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Does environment influence childhood BMI? A longitudinal analysis of children aged 3 to 11

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ABSTRACT

Background: Childhood overweight/obesity has been associated with environmental context, such as green space, gardens, crime and deprivation. This paper assesses the longitudinal association between environment and body mass index (BMI) for children across the ages of 3-11 years. It also investigates the relationship between environment and child overweight/obesity

Methods: 6001 Children from the UK Millennium Cohort Study living in England were analysed. We estimated fixed effects linear and logistic regression models of the association between environment (levels of green space, gardens, crime and deprivation) and BMI/overweight of children at four time points between the ages of 3 and 11. Models were adjusted for age-related changes in weight, child sex, and education level of the main carer.

Results: Statistically significant associations were found between environmental measures of both more gardens and lower levels of crime and lower BMI (effect size [95% confidence interval (CI)] respectively: -0.02 [-0.04–0.00], -0.04 [-0.07– -0.02]). Areas with less crime were associated with a slightly lower odds of overweight among children with a higher educated parent (odds ratio [OR] 0,93 [0,87 – 0,99])

Conclusions: By exploiting longitudinal measures of environment and BMI this study is able to establish a more causal association between environment and BMI. Environments with more gardens and lower crime tend to result in slightly lower BMI. However, the effect sizes are small and non-significant odds of changing weight status do not support environmental factors as a key determinant of cohort changes in childhood overweight/obesity.

What is already known?

Several studies have shown positive associations between environmental characteristics such as the amount of green space, recreational areas and access to a garden and a child's weight status or BMI. Similarly, negative relationships have been shown for higher levels of crime or a negative perception of the neighbourhood by the parents.

What this study adds?

Assessing causality using a randomised controlled trial is impossible for studies on environmental characteristics but due to the longitudinal nature of the cohort and method of analysis, this study gets closer to assessing causality. The study shows it is unlikely that previously identified relations between environment and childhood weight status are causal. Effect sizes for the relationship between environments with fewer gardens and more crime on higher BMI are small, and are not-significant for other measures of environment. Future studies might benefit from closer attention to selection into neighbourhoods with more or less green space, and revisit assumptions about the ways in which environments independently impact children's activity.

INTRODUCTION

The prevalence of overweight or obese children has increased over the last three decades to 124 million in 2016.[1] In the UK, a country with one of the highest rates of childhood obesity, recent figures show that one in five children are obese. [1] Children who are overweight or obese are at higher risk of developing social- or health related problems.[2,3]

The primary cause of children being overweight or obese is an imbalance between the food intake and caloric expenditure in daily life.[4] The cause of this imbalance is complex and multifactorial.[5,6] A widely accepted model of a child's weight status is the ecological model.[6] In this model the child's personal characteristics and individual risk factors are nested within the family context, incorporating parenting style and other family characteristics, which in turn is nested within the community, and wider social context. Examples of the wider social context are socio-economic inequities, food availability and (cultural) food choices and characteristics of the living environment. Each layer of the ecological model can both influence and interact with family and child characteristics to facilitate or inhibit dietary and physical activity patterns. For example, participation in outdoor activities are shaped not only by parenting orientations but also by community safety (e.g. crime rates), access to recreational facilities such as parks and playgrounds, and the quality and condition of those amenities.

A number of cross-sectional studies have demonstrated associations between environment and the level of physical activity, waist circumference or body mass index (BMI) of children. The availability of parks or green space[7–10] and recreational areas[11,12] was shown to have a moderate association with children's levels of physical activity or their weight. In contrast, one study based on repeat cross-sectional surveys over a period of 7 years did not show an association between an increase of the amount of green space for recreational use or the green appearance in deprived neighbourhoods on adults' physical activity.[13]

Neighbourhood safety measures as increased levels of crime[14–17] or a perception of a less attractive neighbourhood[11,18–20] have also been associated with less physical activity or greater BMI, although there is discussion about the underlying mechanisms. For example, one study showed that lower crime rates were associated with an increase of walking.[21]

Thus far, however, our knowledge is primarily based on cross-sectional studies. Causal relationships have yet to be established between environmental factors and the weight development of children.[6,22] The present study therefore aims to enhance our understanding of the causal relationship between environment, comprising level of green space, gardens, crime or multiple deprivation of a neighbourhood, and children's BMI by exploiting a longitudinal study with repeat measures on individual children and their circumstances at ages 3, 5, 7 and 11.

