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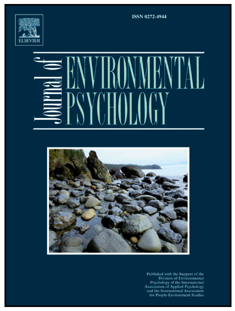

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Neighbourhood greenspace and children's trajectories of self-regulation: findings from the UK Millennium Cohort Study

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Neighbourhood greenspace and children's trajectories of self-regulation: findings from the UK Millennium Cohort Study

Abstract

Self-regulation in childhood is associated with multiple short- and long-term outcomes, including academic achievement, and physical and mental health. The literature to date suggests several individual and family factors that can influence children's development of self-regulation. However, the role of the wider context, particularly the wider physical context, remains less clear. In the present study, we investigated the association of neighbourhood greenspace quantity—a key physical environment factor—with children's self-regulation, using data from the UK Millennium Cohort Study (MCS). We modelled the trajectories of independence and emotional dysregulation of 13,774 children across the ages of three, five, and seven years, using growth curve modelling. Models accounted for neighbourhood air pollution and deprivation, urbanicity, home physical environment, family background, maternal education and depression, and child-level covariates. After full adjustment, some aspects of the home physical environment were associated with children's self-regulation: damp and condensation and secondhand smoke were associated with higher levels of emotional dysregulation. We did not find an association of neighbourhood greenspace quantity with either aspect of self-regulation in children. On the whole, child- and family-level covariates best explained children's differences in independence and emotional dysregulation.

Keywords: greenspace; self-regulation; independence; emotional dysregulation; neighbourhood; Millennium Cohort Study

1. Introduction

Self-regulation is the ability to control, direct, and plan cognitions, emotions, and behaviours. Successful self-regulation is fundamental for humans to be able to conform to personal standards and to social expectations, and to cope with adversity and stressors. As a complex, multidimensional construct that involves cognitive, affective, and motivational processes, it is an integral part of healthy child development (Eisenberg, Smith, Sadovsky, & Spinrad, 2004; Erdmann & Hertel, 2019; Heatherton & Baumeister, 1996; Hofmann, Schmeichel, & Baddeley, 2012; McClelland & Cameron, 2012; Rademacher & Koglin, 2019; Zimmerman, 2000). In the present study, we investigated the development of two distinct components of self-regulation—independence and emotional dysregulation—in early and middle childhood, using data from a large UK general population sample. In light of the established links between greenspace and positive child development (McCormick, 2017; Tillmann, Tobin, Avison, & Gilliland, 2018; Vanaken & Danckaerts, 2018; Weeland et al., 2019), we investigated the associations of greenspace in the residential neighbourhood with children's self-regulation capacity.

1.1. Development of Self-Regulation in Children

Self-regulation develops from infancy into adulthood, with striking developments during early and middle childhood when children become more independent from external regulations and progress from often reactive and co-regulated behaviour to self-regulated behaviour (Erdmann & Hertel, 2019; Montroy, Bowles, Skibbe, McClelland, & Morrison, 2016; Rothbart, Posner, & Kieras, 2008). A large body of research indicates that the early development of self-regulation is associated with numerous short- and long-term outcomes, including academic achievement (Coelho, Cadima, Pinto, & Guimarães, 2019; Graziano, Reavis, Keane, & Calkins, 2007; Matthews, Ponitz, & Morrison, 2009; McClelland et al., 2007; Morrison, Ponitz, & McClelland, 2010; Wickstrom & Pelletier, 2019), and physical and mental health (Brocki, Forslund, Frick, & Bohlin, 2017; Flouri, Midouhas, & Joshi, 2014a; Howard & Williams, 2018; Kostyrka-Allchorne, Wass, & Sonuga-Barke, 2019; Moffitt et al., 2011; Perry, Calkins, Dollar, Keane, & Shanahan, 2018; Schmitt et al., 2019). Therefore, understanding what factors support or impair children's development of self-regulation is crucial. The existing literature suggests several factors that have an impact on self-regulation in the general child population, including parenting (Baron & Malmberg, 2019; Bridgett et al., 2018; Perry, Dollar, Calkins, Keane, & Shanahan, 2018), family background, and parental education and mental health (Gunzenhauser & von Suchodoletz, 2015; Rhoades, Greenberg, Lanza, & Blair, 2011; Størksen, Ellingsen, Wanless, & McClelland, 2015; van Tetering, de Groot, & Jolles, 2018). Little is known, however, about the role of the physical context, and especially the wider physical environment, in children's development of self-regulation.

1.2. Greenspace and Self-Regulation in Children

A key component of the wider, physical environment is greenspace. The existing literature suggests positive associations of exposure to greenspace with healthy child development (McCormick, 2017; Tillmann et al., 2018; Vanaken & Danckaerts, 2018; Weeland et al., 2019). Studies used different measures of exposures and outcomes and explored links in both younger and older children. Taken together, the evidence suggests positive associations of children's exposure to greenspace with emotional, behavioural, and cognitive outcomes (Amoly et al., 2015; Balseviciene et al., 2014; Dadvand, Nieuwenhuijsen, et al., 2015; Faber Taylor & Kuo, 2009; Feda et al., 2015; Feng & Astell-Burt, 2017a; Flouri, Midouhas, & Joshi, 2014b; Flouri, Papachristou, & Midouhas, 2019; Li, Deal, Zhou, Slavenas, & Sullivan, 2018; Liao et al., 2019; Ward, Duncan, Jarden, & Stewart, 2016; Younan et al., 2016). Many of the outcomes measured—including emotional symptoms, stress, mood, problem behaviour, working memory, and attention—are likely related to (or affected by) children's self-regulation capacity. However, only few studies investigated the links between greenspace and different dimensions of children's self-regulation directly. One of the first was Taylor, Kuo, and Sullivan's (2002) investigation of the association of views of nature with children's self-discipline. The researchers asked mothers of 169 children to rate the amount of nature they could see from their home, and children completed tests on concentration, inhibition of initial impulses, and delay of gratification. The authors found an association of the amount of nature surrounding homes with children's self-discipline, but only in girls. The greener the view from the home, the better a girl's performance in concentration, inhibition of initial impulses, and delay of gratification tasks. In a recent study, Jenkin, Frampton, White, and Pahl (2018) used an experimental approach to investigate the effects of natural (as opposed to urban) environments on children's self-regulation capacity. They tested 79 eight- to 11-year-old children's selective attention, delay of gratification, and mood before and after showing them videos of either natural or urban environments for three minutes. Children in the urban condition were less able to delay gratification (i.e. chose more immediate rewards) after than before exposure. There were no significant differences between pre- and post-exposure delay of gratification for children in the natural condition. In a second study, in which the urban environment was made more cognitively demanding, the researchers did not find an effect of either urban or natural videos on delay of gratification. Finally, Bakir-Demir, Berument, and Sahin-Acar (2019) investigated the mediating role of nature connectedness in the relationships between neighbourhood greenery and children's self-regulation. The authors measured emotional, behavioural, and cognitive self-regulation as well as nature connectedness of 299 children from Turkey at the age of eight to 11 years. Greenery was measured using a composite score of the Normalized Difference Vegetation Index (NDVI) and mothers' and children's perceptions of the amount of nearby nature. The researchers found no direct association of greenery with self-regulation. They did, however, find indirect associations with emotional and cognitive (but not behavioural) self-regulation that were mediated by nature connectedness.

