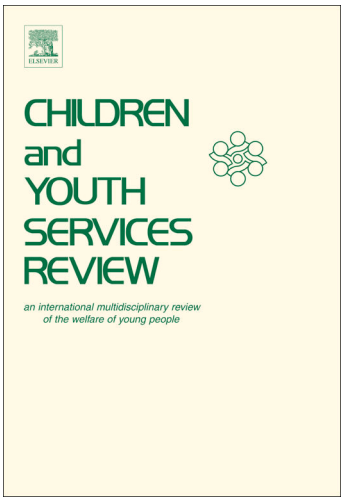

The Role of the Indoor Home Environment in Children's Self-Regulation

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Self-regulation is an important marker of both cognitive and socio-emotional competency. This exploratory study examined the role of the indoor home environment in children's trajectories of two components of self-regulation: emotional dysregulation and independence. We used growth curve modelling to explore the trajectories of self-regulation among *13,774* children from the Millennium Cohort Study, followed at ages three, five and seven years. Disorganisation, quiet and calm were related to both components of self-regulation. Additionally, damp, second-hand smoke and TV noise predicted emotional dysregulation. Our other measures of the home environment (overcrowding, home traffic, presence of open fires and garden access) were unrelated to self-regulation. Our results suggest that the atmosphere and maintenance of the home may directly impact self-regulation in early and middle childhood.

Keywords

Self-Regulation, Emotional Dysregulation, Independence, Home Environment, Longitudinal Birth Cohort, Millennium Cohort Study

Introduction

Self-regulation is a multidimensional construct, integrating motivational, cognitive, behavioural and affective components. Generally defined as the ability to control or direct one's attention, thoughts, emotions and actions, self-regulation and its normative development are strong predictors of socioemotional well-being (McClelland & Cameron, 2012; Howard & Williams, 2018; Robson et al., 2020). Self-regulation can be distinguished into separate yet related subconstructs each playing vital roles in healthy child development. Two of these – emotion dysregulation: the inability to regulate internal emotional responses to the external environment, and independence: the ability to select and manage appropriate behavioural responses to internal and external stressors - capture key facets of self-regulation, are related to multiple life outcomes, and are the focus of this study (Rothenberg et al. 2019; Dunsmare et al. 2013; McNeil et al. 2010; McClelland et al. 2013).

Children's socioemotional adjustment and academic performance, for example, are both strongly related to these aspects of self-regulation. As early as 2002, Blair et al. (2002) showed that children starting nursery with low emotional self-regulatory abilities were more likely to be rejected by peers and perform worse in school. Self-regulation in children is also associated with school readiness, a strong determinant of later academic achievement (Williams et al., 2016; Blair & Raver, 2015), as well as directly with literacy, vocabulary and maths skills (Clements et al., 2016; Neuenschwander et al., 2012; Sasser et al., 2015). The impacts of poor self-regulation for children are seen in other domains too. For example, failure to adequately self-regulate in early childhood increases the likelihood of excessive weight gain (Grazino et al., 2010; Gorin et al., 2014). Importantly, they can be long term. In a large longitudinal study, Moffit et al. 2011, for example, found that weak self-control in childhood predicted poor physical health, financial difficulties, substance dependence and

offending in adult life, even when controlling for class and family background. Therefore, the formulation of clear intervention strategies targeting the modifiable factors early in life that may negatively impact the development of self-regulation is a key way to improve important outcomes in childhood and adolescence but also adulthood. This study explored if one such factor may be the home's physical environment.

The effects of the home environment on child self-regulation have been well explored, but the emphasis to date has been placed on the social, rather than the physical, components of this microenvironment. Parents, the primary authors of both these aspects of their children's home environment, have been the focus of many studies. It is now well established that alongside temperament self-regulation develops from a child's reciprocal relations with parents and caregivers (McClelland & Cameron, 2011). Similarly, parents who prioritise child autonomy over parental control have children who are better self-regulators (Bernier, Calson & Whipple, 2010; Williams & Howard, 2020). Evidence also suggests that parental belief about the importance and value of emotional self-regulation is associated with the child's own ability to regulate their emotional reactions (Meyer et al., 2014). Parents' mental health also plays a large role in the development of self-regulation in their offspring (Neuenschwander & Oberlander, 2017). Studies have shown that children whose mothers are depressed often struggle with social competence and school adjustment (Kersten-Alvarez et al., 2012). This may be because depressed mothers struggle to form close bonds with their children, and weak parent-child relationships have been shown to negatively impact a child's emotional and behavioural regulation (Goodman et al., 2011).

While there is no denying the importance of social interactions within the home, the home's physical environment is the stage or setting upon which social transactions take place

(Wohlwill, 1983). Although to date there has been no study exploring its link with child self-regulation, there is much evidence showing associations with several outcomes related to self-regulation (Jones-Rounds, Evans, Braubach, 2014; Rollings et al., 2017). For example, poor housing quality has been linked to less task persistence and diminished socioemotional well-being in children even when controlling for household income (Rollings et al., 2017). More recent studies have shown that poor indoor air quality is significantly related to emotional and behavioural problems (Author, 2019) but also cognitive functioning in children as young as age 3 years (Author, 2018). Poor housing conditions are also related to parental ill-mental health (Suglia et al., 2011; Jones-Rounds et al., 2014), an important determinant of many child outcomes, including self-regulation as discussed.

