, .117]	.072	.012 [-.120, .144]	.067	.015 [-.119, .149]	.068
Access to garden	.107 [-.132, .346]	.121	-.018 [-.253, .217]	.119	-.028 [-.260, .204]	.117
Overcrowding			-.001 [-.194, .193]	.098	-.004 [-.195, .186]	.096
Second-hand smoke			.033 [-.108, .174]	.071	.043 [-.099, .184]	.072
Poor home physical environment			-.151 [-.307, .006]	.079	-.138 [-.294, .017]	.078
Poor neighbourhood physical environment			-.153*[-.305, -.002]	.077	-.145 [-.297, .007]	.077
Age			.055 [-.102, .212]	.079	.039 [-.120, .197]	.080
Pubertal signs	.024 [-.118, .165]	.071	-.040 [-.100, .179]	.071	.037 [-.102, .175]	.070
Female	.008 [-.106, .123]	.058	-.004[-.117, -.109]	.057	-.021 [-.134, .093]	.057
Below the poverty line			-.047 [-.231, .137]	.093	-.025 [-.211, .161]	.094
Mother university-educated	.344***[.181, .507]	.083	.240**[.093, .387]	.074	.219**[.072, .366]	.074
IQ			.010***[.005, .015]	.003	.009***[.004, .014]	.003
Stratum (ref England-Advantaged)						
England - Disadvantaged	-.157*[-.286, -.028]	.065	-.084 [-.219, .051]	.068	-.082 [-.214, .050]	.067
England - Ethnic	-.245**[-.421, -.070]	.089	.078 [-.170, .327]	.126	.073 [-.177, .322]	.126
Ethnicity (ref 'White')						
Mixed			-.116 [-.410, .177]	.148	-.138 [-.429, .154]	.147
Indian			-.002 [-.304, .300]	.153	-.011 [-.310, .289]	.151
Pakistani/Bangladeshi			-.316 [-.714, .083]	.201	-.342 [-.742, .057]	.202
Black/Black British			-.276*[-.545, -.008]	.136	-.304 [-.570, -.038]	.134
Other			-.027 [-.302, .247]	.139	-.053 [-.325, .219]	.137
Internalising problems					.007 [-.014, .028]	.011
Externalising problems					-.027**[-.046, -.007]	.010
Constant	.619 [.306, .933]	.158	-.586 [-2.47, 1.30]	.955	-.204 [-2.11, 1.70]	.965

*p<.05; **p<.01; ***p<.001

Table 4. Multiple linear regression model results for quality of decision-making (N=1,701)

	Model 1		Model 2		Model 3	
	Coef. [95% CI]	S.E.	Coef. [95% CI]	S.E.	Coef. [95% CI]	S.E.
Greenspace: bottom decile	.020 [-.000, .040]	.010	**.024*[.005, .043]**	**.010**	**.024*[.005 .043]**	**.010**
Access to garden	-.014 [-.049, .021]	.018	-.035*[-.071, -.000]	.018	-.035*[-.070, -.000]	.018
Overcrowding			-.006 [-.044, .031]	.019	-.005 [-.043, .032]	.019
Second-hand smoke			-.012 [-.037, .012]	.012	-.011 [-.035, .013]	.012
Poor home physical environment			-.003 [-.031, .024]	.014	-.002 [-.030, .025]	.014
Poor neighbourhood physical environment			-.012 [-.038, .013]	.013	-.011 [-.037, .014]	.013
Age			.010 [-.017, .038]	.014	.010 [-.018, .037]	.014
Pubertal signs	-.010 [-.033, .014]	.012	-.006 [-.030, .017]	.012	-.006 [-.030, .017]	.012
Female	.022*[.001, .043]	.011	.019 [-.001, .040]	.010	.019 [-.001, .039]	.010
Below the poverty line			-.013 [-.047, .021]	.017	-.011 [-.045, .023]	.017
Mother university-educated	.055***[.034, .077]	.011	.038***[.018, .058]	.010	.037***[.017, .057]	.010
IQ			.002***[.001, .002]	.000	.002***[.001, .002]	.000
Stratum (ref England-Advantaged)						
England - Disadvantaged	-.024*[-.045, -.003]	.011	-.012 [-.033, .010]	.011	-.012 [-.033, .010]	.011
England - Ethnic	-.028*[-.055, -.001]	.014	.018 [-.019, .056]	.019	.018 [-.020, .055]	.019
Ethnicity (ref 'White')						
Mixed			.000 [-.055, .056]	.028	-.001 [-.056, .055]	.028
Indian			.006 [-.033, .045]	.020	.005 [-.035, .044]	.020
Pakistani/Bangladeshi			-.033 [-.087, .021]	.027	-.034 [-.088, .021]	.028
Black/Black British			-.061**[-.103, -.019]	.021	-.062**[-.104, -.020]	.021
Other			-.019 [-.065, .028]	.023	.018 [-.063, .028]	.023
Internalising problems					-.001 [-.005, .003]	.002
Externalising problems					-.001 [.004, .003]	.002
Constant	.801***[.751, .851]	.025	.551**[.206, .896]	.174	.568**[.222, .914]	.175

*p<.05; **p<.01; ***p<.001

Table 5. Multiple linear regression model results for deliberation time (N=1,701)