The three studies described above provide mixed evidence for the link between exposure to greenspace and children's self-regulation. The different measures of exposure to greenspace used in each may explain the inconsistent findings, at least partly. The three studies also measured different outcomes, investigating cognitive, behavioural, and emotional dimensions of self-regulation. The wide range of measures of exposures and outcomes makes comparing findings difficult, but also highlights the complexity of associations and the necessity for more research. The link is certainly plausible, however, not least because of a number of different putative pathways underlying it, discussed below.

1.3. Pathways Underlying Links Between Greenspace and Self-Regulation

Markevych et al. (2017) propose three general functions of greenspace, reducing harm, restoring capacities, and building capacities, that arguably also affect children's self-regulation capacity (Weeland et al., 2019). First, exposure to greenspace can reduce harm by reducing exposure to environmental stressors, such as air pollution and noise. Air pollution and noise have been associated with many adverse outcomes in children (Brockmeyer & D'Angiulli, 2016; Haines & Stansfeld, 2003; Klatte, Bergström, & Lachmann, 2013; Suades-González, Gascon, Guxens, & Sunyer, 2015; Zare Sakhvidi, Zare Sakhvidi, Mehrparvar, & Dzhambov, 2018). Air pollution is linked to diseases of the central nervous system, including neurodevelopmental disorders (Block & Calderón-Garcidueñas, 2009; Genc, Zadeoglulari, Fuss, & Genc, 2012), while noise pollution is associated with distraction, annoyance, and sleep disturbance (Grelat et al., 2016; Haines, Stansfeld, Job, Berglund, & Head, 2001; Lim et al., 2018; Pirrera, De Valck, & Cluydts, 2010; Stansfeld et al., 2005, 2009). Children exposed to high levels of air pollution and noise need resources to cope with these stressors, which leaves them with reduced capacity to regulate emotions and cognitions. Surrounding greenspace can protect children from environmental stressors, for example, by cleaning the air or by serving as a sound barrier (Beckett, Freer-Smith, & Taylor, 2000; Dadvand et al., 2015; Kumar et al., 2019; Li, Van Renterghem, Kang, Verheyen, & Botteldooren, 2020; Nowak, Crane, & Stevens, 2006; Vieira et al., 2018). Second, in addition to protecting children's self-regulation capacity, exposure to greenspace can restore already exhausted coping repertoires. Two well-established theories describe the restorative functions of greenspace: the attention restoration theory (ART; Kaplan & Kaplan, 1989; Ohly et al., 2016) and the stress recovery theory (SRT; Berto, 2014; Ulrich, 1981; Ulrich et al., 1991). The ART proposes positive effects of natural environments on attention by encouraging undirected (effortless) attention to features of the natural environment and thereby restoring directed attention resources (Kaplan & Berman, 2010;

Ohly et al., 2016; Stevenson, Schilhab, & Bentsen, 2018). The SRT proposes that natural environments support the recovery from physiological stress and from negative affect (Berto, 2014). Greenspace in the residential neighbourhood, therefore, may allow children to replenish exhausted cognitive and emotional resources, which prepares them to cope with new stressors and to manage new demanding tasks. Finally, greenspace not only has a restorative function, but also offers opportunity for physical activity which, in turn, is linked to positive outcomes in children, such as physical and mental health, and self-regulation (Ahn & Fedewa, 2011; Becker, McClelland, Loprinzi, & Trost, 2014; Biddle & Asare, 2011; Hills, Andersen, & Byrne, 2011; Kybartas, Oody, Fairbrother, Durham, & Coe, 2019; Sibley & Etnier, 2003; Tandon et al., 2016).

1.4. The Present Study

The literature to date suggests positive associations of exposure to greenspace with several domains of child development, including physical and mental health, behaviour, and cognition. The evidence also suggests links between exposure to greenspace and children's self-regulation, but findings are mixed and obtained from small studies. In the present study, we added to and improved on this evidence by investigating the longitudinal associations of greenspace in the neighbourhood with the development of self-regulation across early and middle childhood in a large general-population cohort. In particular, we examined the associations of neighbourhood greenspace quantity with two domains of children's self-regulation, independence and emotional dysregulation, while adjusting for neighbourhood air pollution and deprivation, the home physical environment, family background, maternal education and depression, and key child-level covariates.

2. Methods

2.1. Study Sample

We used data from the Millennium Cohort Study (MCS; https://cls.ucl.ac.uk/cls-studies/millennium-cohort-study/; University of London, Institute of Education, Centre for Longitudinal Studies, 2017a-f). The MCS is a UK longitudinal study that follows families with children born between 1 September 2000 and 31 August 2001 (England and Wales) or between 24 November 2000 and 11 January 2002 (Scotland and Northern Ireland). The MCS sample is disproportionately stratified to ensure adequate numbers for the four UK countries and for electoral wards with disadvantaged or ethnic minority populations (for details, see Plewis, 2007). To this day, children have been followed from around nine months (at Sweep 1) to around 17 years (at Sweep 7), with a total of 19,243 productive families. We used data from sweeps two, three, and four, when self-regulation was measured in the MCS, at child ages around three, five, and seven years, respectively. In the case of multiple births, we used data on first-born twins and triplets only. Self-regulation was measured with two scales: independence and emotional dysregulation. Our analytic sample included children who had at least one record of independence or emotional dysregulation across the three sweeps and who were present at Sweep 4 (n = 13,774). Our non-analytic sample was the remaining MCS children (n = 5,469).