To an extent, the role of home physical environment in child self-regulation has been explored indirectly. For example, home chaos - which has been shown to hamper children's well-being and learning, increase problem behaviours and reduce regulatory ability (Evans & Wachs, 2010; Marsh et al., 2020) - indexes a range of social but also physical conditions of the home. Defined as 'environments characterised by high levels of noise, crowding and instability, as well as a lack of temporal and physical structuring'(Evans and Wachs, 2010), chaotic homes have been linked to child outcomes closely associated with self-regulation, such as cognitive functioning, socio-emotional functioning and self-directed learning (Marsh et al., 2020). Noise exposure, for example, has been linked to poorer reading and language ability, diminished central auditory processing and reduced general intellectual functioning in children (Erikson & Newman et al., 2017; Ferguson et al., 2013; Niemitalo-Haapola et al., 2015; Dreger et al., 2015). In very noisy environments, children learn to ignore stimuli but do so indiscriminately, reducing the synchrony between visual and auditory information which in turn negatively impacts the early development of language (Hollich, Newman & Jusczyk,

2005; Barutchu et al., 2010). The type of noise may also matter. TV noise, for instance, is associated with attentional problems, depression, anxiety and aggression (Martin et al., 2012). Crowding has also been shown to exert a negative influence on child development (Ferguson et al., 2013), by increasing aggression and conflict and reducing co-operation (Evans, 2006; Solari & Mare, 2012). Children living in overcrowded homes are also more likely than other children to isolate themselves in an attempt to reclaim privacy, resulting in socioemotional problems (Lepore et al., 1992), whereas the lack of availability and safety of play areas, often seen in crowded homes, can negatively impact self-directed learning and independence (Whitebread, 2009; Frost, Wortham, & Reifel, 2008). However, this view of crowding may be attributable to Eurocentric standards of home and family. In many cultures, the presence of multiple adults in the home provides an opportunity to distribute the responsibility of care across multiple caregivers (Weiser, 2010), highlighting the importance for future studies to include large samples of families varying in ethnicity and culture.

In summary, the literature suggests a link between 'physical' attributes of the home and child self-regulation. However, no study to date has explored their role while considering the home's social context, thus taking a holistic view of the home as an ecological system. In this study we conduct a large scale exploration of the association between the indoor physical environment and self-regulation in early and middle childhood. Through the use of the Millennium Cohort Study (MCS), a large, general population, longitudinal cross-UK dataset, we are able to analyse whether the home's physical environment was associated with the trajectories of children's self-regulation over and above individual, family and area level covariates. The MCS is a rich dataset with information about various aspects of the home, including background noise, damp, second hand smoke, garden access, open fires, disorganisation, home traffic, overcrowding, darkness, cleanliness, clutter and calm. We explored the relationships between these aspects of the home environment and two aspects of

self-regulation: emotional dysregulation and independence. Given the significance of early and middle childhood for the development of self-regulation, the MCS only recorded data for this construct along 3 timepoints, resulting in our trajectories being modelled using data from ages 3, 5 and 7 years.

We hypothesised that factors such as garden access and cleanliness would promote self-regulation, while factors such as second hand smoke, damp, clutter and background noise would impair it. We also expected that the contribution of factors such as overcrowding and home traffic to self-regulation would be reduced by the inclusion of cultural and socio-economic factors such as ethnicity, family structure, home ownership and maternal education in our model (Weiser, 2010). We also hypothesized that the inclusion of maternal depression would minimise the contribution of factors such as disorganisation and calm (Bates et al., 2020; Zvara et al., 2020). Given the size and diversity of the cohort study that our data is pulled from, we expected to produce results well generalisable to the UK context.

Methods

Participants and Procedure

The Millennium Cohort Study (MCS)[1] is a longitudinal survey drawing its sample from all births in the UK over a year, starting on 1 September 2000. There have been seven sweeps of data thus far with 19,519 children (19,243 families) participating in at least one of these sweeps. The sample is disproportionately stratified to ensure sufficient numbers of the four UK countries and electoral wards and adequate representation of disadvantaged and ethnic

[1] University of London. UCL Institute of Education. Centre for Longitudinal Studies, Millennium Cohort Study: First Survey, 2001-2003 [computer file]. 6th Edition. Colchester, Essex: UK Data Archive [distributor], March 2007. SN: 4683.

minority populations (Plewis, 2007). As self-regulation (emotional dysregulation and independence) was measured in MCS at Sweeps 2-4, we used data from Sweeps 1 (at age 9 months, dates ranging June 2001 to January 2003), 2 (at 3 years, dates ranging September 2003 to April 2005), 3 (at 5 years, dates ranging January to December 2006) and 4 (at 7 years, dates ranging from January to December 2008). In the case of twins and triplets we used records for only the first-born, so the number of children is equal to the number of families. Our 'analytic' sample (*n = 13,774)* included cohort members with at least one valid scale score for emotional dysregulation and independence and who were present at sweep four.

Measures

Self-regulation was measured at ages three, five and seven with 10 parent-reported items from the Child Social Behaviour Questionnaire (CSBQ) based on the Adaptive Social Behaviour Inventory (Hogan, Scott, & Bauer, 1992). The CSBQ was developed and construct 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). The number of CSBQ items in the MCS was five for each scale with items rated on 3-point response scales. Examples of items from the emotional dysregulation scale are 'gets over excited' and 'is easily frustrated'. Independence items include 'persists in the face of difficult tasks' and 'chooses activities on his/her own'. Each item was scored on a three-point response scale: zero if the item was 'not true', one for 'somewhat true' and two for 'certainly true'. Cronbach's alphas ranged from .58 to .68 for independence and .61 to .69 for emotional dysregulation.

The home's indoor physical environment was measured by both experimenter reports and parent reports. Home traffic, room traffic, darkness, cleanliness and clutter were all binary items (i.e., 1 = yes, or 0 = no) recorded by the experimenter as observed during home visits. The parent-reported items were as follows: level of damp/condensation ('no damp', 'not much of a problem', 'great problem'), extent to which the home 'was really disorganised', a 'place that's hard to think' or 'had a calm atmosphere' (measured on a five-point scale from 'strongly agree' to 'strongly disagree'), and access to a garden, presence of open fires and presence of second-hand smoke ('yes' or 'no'). Overcrowding ('yes' or 'no') was calculated by dividing the number of people by the number of rooms and the threshold was set at 1 person per room.