METHODS

Study design

The study uses the Millennium Cohort Study (MCS) which has collected data about and from the children at five points between the ages of around 9 months and around 11 years.[23] Additionally, we used measures of the amount of green space, gardens and crime rates and the level of deprivation in the local area of these children at each time point, focusing only on those living in England and for whom complete information on all relevant variables was available across all sweeps (N=6001). By taking account of idiosyncratic individual level factors through repeat observations, we can more directly estimate the causal effect of environment on child BMI. Moreover, we can also directly estimate the relationship between change in environment and change in BMI at the child level.

Data

The MCS is a multi-topic multi-purpose longitudinal cohort survey of 18818 children born between September 2000 and January 2002 in the United Kingdom. UK Cohort members were sampled from child benefit records relating to children born within this period. A stratified clustered sample design was employed to over-represent children living in disadvantaged areas and from ethnic minority groups.[24] At the first survey, the cohort children were aged around nine months.[25] They have since been followed up at around age three (2003-2004: MCS2),[26] five (2005-2006: MCS3),[27] seven (2007-2008: MCS4)[28] and eleven (2011-2012: MCS5).[29] Information was collected from in-home interviews (by trained interviewers) with the main responder of the cohort child, typically the natural mother, and with the main responder's partner – typically the father. From age 3, physical measures and assessments were carried out in the home with the cohort children. For our sample, we focused on singleton children living in England at each survey sweep amounting to 8127 children and families. Many studies have shown that the level of education of the main carer has a significant influence on the child's BMI.[20,30] Since this study aims to evaluate the longitudinal influence of environment on a child's BMI, we wanted to maintain other possible influences consistently throughout the sweeps. Therefore the children where the main responder was not the same person throughout all sweeps (n=2126) were excluded, resulting in a total sample size of 6001**.**

Outcome measure

The anthropometric were assessed by trained interviewers, who had to demonstrate that they could carry them out according to the protocol and were certified prior to fieldwork. Children were weighed and measured, without shoes or outdoor clothing using Tanita HD-305 scales (Tanita UK Ltd., Middlesex, UK) and Leicester Height Measure Stadiometers (Seca Ltd., Birmingham, UK). Weight and height were recorded in kilograms to the first decimal place and centimetres to the nearest millimetre respectively. Body Mass Index (BMI) was calculated from these measures (weight (kg)/ height^2 (m^2)), as a continuous measure.

Independent variables

The amount of green space and gardens in a neighbourhood and the level of crime and multiple deprivation were assessed at the Lower Level Super Output Area (LSOA). LSOAs are geographical units for reporting small-area statistics in England.[31] There are 32 482 LSOAs in England and each area contains 400-1200 households.[31] For each LSOA a distinction was made between green spaces and garden areas and other types of land use (i.e. domestic buildings, non-domestic buildings, road, rail, path and water). The distribution of green space and gardens across English LSOA's were then ranked and divided into tenths, with 1 representing the least green space and 10 representing the most green space. The tenth of the LSOA in which the cohort child was living at the time was linked to the child's record at the postcode level, thereby allocating them to a given tenth of the distribution of green space at each survey.

For both crime and multiple deprivation, we used the Indices of Multiple Deprivation (IMD) from the Office of the Deputy Prime Minister Indices of Multiple Deprivation 2004.[32] Crime rates were derived from the crime component of Police Force data on four criminal offences (burglary, theft, criminal damage and violence) between April 2002-March 2003. These were measured at the Crime and Disorder Reduction Partnership (CDRP) level.[33] The indices of multiple deprivation also provide scores and rankings at the LSOA level for a weighted measure combining information on low income, employment, health & disability, education and skills, housing and services, crime and environment t. We linked the decile rank of each measure for the LSOA where the child was living at each sweep, based on the child's postcode. In line with the ranking used in the IMD, the ranks ran from 1=most deprived / most crime to 10=least deprived, least crime.

Analytical approach

To evaluate the (longitudinal) effect of environment (e.g. level of green space, gardens, crime and multiple deprivation) on child's BMI (measured as a continous outcome) we estimated a linear fixed effects regression model, exploiting the repeat measures on individuals in the longitudinal data (xtreg, *Stata Statistical Software: Release 15*. StataCorp LLC).