2.2. Measures

Self-regulation. Children's self-regulation was measured with two scales, independence and emotional dysregulation, at ages three, five, and seven years, with items from the Child Social Behaviour Questionnaire (CSBQ). The CSBQ was based on the Adaptive Social Behavior Inventory (Hogan, Scott, & Bauer, 1992) and was developed and validated as part of the Effective Provision of Pre-School Education project for England (Sammons et al., 2004) and Northern Ireland (Melhuish et al., 2004). It has good internal consistency, established with samples of five-year-old children. In the MCS, the number of CSBQ items was restricted to five for each scale. Items were completed by the parents, usually the mothers, on a three-point scale ranging from 1 ('not true') to 3 ('certainly true'). The five items of the independence scale were 'likes to work things out for self', 'does not need much help with tasks', 'chooses activities on their own', 'persists in the face of difficult tasks', and 'moves to new activity after finishing task'. The items of the emotional dysregulation scale were 'shows mood swings', 'gets over excited', 'easily frustrated', 'gets over being upset quickly' (reversed), and 'acts impulsively'. Cronbach's alphas in our sample were .58, .62, and .65 for independence, and .61, .66, and .68 for emotional dysregulation (for sweeps two, three, and four, respectively).

Neighbourhood environment. Neighbourhood greenspace was measured—also at sweeps two, three, and four—with data from the Multiple Environmental Deprivation Index (MEDIx; https://cresh.org.uk/cresh-themes/environmental-deprivation/medix-and-medclass/). The greenspace measure in the MEDIx was built on combined data from the Coordination of Information on the Environment (CORINE; EEA, 2000) and the 2001 Generalised Land Use Database (GLUD; Office of the Deputy Prime Minister, 2005). CORINE is a land cover dataset from 2000 for the UK that was derived from remotely sensed satellite imagery. It is only sensitive to larger green spaces and does not capture green spaces smaller than about 1 ha. GLUD classifies land use across England at high geographical resolution into nine categories: greenspace, domestic gardens, fresh water, domestic buildings, non-domestic buildings, roads, paths, railways, and other. Richardson and Mitchell (2010) combined data of CORINE and GLUD to create a neighbourhood greenspace measure of the percentage of greenspace in every UK ward (a geographic unit based on electoral boundaries), including all vegetated areas larger than 5 m^2 (except for domestic gardens) regardless of their accessibility (i.e. public or private). In the MCS, greenspace data were converted into deciles ranging from 1 ('most deprived' or 'least green') to 10 ('least deprived' or 'most green').

Neighbourhood air pollution was measured using estimates of air pollution concentrations, also at sweeps two, three, and four, from the MEDIx. The MEDIx includes estimates of particulate matter smaller than 10 micrometres (PM_{10}), nitrogen dioxide (NO_2), sulphur dioxide (SO_2), and carbon monoxide (CO) concentrations at ward-level. In the present study, we used PM_{10} as an indicator of neighbourhood air pollution. PM_{10} was highly correlated with NO_2, CO, and SO_2 (with correlation coefficients of .88, .82, and .54) and is an appropriate indicator of neighbourhood air pollution. PM_{10} concentrations were measured as annual mean concentrations in micrograms per cubic meter air (μg/m^3) for each UK ward. The PM_{10} data were taken from 1-km grids, modelled from National Atmospheric Emissions Inventory data. Mean concentrations covered the years 1999 to 2003 and were population weighted (using output area units). In the MCS, air pollution data were converted into deciles ranging from 1 (‘least polluted’) to 10 (‘most polluted’).

Our analysis examined two additional neighbourhood variables: neighbourhood deprivation and urbanicity. Neighbourhood deprivation was measured with the nine MCS strata at study entry (Sweep 1): England-Advantaged, England-Disadvantaged, England-Ethnic Minority, Wales-Advantaged, Wales-Disadvantaged, Scotland-Advantaged, Scotland-Disadvantaged, Northern Ireland-Advantaged, and Northern Ireland-Disadvantaged (see Plewis, 2007). Urbanicity was measured with a binary variable (rural/urban) at each sweep, based on UK country-specific definitions of rural and urban areas (i.e. ONS Rural Urban Classifications [2005] for England and Wales, Scottish Executive Urban Rural Classifications [2005-2006], and NISRA Urban Rural Classifications [2005] for Northern Ireland).

Home physical environment. To control for the immediate physical environment, we adjusted for the following home physical environment factors that were all time-varying for the three sweeps: access to a private garden (no/yes), presence of open fires (no/yes), level of damp/condensation (ranging from 1 ‘no damp’ to 4 ‘great problem’), and presence of secondhand smoke (whether anyone smoked in the same room as the child; no/yes). Access to a garden was an indicator of proximal greenspace, whereas open fires, damp/condensation, and secondhand smoke were indicators of indoor air quality.

Family background. Family-level variables were maternal education (University education at sweep four; no/yes), and the following time-varying characteristics: poverty (family above or below the poverty line), maternal psychological distress (measured with the six-item Kessler Psychological Distress scale, ranging from 0 to 24, with higher scores indicating higher levels of distress), family structure (whether both natural [i.e. biological] parents resided in the home; no/yes), residential mobility (whether the family had moved since the last sweep; no/yes), and home ownership (whether the family owned its home; no/yes).

Child-level covariates. Child-level covariates were sex (male/female), ethnicity (White, Mixed, Indian, Pakistani and Bangladeshi, Black or Black British, or Other), and general cognitive ability (IQ). The most comprehensive assessment of IQ in the MCS (which we used here) was at age five by three subscales of the British Ability Scales: naming vocabulary, pattern construction (measuring spatial problem-solving), and picture similarities (measuring non-verbal reasoning). The score derived from a principal components analysis of the three subscales was transformed into a standardised score (M = 100, SD = 15).

2.3. Statistical Analysis

To investigate children's trajectories of independence and emotional dysregulation from age three to seven years, we fitted growth curve models (GCMs) for both outcomes. The GCMs had three levels: occasions (level one) were nested in children (level two) who were clustered in wards (level three). Including a third level for the clustering in electoral wards was necessary to adjust for dependency of observations. In our sample, children were clustered in 398 UK wards. Children's age was measured in months and was grand mean centred, so that the intercept was set at around 64 months (or 5.33 years). In addition to a linear age term, we included a quadratic age term in the fixed part of the models to account for the curved shapes of children's trajectories of independence and emotional dysregulation. Models were fitted with random intercepts for levels two (children) and three (wards), and with a random slope for age. The latter was added to allow for children to have individual slopes (i.e. slopes that vary from the average slope), as we expected that children would differ in their development of self-regulation over time. We fitted two models for each outcome: a minimally adjusted model and the fully adjusted model. The minimally adjusted model included the linear age term, the quadratic age term, neighbourhood greenspace and deprivation, and urbanicity (Tables 3 and 4). The fully adjusted model added neighbourhood air pollution, factors of the home physical environment, maternal education and depression, indicators of family background, and child-level covariates (Tables 5 and 6). The Akaike Information Criterion (AIC) was used to compare the fully adjusted models to the minimally adjusted models. The fully adjusted models showed better fit than the minimally adjusted models, indicated by smaller AIC values. The AIC values of the minimally adjusted models were 24237 and 38731 for independence and emotional dysregulation; the AIC values of the fully adjusted models were 19376 and 31976, respectively. In all models, the MCS stratum was controlled for to account for the disproportionately stratified design of the study. Attrition and non-response were taken into account by using study-specific weights, provided by the MCS, to ensure that our sample remained representative of the general population despite selective attrition (see below). All analyses were run in Stata 15.