The child level covariates were age (in months), ethnicity (White, Mixed, Indian, Pakistani or Bangladeshi, Black/Black British, or Other), sex (male/female) and general cognitive ability (IQ). IQ was assessed with three of the British Ability Scales at age 5 years: naming vocabulary, pattern construction (for spatial problem-solving), and picture similarities (for non-verbal reasoning). We calculated IQ using a score derived from a principal components analysis of the three scales, which was then transformed into a standardised IQ score with a mean of 100 and a standard deviation of 15. The family level covariates were poverty (whether family income fell below 60% of the UK's median household income), presence of the child's natural parents in the home or not, mother's level of education (University education or not), maternal psychological distress (measured with the six-item Kessler psychological distress scale), residential mobility (whether family had moved or not since last sweep) and home ownership. We also controlled for neighbourhood physical and social environment (greenspace, air pollution and deprivation) and urbanicity (if the population was equal to or greater than 10,000). Greenspace and air pollution (PM_{10}) were measured from

the Multiple Environmental Deprivation Index (https://cresh.org.uk/cresh-themes/environmental-depreivation/medix-and-medclass/). Neighbourhood greenspace quantity in particular was measured by combining land use data from the Coordination of Information on the Environment (EEA, 2000) and the 2001 Generalised Land Use Database (Office of the Deputy Prime Minister, 2005) (Richardson & Mitchell, 2010). Neighbourhood deprivation was measured using the nine MCS 'strata': England-Advantaged, England-Disadvantaged, England-Ethnic Minority, Wales-Advantaged, Wales-Disadvantaged, Scotland-Advantaged, Scotland-Disadvantaged, Northern-Ireland-Advantaged, and Northern Ireland-Disadvantaged.

Statistical analysis

First we tested for bias in the selection of our analytic sample (Table 1) and the shape of the average trajectories of both the independence and the emotional dysregulation scores, which was curvilinear, we also inspected the correlations between our main variables and covariates (see Supplementary Tables). To meet our study objective, we then fitted growth curve models. In three-level models, fitted separately for independence and emotional dysregulation, time points (level one) were nested in individuals (level two) nested in wards (level three). Models were fitted with random intercepts for levels two and three, and a random slope for age (Tables 2 to 5). Age was grand-mean centred so intercept was set at age about 5 years. We also included a fixed quadratic term for age in order to account for the curved shape of children's average trajectories. For each outcome, we fitted two models, one unadjusted and one fully adjusted. In the unadjusted model we included the linear and quadratic age terms and the home's indoor physical environment variables. In the fully adjusted model, we also added the child, family and neighbourhood covariates. Attrition and

non-response were taken into account by using study-specific weights. All analyses were run in Stata 16.

Results

Bias analysis

We explored whether the families included in our analytic sample (n = 13,774) were different (at p<.05) from families excluded from it (n = 5,569) on our outcome variables (Table 1). As can be seen, children in the analytic sample had higher independence scores and lower emotional dysregulation scores. These children were more likely to live in homes that were calm, clean, without background noise and where parents could 'hear themselves think', but were also less likely to live in dark, damp or overcrowded conditions in some sweeps. Those children were also more likely to have access to a garden, to have open fire heating and to live in greener, less polluted and less urban areas. They were less likely to live in homes with high amounts of internal traffic and be exposed to second hand smoke. These children also had higher IQs, were more likely to be female, younger and White. They were more likely to come from England's or Wales' advantaged 'strata', less likely to come from England's or Scotland's disadvantaged areas and less likely to live in poverty. Children in the analytic sample were more likely to live with both natural parents, and their caregivers were more likely to own their home and be university educated and less likely to move home or suffer from depression. We factored out these specific biases by controlling for these characteristics in our model, as explained.

Descriptive statistics

From ages three to five, emotional dysregulation scores decreased and independence scores increased. Both neared a plateau from ages five to seven, with emotional dysregulation

showing a greater level of change over time than independence did, on average (Table 1). In general, the variables denoting a more negative indoor housing environment were negatively correlated with independence and positively correlated with emotional dysregulation. The inverse appeared with variables associated with a positive indoor housing environment (Table 2 and 3).

Model results

As also suggested by the descriptive results above, child self-regulation trajectories did not change linearly over time. While independence increased and emotional dysregulation decreased, scores peaked or troughed, respectively, at around 5 years suggesting a quadratic relationship. The positive covariance of intercept and slope for both self-regulation measures suggests that a higher intercept was associated with a steeper slope. The fixed effects part of the unadjusted model showed that independence scores were lower for children in homes that were described as dark, uncluttered, disorganised or a place where parents could not 'hear themselves think'. Independence scores were higher when the home was described as having a 'calm atmosphere' (Table 2). For emotional dysregulation, damp or condensation, second hand smoke and background noise from the TV/radio significantly predicted higher scores as did living in homes that were disorganised, dark or a place where parents could not 'hear themselves think'. Children had lower emotional dysregulation scores when their homes had a garden, a calm atmosphere and an open fire (Table 3).

In our fully adjusted model for independence (Table 4), scores were lower when caregivers described the home as 'really disorganised', a place where they could not 'hear [themselves] think' or as not having a 'calm atmosphere'. As expected, child-level and family-level covariates were also significant. For example, girls, children with higher cognitive ability,

those in more residentially stable families, with home-owning parents and with less psychologically distressed mothers had higher independence. Children of a Pakistani or Bangladeshi background, compared to white, had lower independence scores. At a neighbourhood level, we found children in Scottish and Northern-Irish advantaged strata had higher independence scores as did those in the Welsh-disadvantaged stratum. Results from the random effects part of the model suggest that children varied both in their initial levels of independence at around five years of age and in the development of independence over time. The intercept and slope covariance remained positive as in the unadjusted model.

After full adjustment, emotional dysregulation (Table 5) scores were also significantly predicted by several features of the indoor housing environment. Homes with more damp or condensation, those with exposure to second hand smoke and to background noise generated by the TV or a radio, and those described as really disorganised, not calm and places where the caregivers could not 'hear [themselves] think' housed children with greater levels of emotional dysregulation. Furthermore, as expected, children scored lower on emotional dysregulation if they were female, had a higher IQ, lived with University-educated mothers, mothers with lower psychological distress, and in residentially stable, intact families and with home-owning parents. Children belonging to Welsh and English disadvantaged strata or to the English ethnic minority stratum had higher levels of emotional dysregulation, as did children of Pakistani and Bangladeshi backgrounds. Black or Black British children showed less emotional dysregulation. Results from the random effects part of the model again suggested that children varied both in their initial levels of independence and in the development of independence over time. The intercept and slope covariance remained positive as in the unadjusted model.