A fixed effects model does not require the assumption that individual specific effects are uncorrelated with the independent variables. It nets out time-constant individual-level characteristics, resulting in within-child estimates. It is identified by change in the dependent and independent variables. Fixed effects models offer a better approximation to a causal estimate of the association between environment and BMI than cross-sectional estimates, since the latter may be affected by individual-level unobserved heterogeneity influencing both the selection into the area and the outcome. We additionally estimated fixed effects logistic regression model of normal versus overweight/obesity using appropriate age and sex specific cut off values.[34] We estimated these models only for those measures that were significant in the linear model.

All analyses were adjusted for the age of the child at the time of the assessment. BMI of children changes according to their development, regardless of other influences[34] and therefore should be accounted for when evaluating other influences on longitudinal changes of BMI in childhood. We evaluated which polynomial function of age would adjust for most variance (age, age^2, age^3 or age^4) by stepwise comparison of the -2loglikelihood of each addition. Age^4 significantly accounted for most variance and was subsequently added to all analyses.

First, analyses with each individual independent variable were conducted. The environmental variables that were independently predictive of BMI ($p<0.2$) were subsequently combined in the full model. In the multivariate model, predictors were removed stepwise until all predictors were significant at $p \leq 0.1$. This multivariate model was subsequently tested for effect modification for both the self-reported highest obtained level of education of the main carer and the sex of the child. Lower levels of parental education have been shown to increase the chances of childhood overweight or obesity or higher BMI, and parental education can also moderate the environmental effects on the child's weight status.[20,35] In relation to sex of the child, studies have shown that physical activity and playing outside differ between boys and girls.[35,36] We therefore considered it important to address whether environmental effects differed by level of parental education and the sex of the child. Based on previous work with these data, education level was dichotomised into secondary school vs vocational training or higher.[20]

Sensitivity Analysis

We performed a sensitivity analysis excluding age 3 data, since older children might be expected to play outside more often.

RESULTS

Table 1 shows the characteristics of the participants at each age (survey) and summarises the changes in their environment between each pair of surveys. The MCS data represents this recognized pattern found earlier by Cole *et al.*[34] The rates of normal weight, overweight and obesity are derived from widely used age and sex specific cut off values.[34]

Table 1. Participant's characteristics.

Total		6001							
Male (%)		2986	(49,8)	**Education level main Respondent (%)**					
Female (%)		3015	(50,2)	Secondary school	1855	(11,1)			
BMI avg (SD)	age 3	16,4	(2,1)	Vocational training	883	(30,9)			
	age 5	16,1	(2,4)	Undergraduate	2027	(14,7)			
	age 7	16,5	(2,3)	Post graduate or higher	571	(33,8)			
	age 11	19,1	(3,6)	Other	665	(9,5)			
	AGE (year)	**3**		**5**		**7**		**11**	
		n	%	n	%	n	%	n	%
Weight category	Normal	4360	72,7	4750	79,2	4834	80,6	4295	71,6
	Overweight	951	15,8	901	15,0	828	13,8	1200	20,0
	Obese	295	4,9	304	5,1	339	5,6	357	5,9
	Missing	395	6,6	46	0,8	0	-	149	2,5
PERIOD BETWEEN AGE		**9 mtns- 3y**		**3-5 y**		**5-7 y**		**7-11 y**	
CHANGE IN:		n	%	n	%	n	%	n	%
Green space	Less	504	8,4	356	5,9	285	2,8	438	7,3
	No change	4474	74,6	5111	85,1	5256	91,5	4951	82,5
	More	988	16,4	484	8,2	405	4,7	562	9,4
	Missing	35	0,6	50	0,8	55	0,9	50	0,8
Garden	Less	763	12,7	438	7,3	370	6,2	472	7,9
	No change	4435	73,9	5100	85,0	5241	87,3	4935	82,2
	More	541	12,8	414	6,9	336	5,6	545	9,1
	Missing	34	0,6	49	0,8	54	0,9	49	0,8
Crime	Less	626	10,4	375	6,2	273	4,5	372	6,2
	No change	4484	74,7	5114	85,2	5276	87,9	4992	83,2
	More	857	14,3	463	7,8	398	6,7	583	9,7
	Missing	34	0,6	49	0,8	54	0,9	54	0,9
Deprivation	Less	517	8,6	294	4,9	220	3,7	352	5,9
	No change	4577	76,3	5157	85,9	5324	88,7	5016	83,6
	More	873	14,5	501	8,4	403	6,7	569	9,4

Missing	34	0,6	49	0,8	54	0,9	64	1,1

The initial analyses for each independent variable separately showed a statistically significant relationship for the levels of crime and the amount of gardens in the area with BMI (Table 2). An increase in in the rank of the crime measure (i.e. less crime) or an increase in the rank of the gardens measure (i.e. more gardens) was associated with significantly lower BMI.