3. Results

3.1. Bias Analysis

We tested whether children in the analytic sample (n = 13,774) were different from children in the non-analytic sample (n = 5,469) on the study variables (see Table 1). On average, children in the analytic sample lived in greener and less polluted areas, were more likely to have access to a garden, were less likely to be poor, had a higher IQ, and were more likely to be female. For a comprehensive summary of the differences between the two samples, see Table 1.

3.2. Descriptive Statistics

On average, independence and emotional dysregulation scores increased and decreased, respectively, from age three to five and then nearly plateaued from age five to seven (see Table 1). The average change over time was larger for emotional dysregulation than for independence. Children lived in comparatively less green and more polluted areas across the distribution of wards in the UK (on the fifth and seventh deciles, respectively). Using unweighted estimates, approximately 77 per cent of the children lived in urban areas, over 90 per cent had access to a garden, and about 10 per cent had homes with open fires. Correlation coefficients suggest that neighbourhood greenspace was positively associated with independence and negatively associated with emotional dysregulation (see Table 2). Further, greenspace was negatively associated with neighbourhood air pollution, as expected. Greenspace was also associated with the home physical environment, particularly with the presence of open fires and access to a private garden: children who lived in greener areas were more likely to live in homes with open fires and to have access to a garden. The home physical environment was also linked to self-regulation, with more consistent patterns for emotional dysregulation: open fires in the home and access to a private garden were negatively associated, whereas higher levels of damp/condensation and the presence of secondhand smoke were positively associated with emotional dysregulation. For all correlations between outcomes, wider physical environment, and home physical environment, see Table 2.

3.3. Model Results

The minimally adjusted models are summarised in Tables 3 and 4. On average, children's independence and emotional dysregulation increased and decreased, respectively, but non-linearly over time. The random part of the model indicates that children varied in their levels of self-regulation at age five and in the development of self-regulation over time. Furthermore, the positive covariances of intercepts and slopes suggest that higher intercepts were associated with steeper slopes. As expected, emotional dysregulation (particularly) varied by ward as well. Our main factor of interest, neighbourhood greenspace, predicted emotional dysregulation but not independence. On average, higher levels of greenspace were associated with lower levels of emotional dysregulation.

The fully adjusted models are summarised in Tables 5 and 6. The average linear slope appeared steeper for emotional dysregulation than for independence. Again, quadratic age terms suggest that changes over time were not linear. As in the minimally adjusted model, neighbourhood greenspace did not predict children's levels of independence (see Table 5). Independence was, however, predicted by family- and child-level covariates. On average, children's independence was higher if they had not moved since the previous sweep, and if their mothers had higher levels of education and lower levels of psychological distress. Also, independence was higher in girls and in children with a higher IQ. In addition, we found two effects that were unexpected: children of families who owned their home and children who had access to a garden had lower levels of independence. A sensitivity analysis (not shown) revealed that these relationships were modified by urbanicity. In separate GCMs for urban and rural cases, we found significant negative coefficients only for the urban children. Finally, the random part of the model indicates that children varied in their independence at age five and in their development of independence over time. The positive covariance of intercept and slope suggests that higher independence at age five was associated with steeper slopes. The ward-level variance estimate remained unchanged from the previous model.

Neighbourhood greenspace did not remain a significant predictor of children's emotional dysregulation after full adjustment (see Table 6). Two of the home physical environment factors, however, yielded positive effects: on average, higher levels of damp/condensation and the presence of secondhand smoke in the home were associated with higher levels of emotional dysregulation. In addition, children's emotional dysregulation was lower if they lived with both their natural parents, if their mothers had higher education and lower psychological distress, and if their families had not moved since the previous sweep and owned their home. Finally, on average, emotional dysregulation decreased with increasing IQ, and girls had lower emotional dysregulation than boys. The random part of the model indicates that, as in the minimally adjusted model, children varied in their levels of emotional dysregulation at age five and in the development of emotional dysregulation over time. Furthermore, the covariance of intercept and slope was still positive. However, the amount of variance explained by ward was significantly reduced, suggesting that the area effect found in the minimally adjusted model was largely due to the child and family characteristics we subsequently controlled for.

3.4. Sensitivity Analysis

We ran two sensitivity analyses to further explore our findings (also provided as supplementary material). First, in view of the strong association between greenspace and air pollution and the robust association of the latter with outcomes closely linked to self-regulation, we explored the role of air pollution in more detail. We found that greenspace was a predictor of emotional dysregulation (but not independence) when air pollution was removed from the fully adjusted model (see Table S1). This suggests a confounding or mediating role of air pollution in the association of greenspace with emotional dysregulation. However, in a fully adjusted model with greenspace removed, air pollution did not predict emotional dysregulation (see Table S2). This suggests that air pollution, either adjusted or unadjusted for greenspace, does not have a direct effect on children's emotional dysregulation after controls for child and family characteristics. Second, we explored the role of greenspace in the slopes of the trajectories of independence and emotional dysregulation. The effect of greenspace was not significant on either slope, which suggests that age does not moderate the effect of greenspace on either independence or emotional dysregulation (see Tables S3 and S4). In view of the narrow range of years (i.e. three to seven) in our sample, this finding was expected.