Discussion

The main objective of this study was to investigate the individual contributions made by different measures of the indoor housing environment to self-regulation trajectories from age 3 to age 7 years in the general population. The findings show that damp, second hand smoke, background noise from the TV/radio, lack of clam and quiet, and home disorganisation were associated with poor self-regulation, reflecting links with emotional dysregulation rather than low independence.

Damp and second hand smoke both had a significant positive impact on emotional dysregulation scores. Damp and condensation can cause mould in the home. Both second hand smoke and mould are a source of poor air quality, which has been shown to have detrimental effects on development (Author, 2018; Kloppenborg et al., 2014). Children are particularly sensitive as the protective barriers in their lungs are less developed and their breathing rate to body size ratio is higher, leaving them much more vulnerable to a pollutant's negative effects (Vanos, 2015). Because an immune response is initiated when air pollutants enter the body, children, who have a less robust blood brain barrier, can experience a neuroinflammatory cascade in their brains, in turn leading to loss and damage of neural tissues (Brockmeyer & Angiulli, 2016). Our findings extend Author and colleagues' (2018) finding that children exposed to second hand smoke had diminished school readiness and verbal ability [both well-associated with self-regulation (Duncan et al., 2007; McClelland et al., 2007)], and that those in homes with damp and condensation also had lower school readiness. However, while we did find an effect on emotional dysregulation, second hand smoke and damp did not have a significant effect on independence. The inability to regulate negative and intense emotions (emotional dysregulation) is related to, but is causally distinct from, self-directed learning (independence) (Hadwin et al., 2018).

Open fires were not related to self-regulation scores, despite also being a source of air pollutants. In the UK, homes with open fires are rare, with only 7-10% of our analytic sample having such homes. Open fires are also more likely in houses than in flats and they are more likely to be found in larger homes. We did not control for either size or type of dwelling, and, given that larger houses are less likely to feel cramped or cluttered and are more likely to belong to wealthier families, the potential impact of open fires may have been washed out by our other variables. Open fires were negatively correlated with urbanicity *(r = -.21 to -.29)* and air pollution *(r = -.16 to -.21)* and positively correlated with greenspace *(r = .23 to .29)*, suggesting that the homes with them were in more rural, green and spacious areas (see Supplementary Table 3). In turn, access to such areas has been associated with improved mental well-being, overall health and cognitive development in children (McCormick, 2017). Access to a garden also did not have a predictive effect on either emotional dysregulation or independence despite potentially combatting the impact of indoor air pollution on child development. The quality and size of the garden or the frequency of its use however were not recorded in the MCS and these factors may play a large moderating role on the impact that garden access may exert on child self-regulation. There is also the possibility that homes with gardens, especially in more urban areas, are likely wealthy. Poverty, socioeconomic status (SES) and urbanicity were already accounted for in our models.

We also found that children in homes with more background noise generated by the TV or radio had higher emotional dysregulation scores. This is in line with findings from Landhuis et al.'s (2007) longitudinal study that showed an association between parental estimates of children's television watching and their attentional problems. In our study background noise was measured by the experimenter during the interview, not the parent. A higher score for

background noise from the TV/radio therefore indicates overexposure to these devices as parents who leave the TV or radio on during the interview (a time more requiring of quiet) are more likely to turn them on in general. This supports Foster & Watkins' (2010) finding that there was not a linear relationship between television watching in children and attentional problems; only those children who were chronically exposed to television viewing suffered subsequent attentional problems. Importantly, unlike Foster & Watkins' (2010), our findings are robust to controls. However, we did fail to find a significant relationship between independence and TV/radio noise. This was not unexpected, given that emotional dysregulation rather than lack of independence is common in individuals with attention difficulties (Hirsch et al., 2018; van Stralen, 2016).

Our study also indicated a significant association between the organisation and atmosphere of the home and both emotional dysregulation and independence. The extent to which parents thought that their homes were really disorganised, a place where they were 'unable to hear themselves think' or that did not have a calm atmosphere predicted lower independence and greater emotional dysregulation. These items were derived from the Confusion, Hubbub and Order Scale (CHAOS) (Matheny, Wachs, Ludwig, & Phillips, 1995). Accordingly, our findings fit into the wider home chaos literature, which shows strong links with lower cognitive ability, and increased socioemotional and behavioural problems in children (Marsh et al., 2020). Surprisingly, experimenter-recorded clutter, darkness and cleanliness, seemingly similar measures, were not related to either measure of self-regulation in this study. While experimenter-recorded items are more likely to be 'objective' across households, they were limited to a single visit in the MCS homes (when cohort children were aged about 3 years). By contrast, the parent-reported CHAOS questions discussed above were asked at two or three timepoints and so are more likely to reflect a home's long-term problem with lack of

organisation. As to the pathway through which the organisation and atmosphere of the home may influence self-regulation, the literature on home chaos points to parenting. Zvara et al. (2020), for example, found that parents in more chaotic homes showed less sensitive and more intrusive parenting behaviour. Earlier, Coldwell et al. (2006) had found both direct effects, such that children in chaotic homes may adaptively filter out extra unwanted stimuli in turn ignoring useful stimulation as well, and indirect effects via parenting. Children may also struggle to access resources in these environments and feel more frustrated, related to both lower independence and greater emotional dysregulation.

Given the correlational nature of our data other explanations for the association between the organisation and atmosphere of the home and child self-regulation are possible. First, it is possible that children with greater emotional dysregulation and lower independence (more prone to throwing tantrums or requiring more assistance completing tasks) are harder to look after by their parents and therefore more likely to cause disorder in the home (Barnes et al., 2013). Second, the association may be confounded by parental depression. Depression is related to a more negative bias and therefore depressed parents may be more likely to describe both their homes and their children as more disorderly. However our findings were robust to the inclusion of maternal psychological distress as a covariate in our models. While maternal psychological distress significantly predicted both greater emotional dysregulation and lower independence, our findings about home organisation and atmosphere remained robust to this adjustment.