	Model 1		Model 2		Model 3	
	Coef. [95% CI]	S.E.	Coef. [95% CI]	S.E.	Coef. [95% CI]	S.E.
Greenspace: bottom decile	-14.2 [-246, 218]	117	-11.9 [-262, 238]	126	-6.20 [-255, 242]	126
Access to garden	341***[166, 516]	88.3	310**[124, 497]	94.3	303**[114, 492]	95.5
Overcrowding			23.3 [-229, 276]	128	9.32 [-240, 259]	126
Second-hand smoke			141 [-50.6, 332]	96.8	127 [-64.1, 319]	96.8
Poor home physical environment			89.0 [-254, 431]	173	83.4 [-263, 430]	175
Poor neighbourhood physical environment			-40.5 [-241, 160]	101	-53.4 [-249, 142]	99.0
Age			-29.0 [-221, 163]	97.0	-27.6 [-220, 165]	97.3
Pubertal signs	153 [-14.5, 321]	84.6	124 [-45.4, 294]	85.7	122 [-47.2, 292]	85.7
Female	71.5 [-91.0, 234]	82.1	107 [-51.9, 266]	80.2	102 [-59.6, 263]	81.4
Below the poverty line			-272*[-504, -39.6]	117	-286*[-514, -57.6]	115
Mother university-educated	-274**[-428, -120]	77.6	-213**[-366, -59.1]	77.7	-214**[-371, -57.9]	79.1
IQ			-10.7***[-16.0,-5.35]	2.69	-10.5***[-16.0,-4.93]	2.80
Stratum (ref England-Advantaged)						
England - Disadvantaged	190*[12.6, 367]	89.7	181*[6.74, 356]	88.3	180*[4.65, 355]	88.6
England - Ethnic	-41.7 [-245, 161]	102.6	-104 [-375, 167]	137	-98.3 [-369, 172]	137
Ethnicity (ref 'White')						
Mixed			79.9 [-211, 371]	147	84.7 [-205, 374]	146
Indian			232 [-153, 617]	195	246 [-138, 630]	194
Pakistani/Bangladeshi			53.1 [-446, .552]	252	46.3 [-450, 543]	251
Black/Black British			74.5 [-219, 368]	148	83.1 [-215, 381]	151
Other			-263 [-498, -28.4]	119	-297 [-561, -33.5]	133
Internalising problems					26.8* [4.08, 49.4]	11.5
Externalising problems					-5.54 [-27.1, 16.1]	10.9
Constant	2777***[2518,3035]	131	4119***[1947,6290]	1098	4064***[1857,6271]	1116

*p<.05; **p<.01; ***p<.001

Table 6. Multiple linear regression model results for delay aversion (N=1,694)

	Model 1		Model 2		Model 3	
	Coef. [95% CI]	S.E.	Coef. [95% CI]	S.E.	Coef. [95% CI]	S.E.
Greenspace: bottom decile	-.013 [-.060, .033]	.023	-.012 [-.053, .028]	.021	-.013 [-.054, .028]	.021
Access to garden	.033 [-.042, .108]	.038	.014 [-.044, .073]	.030	.016 [-.043, .074]	.029
Overcrowding			-.004 [-.051, .044]	.024	-.003 [-.050, .045]	.024
Second-hand smoke			-.007 [-.042, .028]	.018	-.008 [-.043, .028]	.018
Poor home physical environment			.013 [-.025, .052]	.020	.012 [-.026, .051]	.019
Poor neighbourhood physical environment			.028 [-.012, .068]	.020	.027 [-.013, .067]	.020
Age			-.024 [-.066, .018]	.021	-.022 [-.064, .020]	.021
Pubertal signs	-.019 [-.056, .017]	.018	-.015 [-.051, .021]	.018	-.015 [-.051, .021]	.018
Female	-.022 [-.057,.012]	.017	-.023[-.056, .010]	.017	-.021 [-.054, .012]	.017
Below the poverty line			-.022 [-.074, .029]	.026	-.025 [-.076, .026]	.026
Mother university-educated	-.028 [-.062, .007]	.017	-.016 [-.053, .020]	.018	-.014 [-.050, .022]	.018
IQ			-.001 [-.002, .000]	.001	-.001 [-.002, .000]	.001
Stratum (ref England-Advantaged)						
England - Disadvantaged	.004 [-.035, .043]	.020	.003 [-.032, .038]	.018	.003 [-.032, .038]	.018
England - Ethnic	.076**[.024, .127]	.026	.061 [-.015, .137]	.038	.062 [-.015, .138]	.038
Ethnicity (ref 'White')						
Mixed			-.005 [-.077, .066]	.036	-.003 [-.075, .069]	.036
Indian			.012 [-.064, .088]	.039	.013 [-.063, .088]	.038
Pakistani/Bangladeshi			.047 [-.030, .124]	.039	.050 [-.026, .127]	.039
Black/Black British			-.116 [-.257, .025]	.071	-.112 [-.254, .030]	.072
Other			-.022 [-.095, .051]	.037	-.018 [-.090, .054]	.036
Internalising problems					-.001 [-.006, 003]	.002
Externalising problems					.003 [-.001, .008]	.002
Constant	.306***[.212, .399]	.047	.649*[.142, 1.16]	.256	.602*[.101, 1.10]	.253