Table 1
Bias analysis of study variables between analytic and non-analytic samples

	Analytic sample (n = 13,774)		Non-analytic sample (n = 5,469)		Test
Continuous variables					
	n	M (SD)	n	M (SD)	F
Independence Sweep 2	12,107	2.46 (0.35)	2,727	2.44 (0.36)	7.80**
Independence Sweep 3	12,874	2.53 (0.35)	1,899	2.51 (0.37)	4.59*
Independence Sweep 4	13,488	2.50 (0.37)	-	-	-
Emotional dysregulation Sweep 2	12,109	1.88 (0.45)	2,727	1.91 (0.46)	10.50**
Emotional dysregulation Sweep 3	12,874	1.72 (0.46)	1,899	1.78 (0.47)	22.46**
Emotional dysregulation Sweep 4	13,489	1.73 (0.47)	-	-	-
Greenspace Sweep 2	12,603	4.48 (2.70)	2,986	4.04 (2.61)	66.76**
Greenspace Sweep 3	13,158	4.56 (2.72)	2,087	4.04 (2.63)	65.12**
Greenspace Sweep 4	13,772	4.58 (2.72)	83	1.89 (1.37)	80.72**
Air pollution (PM_{10}) Sweep 2	12,603	6.25 (3.04)	2,986	6.69 (3.08)	50.47**
Air pollution (PM_{10}) Sweep 3	13,158	6.18 (3.04)	2,087	6.69 (3.11)	49.76**
Air pollution (PM_{10}) Sweep 4	13,772	6.18 (3.04)	83	9.16 (1.63)	79.52**
Damp/condensation Sweep 2	12,520	1.23 (0.62)	2,927	1.27 (0.69)	13.18**
Damp/condensation Sweep 3	13,111	1.22 (0.62)	2,043	1.28 (0.72)	17.50**
Damp/condensation Sweep 4	13,693	1.25 (0.66)	69	1.57 (0.93)	15.75**
Maternal psychological distress Sweep 2	11,166	3.23 (3.69)	2,424	3.50 (4.09)	9.71**
Maternal psychological distress Sweep 3	12,511	3.17 (3.82)	1,821	3.42 (4.18)	6.84**
Maternal psychological distress Sweep 4	13,163	3.15 (3.87)	-	-	-
Child's age (months) Sweep 2	12,598	38.14 (2.42)	2,984	38.75 (2.96)	144.61**
Child's age (months) Sweep 3	13,159	63.49 (2.99)	2,086	63.55 (3.16)	0.71
Child's age (months) Sweep 4	13,774	88.00 (3.00)	83	88.27 (2.88)	0.66
Child's IQ	12,902	100.64 (14.83)	1,961	95.78 (15.44)	180.54**
Categorical variables					
	n	%	n	%	Chi^2
England-Advantaged	3,785	27.5	1,043	19.1	147.25**
England-Disadvantaged	3,366	24.4	1,439	26.3	7.34**
England-Ethnic Minority	1,611	11.7	980	17.9	130.12**
Wales-Advantaged	621	4.5	211	3.9	4.00*
Wales-Disadvantaged	1,393	10.1	535	9.8	0.48
Scotland-Advantaged	828	6	317	5.8	0.32
Scotland-Disadvantaged	799	5.8	392	7.2	12.60**
Northern Ireland-Advantaged	534	3.9	189	3.5	1.92
Northern Ireland-Disadvantaged	837	6.1	363	6.6	2.11
Urban Sweep 2	9,800	77.8	2,427	81.3	17.68**
Urban Sweep 3	10,098	76.8	1,716	82.2	30.88**
Urban Sweep 4	10,546	76.6	81	97.6	20.39**
Open fires Sweep 2	1,256	10	227	7.8	14.17**
Open fires Sweep 3	1,031	7.9	102	5	21.03**
Open fires Sweep 4	1,195	8.7	0	0	6.50*
Secondhand smoke Sweep 2	2,162	17.3	632	21.6	29.93**
Secondhand smoke Sweep 3	1,859	14.2	346	16.9	10.54**
Secondhand smoke Sweep 4	1,775	13	4	5.6	3.37
Access to garden Sweep 2	11,723	93.2	2,636	88.8	64.58**
Access to garden Sweep 3	12,274	93.5	1,837	88.5	67.85**
Access to garden Sweep 4	12,848	93.5	61	77.2	33.53**
Below poverty line Sweep 2	3,863	31	1,223	41.9	128.83**
Below poverty line Sweep 3	4,165	31.8	976	47.9	202.96**
Below poverty line Sweep 4	4,101	29.8	61	75.3	79.25**
University education (mother)	4,117	29.9	936	17.3	320.11**
Two natural parents Sweep 2	10,206	81	2,142	71.7	125.51**
Two natural parents Sweep 3	10,075	76.6	1,383	66.3	102.40**
Two natural parents Sweep 4	9,945	72.2	68	81.9	3.89*
Changed address Sweep 2	3,527	29.6	901	33.3	14.67**
Changed address Sweep 3	2,052	15.6	425	20.4	30.09**
Changed address Sweep 4	1,356	9.9	6	7.2	0.64
Own home Sweep 2	8,318	66.4	1,542	52.7	194.44**
Own home Sweep 3	8,713	66.5	1,012	49.6	219.12**
Own home Sweep 4	9,053	66.1	32	47.1	10.93**
Ethnicity White	11,584	84.1	4,159	76.4	170.64**
Ethnicity Mixed	382	2.8	212	3.9	15.92**
Ethnicity Indian	336	2.4	161	3	3.96*
Ethnicity Pakistani and Bangladeshi	843	6.1	507	9.3	59.55**
Ethnicity Black or Black British	451	3.3	279	5.1	35.81**
Ethnicity Other ethnic group	177	1.3	127	2.3	27.08**
Female	6,794	49.3	2,555	46.7	10.65**

Note. Ns, means, and %s are all unweighted. *p < .05, **p < .01.

Table 2

Correlations between neighbourhood physical environment, home physical environment, and outcomes (n = 13,774)