Table 2 Linear regression fixed effect analyses; for each independent variable separate.

		Main model			Sensitivity analysis 5-11 years		
		B1	(95% CI)	p-value	B1	(95% CI)	p-value
Independent variables	Green	-0,010	(-0,032 - 0,012)	0,380	0,000	(-0,026 - 0,027)	0,982
	Garden	-0,019*	(-0,040 - 0,001)	0,066	-0,023*	(-0,047 - 0,002)	0,074
	Crime	-0,042*	(-0,068 - -0,015)	0,002	-0,037*	(-0,069 - -0,005)	0,024
	Deprivation	-0,018	(-0,046 - 0,011)	0,221	0,000	(-0,034 - 0,035)	0,980

* p ≤ 0,2 variables into multivariable model

The multivariate model shows similar results (Table 3; main model). Both the highest obtained level of education (dichotomous) of the main carer and sex of the child were effect modifiers. Therefore, we performed stratified analyses (Table 3). These showed that more crime (a lower rank) was associated with higher BMI for boys, while fewer gardens was associated with higher BMI for girls. Turning to education, both higher crime and fewer gardens were significantly associated with increased child BMI for higher educated parents. Neither levels of crime, nor the amount of gardens seem to have an effect on child BMI for those with a lower educated main carer.

Table 3 Linear fixed effect regression analyses, multivariate models

		Multivariable model					
		Main model			Sensitivity analysis 5-11 years		
		B1	(95% CI)	p-value	B1	(95% CI)	p-value
	Garden	-0,020*	(-0,041 – 0,001)	0,056	-0,024*	(-0,048-0,001)	0,062
	Crime	-0,042**	(-0,069 - -0,016)	0,002	-0,038**	(-0,070- -0,006)	0,020
		Stratified for sex and education level					
		B1	(95% CI)	p-value	B1	(95% CI)	p-value
Male	Garden	-0,010	(-0,041 - 0,021)	0,524	-0,003	(-0,039 - 0,034)	0,890
	Crime	-0,061**	(-0,102 - -0,021)	0,003	-0,029	(-0,077 - -0,019)	0,237
Female	Garden	-0,029**	(-0,057 - -0,002)	0,036	-0,043**	(-0,077 - -0,010)	0,012
	Crime	-0,029	(-0,063 - 0,006)	0,101	-0,048**	(-0,091 - -0,006)	0,025
		B1	(95% CI)	p-value	B1	(95% CI)	p-value
NVQ1[a]	Garden	-0,016	(-0,056 - 0,023)	0,411	-0,032	(-0,079 – 0,015)	0,178
	Crime	0,018	(-0,033 - 0,069)	0,500	0,007	(-0,056 – 0,071)	0,820
NVQ2[b]	Garden	-0,021*	(-0,046 - -0,003)	0,086	-0,020*	(-0,049 - 0,009)	0,175
	Crime	-0,062**	(-0,093 - -0,031)	0,000	-0,053*	(-0,090 - -0,016)	0,005

Independent variables Garden and Crime added from individual analyses (table 2).
*significant findings (p ≤0.1); ** significant at p<0.05
[a]NVQ1; secondary school
[b]NVQ2; vocational training or higher

Turning to whether these effects increased the probability of overweight, the fixed effect logistic regression of normal versus overweight showed that neither levels of crime, nor of gardens affected weight status (Table 4). After stratification for the child's sex, however, consistent with our main model of BMI, we did find lower odds of overweight for boys in areas with lower crime levels (Table 4). After stratification for education level of the main carer. We also found that lower levels of crime were related to lower odds of being overweight among those children with parents with a higher level of education.