Nonetheless, overcrowding, home/room traffic and background conversation were not significant predictors of children's self-regulation, despite also being indicators of home chaos (Solari & Mare 2012). In this study, however, background conversation and home and

room traffic were all recorded by the experimenter at one visit only, at age 3 years. Therefore, like darkness, cleanliness and clutter, they may not be able to tell us much about the long-term lived experience of the family. The MCS also does not include information on the content of those background conversations nor does it identify the people speaking or those leaving or entering the room. Background conversation could be taking place for example because a caregiver was instructing or responding to a child, indicating a healthy home learning environment. Likewise, home and room traffic might be due to other family members checking on the parent's welfare, indicating a nurturing and supportive environment. Relatedly, our measure of overcrowding (more than 1 individual per room), while standard, may have overestimated crowding in urban dwellings, especially among ethnic minority families. Additionally, our study is limited by the brevity and the rather low internal validity of the self-regulation measures (only two five-item scales were included, and Cronbach's alpha for each was below .70). The correlational nature of this study is another limitation, as explained. Our results may also be hampered by the lack of inclusion of measures of the indoor characteristics of schools and other institutional child care contexts (e.g., religious congregations, after school clubs) as these settings are also important influence of self-regulation (Eccles and Roeser et al., 2011).

A major strength of our study however is the large, diverse, general-population longitudinal sample and the inclusion of detailed information about each family's social, demographic, economic and geographic circumstances, producing results that are generalisable to the UK. Our results highlight the importance of a tidy, quiet and calm home environment for the development of self-regulation in children, over and above the effects of socio-economic factors and other family and neighbourhood covariates. This suggests that the careful consideration of these factors by policy that addresses the safety and suitability of the home's

physical environment may positively impact children's developmental outcomes. Our results also add to the body of literature highlighting the negative impact of exposure to second hand smoke and damp on child development. Damp and second hand smoke, both of which approximate well socio-economic circumstances and indoor air quality, had robust associations with emotional dysregulation. Future work exploring the role of these factors in child self-regulation could benefit from investigating what may mediate this relationship.

To conclude, in this study we assessed the individual contribution of a variety of physical characteristics of the home environment and found that damp, second-hand smoke, TV noise, disorganisation and lack of calm and quiet uniquely predicted poor self-regulation in children. The other home environment measures we considered, including overcrowding, home and room traffic, clutter, darkness and garden access, had no effect on self-regulation, despite contrary indications from previous studies. We must acknowledge however that differences in the way these variables were measured, for example whether they were recorded at one or multiple timepoints and whether they were parent reports or third-party assessments, may have played a role in our results. Our findings suggest that several aspects of the indoor home environment can directly impact on self-regulation in early and middle childhood.

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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**
SR Independence Sweep 2	12,107	2.46(0.35)	2,727	2.44(0.36)	7.80*
SR Independence Sweep 3	12,874	2.53(0.35)	1,899	2.51(0.37)	4.59*
SR Independence Sweep 4	13,488	2.50(0.37)	-	-(-)	-
SR Emotional dysregulation Sweep 2	12,109	1.88(0.45)	2,727	1.91(0.46)	10.50*
SR Emotional dysregulation Sweep 3	12,874	1.72(0.46)	1,899	1.78(0.47)	22.46**
SR Emotional dysregulation Sweep 4	13,489	1.73(0.47)	-	-(-)	-
Really disorganised Sweep 2	12,520	2.21(0.96)	2,926	2.13(0.95)	0.02
Really disorganised Sweep 3	13,101	2.35(1.05)	2,030	2.38(1.05)	1.79
Really disorganised Sweep 4	13,684	2.28(1.06)	67	2.31(0.92)	0.08
Can't hear myself think Sweep 2	12,520	2.42(0.98)	2,926	2.49(1.01)	12.05**
Can't hear myself think Sweep 3	13,097	2.47(0.99)	2,029	2.55(1.02)	11.88**
Calm atmosphere Sweep 2	12,520	3.63(0.84)	2,926	3.65(0.86)	0.76
Calm atmosphere Sweep 3	13,098	3.56(0.88)	2,036	3.51(0.89)	6.31*
Background noise (TV/radio) Sweep 2 (1 = no noise, 2 = moderate, 3 = loud)	11,713	1.32(0.50)	2,712	1.38(0.54)	27.11**
Background noise (TV/radio) Sweep 3 (1 = no noise, 2 = moderate, 3 = loud)	12,565	1.17(0.40)	1,932	1.21(0.44)	22.65**
Background noise (conversation) Sweep 2 (1 = no noise, 2 = audible but not loud, 3 = loud)	11,713	1.17(0.42)	2,712	1.21(0.47)	12.26**
Background noise (conversation) Sweep 3 (1 = no noise, 2 = audible but not loud, 3 = loud)	12,597	1.33(0.53)	1,938	1.37(0.56)	513.28**
Home traffic Sweep 2 (1 = no one, 2 = once or twice, 3 = three or more times)	11,713	1.30(0.51)	2,712	1.34(0.54)	11.68**
Home traffic Sweep 3 (1 = no one, 2 = once or twice, 3 = three or more times)	12,521	1.22(0.44)	1,909	1.24(0.46)	1.08
Maternal depression Sweep 2	11,166	3.23(3.68)	2,424	3.50(4.09)	9.71**
Maternal depression Sweep 3	12,511	3.17(3.82)	1,821	3.42(4.18)	9.84**
Maternal depression Sweep 4	13,163	3.15(3.87)	0	-(-)	-
Damp Sweep 2	12,520	1.22(0.62)	2,927	1.27(0.69)	13.18**
Damp Sweep 3	13,111	1.22(0.62)	2,043	1.28(0.72)	17.50**
Damp Sweep 4	13,693	1.25(0.66)	69	1.57(0.93)	15.75**
Neighbourhood greenspace (deciles) Sweep 2	12,603	4.48(2.70)	2,986	4.04(2.61)	66.76**
Neighbourhood greenspace (deciles) Sweep 3	13,158	4.56(2.72)	2,087	4.04(2.63)	65.12**
Neighbourhood greenspace (deciles) Sweep 4	13,772	4.58(2.72)	83	1.89(1.37)	80.72**
Air pollution (PM_{10}) (deciles) Sweep 2	12,603	6.25(3.04)	2,986	6.69(3.08)	50.47**
Air pollution (PM_{10}) (deciles) Sweep 3	13,158	6.18(3.04)	2,087	6.69 (3.11)	49.76**
Air pollution (PM_{10}) (deciles) Sweep 4	13,772	6.18(3.04)	83	9.16(1.63)	79.52**
IQ	12,902	100.64(14.83)	1,961	95.78(15.44)	180.54**
Age (months) Sweep 2	12,598	38.14(2.42)	2,984	38.75(2.96)	144.61**
Age (months) Sweep 3	13,159	63.49(2.99)	2,086	63.55(3.16)	0.71
Age (months) Sweep 4	13,774	88.00(3.00)	83	88.27(2.88)	0.66
Categorical Variables					
	N	**%**	**N**	**%**	**Chi²**
Overcrowding Sweep 2	770	6.15	275	9.4	39.61**
Overcrowding Sweep 3	808	6.16	204	9.99	41.48**
Overcrowding Sweep 4	1,015	7.41	15	22.66	20.97**
Dark home Sweep 2	302	2.59	107	3.95	1477**
Clean home Sweep 2	11,118	95.16	2,510	92.76	25.21**
Uncluttered home Sweep 2	1,291	10.99	2,404	87.96	2.45
Open fires Sweep 2	1,256	10.03	227	7.76	14.16**
Open fires Sweep 3	1,031	7.86	102	4.99	21.03**
Open fires Sweep 4	1,195	8.73	68	0	6.50*
Second hand smoke Sweep 2	2,162	17.27	632	21.59	29.93*
Second hand smoke Sweep 3	1,859	14.18	346	16.89	10.54**
Second hand smoke Sweep 4	1,775	12.96	4	5.63	3.37
Access to garden Sweep 2	11,723	93.15	2,969	88.78	64.58**