	IN 2	IN 3	IN 4	ED 2	ED 3	ED 4	GS 2	GS 3	GS 4	AP 2	AP 3	AP 4
IN 2												
IN 3	.38											
IN 4	.32	.50										
ED 2	-.10	-.18	-.19									
ED 3	-.13	-.26	-.27	.53								
ED 4	-.13	-.24	-.32	.48	.65							
GS 2	.02	.03	.04	-.06	-.08	-.08						
GS 3	.02	.04	.04	-.07	-.09	-.09	.92					
GS 4	.03	.05	.04	-.07	-.09	-.09	.87	.94				
AP 2	-.03	-.04	-.05	.05	.07	.08	-.61	-.58	-.56			
AP 3	-.03	-.04	-.05	.06	.07	.08	-.59	-.60	-.58	.97		
AP 4	-.03	-.05	-.05	.06	.07	.08	-.58	-.59	-.60	.95	.98	
OF 2	.01^{n}	.02^{n}	.02	-.07	-.07	-.07	.28	.27	.27	-.20	-.20	-.20
OF 3	.02	.02	.04	-.06	-.07	-.07	.22	.24	.23	-.15	-.16	-.16
OF 4	.02	.02	.02	-.07	-.08	-.07	.23	.24	.25	-.16	-.17	-.18
DC 2	-.02	-.05	-.04	.09	.10	.10	-.06	-.05	-.06	.05	.05	.06
DC 3	-.03	-.05	-.04	.06	.09	.08	-.04	-.05	-.05	.03	.04	.04
DC 4	-.01^{n}	-.04	-.02	.07	.09	.10	-.04	-.04	-.05	.03	.04	.04
SM 2	-.03	-.04	-.05	.17	.16	.14	-.01^{n}	-.02	-.02	-.03	-.02	-.02
SM 3	-.01^{n}	-.04	-.05	.13	.15	.13	-.02^{n}	-.02	-.02	-.02	-.02	-.02
SM 4	-.02	-.04	-.04	.14	.14	.15	-.01^{n}	-.02^{n}	-.02	-.02	-.02	-.02
AG 2	.01^{n}	.02^{n}	.02	-.04	-.06	-.06	.17	.16	.16	-.14	-.13	-.14
AG 3	.01^{n}	.02^{n}	.02	-.03	-.06	-.06	.17	.17	.17	-.13	-.14	-.14
AG 4	.01^{n}	.02^{n}	.02^{n}	-.03	-.05	-.05	.16	.17	.17	-.13	-.14	-.14

Table 2 (continued)

	OF 2	OF 3	OF 4	DC 2	DC 3	DC 4	SM 2	SM 3	SM 4	AG 2	AG 3
OF 2											
OF 3	.42										
OF 4	.38	.51									
DC 2	-.01^{n}	-.02	-.03								
DC 3	-.01^{n}	-.00^{n}	-.01^{n}	.33							
DC 4	-.00^{n}	.01^{n}	.01^{n}	.28	.39						
SM 2	-.03	-.05	-.06	.10	.09	.11					
SM 3	-.02	-.02^{n}	-.04	.08	.09	.10	.49				
SM 4	-.04	-.02^{n}	-.04	.07	.08	.10	.45	.51			
AG 2	.08	.05	.06	-.13	-.09	-.11	-.06	-.05	-.04		
AG 3	.07	.06	.06	-.11	-.12	-.11	-.06	-.04	-.03	.83	
AG 4	.06	.06	.06	-.10	-.11	-.12	-.05	-.04	-.04	.79	.92

Note. IN = independence, ED = emotional dysregulation, GS = greenspace, AP = air pollution, OF = open fires, DC = damp/condensation, SM = secondhand smoke, AG = access to garden. The numbers 2, 3, and 4 indicate the time points (i.e. sweeps). For parsimony, binary variables are included in this table. Correlations are significant at $p < .05$ (except correlations that are highlighted with ^{n}).

Table 3
Minimally adjusted three-level growth curve model predicting independence (n = 13,771)

Fixed effects	**Coefficient (SE)**	**95% CI**
Age	0.001 (0.000)**	[0.001, 0.001]
Age^2	-0.000 (0.000)**	[-0.000, -0.000]
Greenspace	0.002 (0.001)	[-0.001, 0.005]
Stratum		
(reference England-Advantaged)		
England-Disadvantaged	-0.013 (0.008)	[-0.029, 0.002]
England-Ethnic Minority	-0.053 (0.013)**	[-0.078, -0.027]
Wales-Advantaged	0.011 (0.015)	[-0.017, 0.040]
Wales-Disadvantaged	-0.006 (0.010)	[-0.025, 0.014]
Scotland-Advantaged	0.038 (0.012)**	[0.015, 0.062]
Scotland-Disadvantaged	-0.005 (0.013)	[-0.030, 0.020]
Northern Ireland-Advantaged	0.056 (0.015)**	[0.027, 0.086]
Northern Ireland-Disadvantaged	-0.004 (0.012)	[-0.028, 0.021]
Urban	0.007 (0.009)	[-0.010, 0.024]
Constant	2.506 (0.013)**	[2.479, 2.532]
Random effects	**Estimate (SE)**	**95% CI**
Level 3 (ward-level)		
Intercept variance	0.001 (0.000)	[0.001, 0.001]
Level 2 (child-level)		
Intercept variance	0.055 (0.001)	[0.052, 0.058]
Slope (age) variance	0.000 (0.000)	[0.000, 0.000]
Intercept-slope covariance	0.000 (0.000)	[0.000, 0.000]

Note. Age was measured in months and was grand mean centred at 64 months. For fixed effects: *p < .05, **p < .01.

Table 4
Minimally adjusted three-level growth curve model predicting emotional dysregulation (n = 13,772)

Fixed effects	**Coefficient (SE)**	**95% CI**
Age	-0.003 (0.000)**	[-0.003, -0.003]
Age^2	0.000 (0.000)**	[0.000, 0.000]
Greenspace	-0.007 (0.002)**	[-0.012, -0.003]
Stratum		
(reference England-Advantaged)		
England-Disadvantaged	0.136 (0.014)**	[0.108, 0.164]
England-Ethnic Minority	0.101 (0.023)**	[0.056, 0.147]
Wales-Advantaged	-0.023 (0.019)	[-0.061, 0.015]
Wales-Disadvantaged	0.116 (0.018)**	[0.082, 0.151]
Scotland-Advantaged	-0.017 (0.022)	[-0.060, 0.025]
Scotland-Disadvantaged	0.114 (0.024)**	[0.066, 0.161]
Northern Ireland-Advantaged	-0.067 (0.022)**	[-0.111, -0.023]
Northern Ireland-Disadvantaged	0.066 (0.017)**	[0.033, 0.099]
Urban	-0.001 (0.012)	[-0.024, 0.021]
Constant	1.724 (0.020)**	[1.684, 1.765]
Random effects	**Estimate (SE)**	**95% CI**
Level 3 (ward-level)		
Intercept variance	0.005 (0.001)	[0.003, 0.006]
Level 2 (child-level)		
Intercept variance	0.117 (0.002)	[0.113, 0.122]
Slope (age) variance	0.000 (0.000)	[0.000, 0.000]
Intercept-slope covariance	0.000 (0.000)	[0.000, 0.000]

Note. Age was measured in months and was grand mean centred at 64 months. For fixed effects: *p < .05, **p < .01.

Table 5
Fully adjusted three-level growth curve model predicting independence (n = 12,670)

Fixed effects	**Coefficient (SE)**	**95% CI**
Age	0.001 (0.000)**	[0.000, 0.001]
Age^2	-0.000 (0.000)**	[-0.000, -0.000]
Greenspace	0.000 (0.001)	[-0.003, 0.003]
Air pollution (PM_{10})	0.000 (0.002)	[-0.003, 0.003]
Stratum		
(reference England-Advantaged)		
England-Disadvantaged	0.011 (0.008)	[-0.004, 0.027]
England-Ethnic Minority	-0.000 (0.015)	[-0.029, 0.029]
Wales-Advantaged	0.016 (0.014)	[-0.012, 0.043]
Wales-Disadvantaged	0.020 (0.010)*	[0.001, 0.040]
Scotland-Advantaged	0.038 (0.015)*	[0.009, 0.067]
Scotland-Disadvantaged	0.021 (0.013)	[-0.004, 0.047]
Northern Ireland-Advantaged	0.049 (0.012)**	[0.024, 0.073]
Northern Ireland-Disadvantaged	0.002 (0.011)	[-0.020, 0.025]
Urban	0.008 (0.008)	[-0.008, 0.025]
Open fires	-0.001 (0.007)	[-0.015, 0.013]
Damp/condensation	-0.006 (0.003)	[-0.013, 0.001]
Secondhand smoke	-0.004 (0.007)	[-0.018, 0.009]
Access to garden	-0.026 (0.012)*	[-0.050, -0.001]
Below poverty line	0.001 (0.006)	[-0.011, 0.013]
University education (mother)	0.021 (0.006)**	[0.009, 0.033]
Two natural parents	-0.003 (0.007)	[-0.016, 0.011]
Changed address	-0.012 (0.005)*	[-0.022, -0.002]
Maternal psychological distress	-0.008 (0.001)**	[-0.009, -0.007]
Own home	-0.016 (0.006)*	[-0.028, -0.003]
Female	0.075 (0.006)**	[0.064, 0.086]
Ethnicity		
(reference White)		
Mixed	-0.023 (0.019)	[-0.060, 0.014]
Indian	-0.013 (0.021)	[-0.053, 0.028]
Pakistani and Bangladeshi	-0.052 (0.017)**	[-0.085, -0.018]
Black or Black British	-0.003 (0.021)	[-0.043, 0.038]
Other ethnic group	-0.026 (0.032)	[-0.088, 0.036]
IQ	0.004 (0.000)**	[0.004, 0.004]
Constant	2.134 (0.031)**	[2.074, 2.195]

Random effects	**Estimate (SE)**	**95% CI**
Level 3 (ward-level)		
Intercept variance	0.001 (0.000)	[0.000, 0.001]
Level 2 (child-level)		
Intercept variance	0.046 (0.001)	[0.044, 0.049]
Slope (age) variance	0.000 (0.000)	[0.000, 0.000]
Intercept-slope covariance	0.000 (0.000)	[0.000, 0.000]

Note. Age was measured in months and was grand mean centred at 64 months. For fixed effects: *p < .05, **p < .01.

Table 6
Fully adjusted three-level growth curve model predicting emotional dysregulation (n = 12,670)

Fixed effects	**Coefficient (SE)**	**95% CI**
Age	-0.003 (0.000)**	[-0.003, -0.003]
Age^2	0.000 (0.000)**	[0.000, 0.000]
Greenspace	-0.004 (0.002)	[-0.008, 0.000]
Air pollution (PM_{10})	0.001 (0.002)	[-0.002, 0.005]
Stratum (reference England-Advantaged)		
England-Disadvantaged	0.057 (0.010)**	[0.037, 0.078]
England-Ethnic Minority	0.039 (0.018)*	[0.003, 0.075]
Wales-Advantaged	-0.036 (0.016)*	[-0.066, -0.005]
Wales-Disadvantaged	0.037 (0.014)**	[0.010, 0.064]
Scotland-Advantaged	-0.012 (0.019)	[-0.050, 0.025]
Scotland-Disadvantaged	0.028 (0.020)	[-0.011, 0.066]
Northern Ireland-Advantaged	-0.039 (0.017)*	[-0.072, -0.007]
Northern Ireland-Disadvantaged	0.009 (0.016)	[-0.022, 0.040]
Urban	-0.006 (0.012)	[-0.029, 0.017]
Open fires	-0.007 (0.008)	[-0.023, 0.009]
Damp/condensation	0.021 (0.004)**	[0.012, 0.030]
Secondhand smoke	0.057 (0.008)**	[0.041, 0.072]
Access to garden	-0.008 (0.015)	[-0.038, 0.021]
Below poverty line	0.017 (0.008)*	[0.002, 0.032]
University education (mother)	-0.087 (0.008)**	[-0.103, -0.071]
Two natural parents	-0.035 (0.009)**	[-0.052, -0.018]
Changed address	0.017 (0.006)**	[0.004, 0.030]
Maternal psychological distress	0.019 (0.001)**	[0.018, 0.021]
Own home	-0.069 (0.009)**	[-0.086, -0.052]
Female	-0.062 (0.007)**	[-0.075, -0.050]
Ethnicity (reference White)		
Mixed	-0.017 (0.022)	[-0.059, 0.026]
Indian	0.007 (0.032)	[-0.056, 0.070]
Pakistani and Bangladeshi	0.012 (0.019)	[-0.026, 0.051]
Black or Black British	-0.106 (0.028)**	[-0.161, -0.052]
Other ethnic group	-0.058 (0.035)	[-0.127, 0.010]
IQ	-0.004 (0.000)**	[-0.004, -0.003]
Constant	2.118 (0.045)**	[2.029, 2.206]

Random effects	**Estimate (SE)**	**95% CI**
Level 3 (ward-level)		
Intercept variance	0.001 (0.000)	[0.001, 0.002]
Level 2 (child-level)		
Intercept variance	0.094 (0.002)	[0.090, 0.097]
Slope (age) variance	0.000 (0.000)	[0.000, 0.000]
Intercept-slope covariance	0.000 (0.000)	[0.000, 0.000]

Note. Age was measured in months and was grand mean centred at 64 months. For fixed effects: *p < .05, **p < .01.

4. Discussion

In the present study, we investigated the associations of greenspace quantity in the neighbourhood with self-regulation capacity in early and middle childhood, using longitudinal data from a large UK general population birth cohort study. We modelled trajectories of independence and emotional dysregulation across the ages of three, five, and seven years, using growth curve modelling. On average, independence scores increased, and emotional dysregulation scores decreased, from age three to seven years, suggesting an average improvement of children's self-regulation over time. Family rather than area characteristics were more strongly associated with children's self-regulation (with more pronounced effects for emotional dysregulation), which is in line with findings from previous studies on the associations of greenspace with other, related, aspects of child development (Huynh, Craig, Janssen, & Pickett, 2013; Reuben et al., 2019). Some aspects of the home physical environment were also associated with children's self-regulation: access to a private garden predicted independence, while levels of damp and condensation, and the presence of secondhand smoke in the home predicted emotional dysregulation.