Access to garden Sweep 3	12,274	93.51	1,837	88.49	67.85**
Access to garden Sweep 4	12,848	93.47	61	77.22	33.53**
England – Advantaged	3,785	27.48	1,043	19.07	147.25**
England – Disadvantaged	3,366	24.44	1,439	26.31	130.12**
England – Ethnic	1,611	11.70	980	17.92	130.12**
Wales – Advantaged	621	4.51	221	3.86	4.00*
Wales – Disadvantaged	1,393	10.11	535	9.78	0.48
Scotland – Advantaged	828	6.01	317	5.80	0.32
Scotland – Disadvantaged	799	5.80	392	7.17	12.60**
Northern Ireland – Advantaged	534	3.88	189	3.46	1.92
Northern Ireland – Disadvantaged	837	6.08	363	6.64	2.11
In Urban Area Sweep 2	9,800	77.76	2,427	81.28	17.68**
In Urban Area Sweep 3	10,098	76.76	1,716	82.22	30.88**
In Urban Area Sweep 4	13,772	76.58	81	97.59	20.39**
Below the poverty line Sweep 2	3,863	30.95	1,223	41.93	128.83**
Below the poverty line Sweep 3	4,165	31.80	976	47.87	202.96**
Below the poverty line Sweep 4	4.101	29.81	61	75.31	79.25**
University education (mother) Sweep 4	4,117	29.9	936	17.26	320.11**
Two natural parents Sweep 2	10,206	80.99	2,142	71.73	3125.51**
Two natural parents Sweep 3	10,075	76.57	1,383	66.27	102.40**
Two natural parents Sweep 4	9,945	72.20	68	81.93	3.89*
Moved home Sweep 2	3,527	29.56	901	33.31	24.67**
Moved home Sweep 3	2,052	15.60	425	20.36	30.09**
Moved home Sweep 4	1,356	9.85	6	7.23	0.64
Own home Sweep 2	8,318	66.44	1,542	52.68	194.44**
Own home Sweep 3	8,713	66.45	1,012	49.56	219.12**
Own home Sweep 4	9,053	66.1	32	47.06	10.93*
Ethnicity White	11,584	84.11	4,159	76.38	170.64**
Ethnicity Mixed	382	2.77	212	3.89	15.92**
Ethnicity Indian	336	2.44	161	2.96	3.96*
Ethnicity Pakistani and Bangladeshi	843	6.12	507	9.31	59.55**
Ethnicity Black or Black British	451	3.27	279	5.12	35.81**
Ethnicity Other	177	1.29	127	2.33	27.08**
Female	6,794	49.32	2,55	46.72	10.65*

Note. Ns are unweighted, means and %s are weighted. NA = not available. *p < .05, **p < .01. [A]F for categorical variables is the F statistic for design-based Pearson chi-square that is converted to F test to account for the MCS sampling design.

Table 2
Minimally adjusted three-level growth curve model predicting independence (n = 10,720)