In regard to our main variable of interest, greenspace quantity in the neighbourhood, we did not find direct associations with either independence or emotional dysregulation after full adjustment for confounders and covariates. In the context of the existing literature and the theoretical foundations of this study, this was unexpected. We think there are several explanations for such findings. First, we used a measure of neighbourhood greenspace at ward-level, a relatively large geographic unit, based on UK electoral boundaries, that may not reflect children's exposure to greenspace accurately. This is because electoral boundaries are not physical boundaries and, thus, do not limit families' and children's mobility across wards. For example, a child that lives on the edge of a ward that falls into a low greenspace decile is assumed to have little exposure to greenspace. However, if that child lives close to an adjacent ward that falls into a higher greenspace decile, they may be exposed to more greenspace than suggested by our measure. The literature suggests that the definition of the exposure area (e.g. the residential neighbourhood) and its spatial extent (e.g. based on administrative boundaries or circular buffers around residences) can have a great impact on study results (Browning & Lee, 2017; Mitchell, Astell-Burt, & Richardson, 2011; Perchoux, Chaix, Brondeel, & Kestens, 2016; Van Loon, Frank, Nettlefold, & Naylor, 2014; von Stülpnagel, Brand, & Seemann, 2019). Therefore, misclassification may be a limiting factor in our models. Second, we used data on greenspace quantity. We did not have information on proximity to green spaces, quality and use of green spaces, or other factors, such as views of nature from the home or accessibility of green spaces, all arguably very important environmental-level predictors of child outcomes related to self-regulation. For example, the quality of a green space may determine whether and how children use it, which, in turn, will affect how much they may benefit from it. Some of the extant literature does indeed show the relevance of these aspects for child outcomes. For example, Feng and Astell-Burt (2017a) found that mothers' perceptions of the quality of green spaces in their neighbourhoods was associated with their children's well-being. Balseviciene et al. (2014) found that proximity to city parks was beneficial for children of mothers with lower education levels. Finally, Amoly et al. (2015) found that spending more time in green spaces was linked to lower levels of emotional symptoms and peer relationship problems in children, although they did not find a positive association with proximity to green spaces. The mere amount of neighbourhood greenspace, therefore, may not be the most crucial factor in the relationship between neighbourhood greenspace and child development. While greenspace quantity is an important physical environment factor, future studies would benefit from using a range of different greenspace measures, including measures of quality and use.

Our measures of self-regulation also had limitations. First, children's self-regulation was measured with two scales, independence and emotional dysregulation, of five items each. The small number of items limits the informative value of the two scales and may also explain their relatively low internal consistencies. As described earlier, self-regulation is a complex construct that includes multiple components and involves cognitive, emotional, and motivational processes. In our study, we were not able to cover this complexity fully. However, our two measures did index several important aspects of children's self-regulation.

The independence scale included items on cognitive and behavioural dimensions of self-regulation, with two of its items indexing directly the ability to focus and sustain attention, in turn linked to greenspace in previous research (Faber Taylor & Kuo, 2009; Flouri et al., 2019; Taylor et al., 2002). However, the other three items of the scale covered a different aspect of children's self-regulation, namely the ability or tendency to do things independently. One could argue that children living in greener areas may have more opportunities to leave their home independently and to play without supervision. However, this may not be true for young children, especially in view of the general decline in children's independent mobility and outdoor play (Fyhri, Hjorthol, Mackett, Fotel, & Kyttä, 2011; O'Brien & Smith, 2002; Valentine & McKendrick, 1997). Therefore, higher levels of greenspace in the neighbourhood may not benefit young children's development of independence. The emotional dysregulation scale, on the other hand, indexed children's difficulties in regulating emotions and behaviour. In turn, children's emotional and behavioural difficulties have been linked to poor exposure to greenspace (Balseviciene et al., 2014; Feda et al., 2015; Flouri et al., 2014b; Li et al., 2018; Younan et al., 2016). It was therefore unexpected that we did not find a direct link between neighbourhood greenspace and emotional dysregulation. A sensitivity analysis, however, revealed that including air pollution in our models may have blocked some of the effect of greenspace, although air pollution itself was not independently related to children's emotional dysregulation. Together these findings suggest that shedding light on the specific mechanisms underlying the association between the built environment and child self-regulation will have much value. However, without a more comprehensive assessment of the built environment this is difficult. Noise, for example, is likely a very crucial factor to consider because it is correlated with both greenspace and air pollution and has been linked to both poor cognition and health in children. Unfortunately, we could not explore this further because we did not have available data on noise. Finally, we must consider a more general limitation of our measure of self-regulation, that it was parent-reported. This may further limit the quality of our data because parents' ratings may be biased towards their own expectations of their children's behaviour. In fact, research linking greenspace to child well-being has shown that the source of information can have a direct impact on the findings (Feng & Astell-Burt, 2017b). Therefore, future research would benefit from a more comprehensive measure of children's self-regulation capacity that is not limited to parent-reported data but uses other, ideally more objective, data as well.

5. Conclusion

In this study, we investigated the association of neighbourhood greenspace quantity with children's self-regulation in early and middle childhood, using longitudinal data from a large general-population cohort in the UK. In summary, we found no association of neighbourhood greenspace with self-regulation, indexed in our study by independence and emotional dysregulation. Although these findings were unexpected, they are in line with the generally mixed evidence in this area of research and also highlight the complexity of links between exposure to greenspace and child development. In general, it was family background and individual characteristics that best explained children's differences in self-regulation capacity. A number of limitations, especially with regard to our measures of exposure and outcomes, may explain our null results. We suggest that future studies should use measures of greenspace that capture other aspects than quantity (e.g. quality, proximity, and use) and assess the wide range of components of children's self-regulation, using more comprehensive measures (not limited to parent-reported data). On the whole, the results of this study suggest a role of the immediate physical environment rather than the wider physical environment, particularly for children's emotional dysregulation.

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Highlights

- Investigated the role of neighbourhood greenspace in children's self-regulation
- Included two domains of self-regulation: independence and emotional dysregulation
- Accounted for neighbourhood deprivation and home physical environment
- Home physical environment and neighbourhood deprivation predicted self-regulation
- Neighbourhood greenspace quantity did not predict children's self-regulation