	Sweeps Measured	Coefficient (SE)	95% CI
Fixed effects			
Age	2, 3, 4	0.001(0.000)**	[0.001, 0.001]
Age^2	2, 3, 4	-0.000(0.000)**	[-0.000, -0.000]
Damp/condensation	2, 3, 4	-0.006(0.004)	[-0.014, 0.001]
Open fires	2, 3, 4	0.005(0.007)	[-0.009, 0.019]
Second hand smoke	2, 3, 4	-0.011(0.007)	[-0.026, 0.003]
Access to garden	2, 3, 4	-0.010(0.013)	[-0.036, 0.017]
'Really disorganised'	2, 3, 4	-0.012(0.002)**	[-0.016, -0.007]
'Can't hear myself think'	2, 3	-0.023(0.005)**	[-0.032, -0.013]
'Calm atmosphere'	2, 3	0.032(0.006)**	[0.020, 0.043]
Background noise (TV/radio)	2, 3	-0.015(0.011)	[-0.036, 0.006]
Background noise (conversation)	2, 3	-0.007(0.010)	[-0.028, 0.014]
Home traffic	2, 3	0.011(0.010)	[-0.010, 0.031]
Room traffic	2	-0.001(0.005)	[-0.012, 0.009]
Overcrowding	2, 3, 4	-0.002(0.012)	[-0.026, 0.023]
Dark home	2	-0.046(0.020)*	[-0.084, -0.007]
Clean home	2	0.003(0.018)	[-0.032, 0.038]
Uncluttered home	2	-0.027(0.013)*	[-0.052, -0.003]
Constant		2.618(0.058)**	[2.504, 2.733]
Level 2 (child-level)			
Intercept		0.051(0.001)	[0.026, 0.029]
Slope (age)		0.000(0.000)	[0.000, 0.000]
Intercept/slope covariance		0.000(0.000)	[0.000, 0.000]
Level 3 (ward-level)			
Intercept		0.001(0.000)	[0.023, 0.026]

Note. Age was measured in months. Age^2 was grand mean centred. For fixed effects: *p < .05, **p < .01.

Table 3
Minimally adjusted three-level growth curve model predicting emotional dysregulation (n = 10,721)

	Sweeps Measured	Coefficient (SE)	95% CI
Fixed effects			
Age	2, 3, 4	-0.003(0.000)**	[-0.003, -0.003]
Age^2	2, 3, 4	0.000(0.000)**	[0.000, 0.000]
Damp/condensation	2, 3, 4	0.025(0.005)**	[0.016, 0.034]
Open fires	2, 3, 4	-0.025(0.009)**	[-0.044, -0.008]
Second hand smoke	2, 3, 4	0.063(0.008)**	[0.047, 0.079]
Access to garden	2, 3, 4	-0.041(0.017)**	[-0.074, -0.009]
'Really disorganised'	2, 3, 4	0.023(0.003)**	[0.017, 0.028]
'Can't hear myself think'	2, 3	0.968(0.007)**	[0.084, 0.110]
'Calm atmosphere'	2, 3	-0.072(0.007)**	[-0.086, -0.057]
Background noise (TV/radio)	2, 3	0.080(0.014)**	[0.054, 0.110]
Background noise (conversation)	2, 3	0.006(0.014)	[-0.022, 0.033]
Home traffic	2, 3	0.003(0.013)	[-0.031, 0.025]
Room traffic	2	-0.005(0.007)	[-0.020, 0.009]
Overcrowding	2, 3, 4	-0.004(0.012)	[-0.028, 0.019]
Dark home	2	0.070(0.026)**	[0.018, 0.121]
Clean home	2	-0.045(0.023)	[-0.098, -0.008]
Uncluttered home	2	-0.008(0.015)	[-0.037, 0.022]
Constant		1.629(0.069)**	[1.493, 1.765]
Level 2 (child-level)			
Intercept		0.096(0.002)	[0.092, 0.099]
Slope (age)		0.000(0.000)	[0.000, 0.000]
Intercept/slope covariance		0.000(0.000)	[0.000, 0.000]
Level 3 (ward-level)			
Intercept		0.044(0.001)	[0.003, 0.006]

Note. Age was measured in months. Age and age^2 are grand mean centred. For fixed effects: *p < .05, **p < .01.

Table 4
Fully adjusted three-level growth curve model predicting independence (n = 10,459)

	Sweeps Measured	Coefficient (SE)	95% CI
Fixed effects			
Age	2, 3, 4	0.001(0.000)**	[0.000, 0.001]
Age^2	2, 3, 4	-0.000(0.000)**	[-0.000, -0.000]
Damp/condensation	2, 3, 4	-0.004(0.004)	[-0.012, 0.004]
Open fires	2, 3, 4	0.000(0.007)	[-0.015, 0.014]
Second hand smoke	2, 3, 4	-0.005(0.007)	[-0.020, 0.009]
Access to garden	2, 3, 4	-0.019(0.014)	[-0.047, 0.008]
'Really disorganised'	2, 3, 4	-0.009(0.002)**	[-0.013, -0.005]
'Can't hear myself think'	2, 3	-0.009(0.005)*	[-0.019, -0.000]
Calm atmosphere	2, 3	0.028(0.005)**	[0.017, 0.038]
Background noise (TV/radio)	2, 3	-0.000(0.010)	[-0.022, 0.021]
Background noise (conversation)	2, 3	-0.003(0.010)	[-0.022, 0.016]
Home traffic	2, 3	0.015(0.010)	[-0.004. 0.034]
Room traffic	2	0.005(0.005)	[-0.005,0.015]
Overcrowding	2, 3, 4	0.002(0.013)	[-0.023, 0.027]
Dark home	2	-0.022(0.021)	[-0.064, 0.020]
Clean home	2	-0.009(0.017)	[-0.041, 0.024]
Uncluttered home	2	-0.021(0.012)	[-0.044, 0.002]
Stratum (reference England-Advantaged)			
England-Disadvantaged	2, 3, 4	0.012(0.009)	[-0.005, 0.029]
England-Ethnic Minority		0.002(0.016)	[-0.030, 0.033]
Wales-Advantaged		0.018(0.016)	[-0.014, 0.049]
Wales-Disadvantaged		0.022(0.011)*	[0.000, 0.043]
Scotland-Advantaged		0.042(0.016)**	[0.011, 0.072]
Scotland-Disadvantaged		0.021(0.015)	[-0.008, 0.050]
Northern Ireland-Advantaged		0.047(0.014)**	[0.021, 0.074]
Northern Ireland-Disadvantaged		-0.002(0.012)	[-0.025, 0.022]
In urban area	2, 3, 4	0.005(0.009)	[-0.012, 0.022]
Air pollution (PM_{10})	2, 3, 4	-0.000(0.002)	[-0.003, 0.003]
Neighbourhood greenspace	2, 3, 4	0.001(0.002)	[-0.002, 0.004]
Below the poverty line	2, 3, 4	-0.004(0.007)	[-0.017, 0.010]
University education (mother)	4	0.011(0.006)	[-0.002, 0.024]
Two natural parents	2, 3, 4	-0.002(0.007)	[-0.017, 0.012]
Moved home	2, 3, 4	-0.013(0.006)*	[-0.024, -0.002]
Maternal depression	2, 3, 4	-0.007(0.001)**	[-0.008, -0.005]
Own home	2, 3, 4	-0.015(0.006)*	[-0.027, -0.002]
Female	2	0.076(0.006)**	[0.064, 0.087]
Child ethnicity (reference White)			
Mixed	2	-0.020(0.020)	[-0.058, 0.018]
Indian		-0.026(0.020)	[-0.066, 0.014]
Pakistani and Bangladeshi		-0.062(0.018)**	[-0.098, -0.027]
Black or Black British		0.017(0.024)	[-0.031, 0.064]
Other ethnic group		-0.022(0.035)	[-0.091, 0.048]
Child IQ	3	0.004(0.000)**	[0.003, 0.004]
Constant		2.134(0.066)**	[2.004, 2.263]
Random effects			
Level 2 (child-level)			
Intercept variance		0.045(0.001)	[0.042, 0.047]
Slope (age) variance		0.000(0.000)	[0.000, 0.000]
Intercept/slope covariance		0.000(0.000)	[0.000, 0.000]
Level 3 (ward-level)			
Intercept variance		0.001(0.001)	[0.001, 0.001]

Note. Age was measured in months. Age and age^2 are grand mean centred. For fixed effects: *p < .05, **p < .01.

Table 5
Fully adjusted three-level growth curve model predicting emotional dysregulation (n = 10,459)

	Sweeps Measured	Coefficient (SE)	95% CI
Fixed effects			
Age	2, 3, 4	-0.003(0.001)**	[-0.003, -0.003]
Age^2	2, 3, 4	0.000(0.000)**	[0.000, 0.000]
Damp/condensation	2, 3, 4	0.016(0.005)**	[0.007, 0.026]
Open fires	2, 3, 4	-0.009(0.009)	[-0.027. 0.009]
Second hand smoke	2, 3, 4	0.044(0.009)**	[0.027,0.061]
Access to garden	2, 3, 4	-0.001(0.018)	[-0.034, 0.035]
'Really disorganised'	2, 3, 4	0.018(0.003)**	[0.013, 0.024]
'Can't hear myself think'	2, 3	0.071(0.006)**	[0.058, 0.084]
Calm atmosphere	2, 3	-0.066(0.007)**	[-0.080, -0.053]
Background noise (TV/radio)	2, 3	0.038(0.013)**	[0.013, 0.063]
Background noise (conversation)	2, 3	0.000(0.013)	[-0.025, 0.025)
Home traffic	2, 3	-0.014(0.014)	[-0.408, 0.013]
Room traffic	2	-0.012(0.007)	[-0.027, 0.002]
Overcrowding	2, 3, 4	-0.023(0.013)	[-0.049, 0.003]
Dark home	2	0.035(0.029)	[-0.023, 0.092]
Clean home	2	-0.010(0.023)	[-0.055, 0.035]
Uncluttered home	2	0.001(0.015)	[-0.030, 0.028]
Stratum (reference England-Advantaged)	2, 3, 4		
England-Disadvantaged		0.054(0.010)**	[0.034, 0.075]
England-Ethnic Minority		0.062(0.018)**	[0.028, 0.097]
Wales-Advantaged		-0.024(0.017)	[-0.057, 0.010]
Wales-Disadvantaged		0.042(0.013)**	[0.016, 0.068]
Scotland-Advantaged		-0.007(0.021)	[-0.048, 0.033]
Scotland-Disadvantaged		0.027(0.020)	[-0.012, 0.067]
Northern Ireland-Advantaged		-0.024(0.018)	[-0.058, 0.011]
Northern Ireland-Disadvantaged		0.032(0.016)	[-0.000, 0.064]
In urban area	2, 3, 4	-0.008(0.012)	[-0.032, 0.015]
Air pollution (PM_{10})	2, 3, 4	0.001(0.002)	[-0.003, 0.006]
Neighbourhood greenspace	2, 3, 4	-0.003(0.002)	[-0.007, 0.001]
Below the poverty line	2, 3, 4	-0.000(0.008)	[-0.016, 0.016]
University education (mother)	4	-0.061(0.009)**	[-0.078, -0.043]
Two natural parents	2, 3, 4	-0.043(0.009)**	[-0.060, -0.025]
Moved home	2, 3, 4	0.023(0.007)**	[0.010, 0.036]
Maternal depression	2, 3, 4	0.015(0.001)**	[0.013, 0.017]
Own home	2, 3, 4	-0.064(0.010)**	[-0.083, -0.046]
Female	2	-0.056(0.007)**	[-0.071, -0.042]
Child ethnicity (reference White)	2		
Mixed		0.000(0.025)	[-0.048, 0.049]
Indian		0.067(0.033)*	[0.002, 0.132]
Pakistani and Bangladeshi		0.062(0.021)**	[0.021, 0.102]
Black or Black British		-0.086(0.025)**	[-0.135, -0.036]
Other ethnic group		-0.021(0.044)	[-0.108, 0.066]
Child IQ	3	-0.003(0.000)**	[-0.003, -0.002]
Constant		2.06(0.086)**	[1.888, 2.225]
Level 2 (child-level)			
Intercept variance		0.085(0.002)	[0.081, 0.088]
Slope (age) variance		0.000(0.000)	[0.000, 0.000]
Intercept/slope covariance		0.000(0.000)	[0.000, 0.000]
Level 3 (ward-level)			
Intercept variance		0.001(0.000)	[0.001, 0.002]

Note. Age was measured in months. Age and age^2 are grand mean centred. For fixed effects: *p < .05, **p < .01.

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Highlights:

- Explored the impact of the indoor household environment on children's self-regulation trajectories
- Included several measures of the indoor home environment
- Accounted for social and environmental covariates
- Various indices of the indoor home environment uniquely predicted self-regulation