Table 4 Logistic fixed effect regression analyses

		Multivariate model					
		Main model			Sensitivity analysis 5-11 years		
		OR	(95% CI)	p-value	OR	(95% CI)	p-value
	Garden	1,007	(0,967 – 1,050)	0,723	0,974	(0,919 – 1,033)	0,377
	Crime	0,961	(0,911 – 1,013)	0,142	0,971	(0,899 – 1,049)	0,460
		Stratified by child sex and parental education level					
		OR	(95% CI)	p-value	OR	(95% CI)	p-value
Male	Garden	1,004	(0.948 – 1.064)	0,524	0,963	(0,883 – 1,050)	0,391
	Crime	0,939*	(0,872 – 1,011)	0,097	0,997	(0,892 – 1,113)	0,951
Female	Garden	1,010	(0,952 – 1,071)	0,737	0,986	(0,910 – 1,068)	0,728
	Crime	0,985	(0,912 – 1,064)	0,705	0,945	(0,847 – 1,054)	0,312
		OR	(95% CI)	p-value	OR	(95% CI)	p-value
NVQ1[a]	Garden	0,958	(0,889 – 1,032)	0,259	0,936	(0,844 – 1,037)	0,206
	Crime	1,026	(0,932 – 1,129)	0,601	1,052	(0,907 – 1,221)	0,503
NVQ2[b]	Garden	1,030	(0,980 – 1,083)	0,239	0,995	(0,926 – 1,069)	0,884
	Crime	0,931**	(0,872 – 0,994)	0,033	0,942	(0,859 – 1,033)	0,204

Independent variables Garden and Crime chosen based on the lineair regression fixed effect model (table 3).
*Results are statistically significant at p ≤0.1 **p<0.05
[a]NVQ1; secondary school
[b]NVQ2; vocational training or higher

Sensitivity analysis

Excluding 3-year-olds from the analysis resulted in some small differences to our results: for the age 5-11 age range crime levels were significantly associated with BMI for girls but not for boys; but the effects for higher educated parents were consistent (Table 3, sensitivity analysis). In the logistic regression models, the marginal effects of crime were no longer statistically significant (Table 4, sensitivity analysis).

DISCUSSION

The aim of our study was to enhance our understanding of the relationship between environment, comprising level of green space, gardens, crime or multiple deprivation of a neighbourhood, and children's BMI by exploiting a longitudinal study with repeat measures on individual children and their circumstances at ages 3, 5, 7 and 11. Previous studies have found cross-sectional relationships between environmental variables such as the amount of green space or parks,[7–10,20] the level of crime[14–16] or recreational land use[11,12] and a child's weight status. We found a slight decrease in BMI when a child lives in an area with more gardens or less crime. These results were robust to the exclusion of three-year-olds. These relationships were, however, modified by education level of the main respondent and the sex of the child. The effect sizes of these associations are small. Moreover, we found no effects of gardens on children's chances of being overweight, and only effects of crime for higher educated parents or, at marginally significant levels, boys.

Our findings do not, therefore, fully corroborate the cross-sectional relationships previously found between BMI or weight status of a child and the level of green in the environment.[7–10,20] Our analyses did show that living in an area with more gardens was associated with a lower BMI. This can be interpreted in two ways. It might be that more gardens in an environment for younger children is similar in effect to more green (i.e. parks) for older children. Gardens might provide an environment to play and be active with easier supervision than a park or playground. Our results might also imply that environmental variables like parks, recreational areas, and green spaces that have been shown to be related to childhood BMI or physical activity in cross-sectional studies[7–10,20] have been a proxy for underlying mechanisms, properties or decisions. For instance, parents who want to promote physical activity in their children might actively seek to live in a facilitating environment. Our findings might corroborate the latter interpretation, particularly given the moderation by parental educational level.

The model showed that less crime in the environment is associated with lower BMI. Other studies have shown an increase in physical activity or a decrease in weight related measures when the perception of the environment is positive.[7,19,36,37] It may be that the level of crime in a neighbourhood is associated with a change in perception of the neighbourhood and therefore a change in physical activity or related behaviour, leading to a change of BMI. Another interpretation could be that levels of crime are related to social capital.[38,39] Neighbourhoods with more social cohesion have lower crime rates;[39] and social cohesion or social capital on a personal level, has been shown to explain 52-70% of the perception of a neighbourhood. Higher social capital in itself can be related to increased duration of weekly walking[21] or more physical activity in adults.[40]

Another contributing factor that is widely reported is socioeconomic status (SES) of the carer(s) and the sex of the child. Most studies that found cross-sectional associations, have adjusted for SES-related variables such as level of education,[9,10,19,20] (level of) income[7,10] or marital status.[9] Our model showed that relationships between the environment and a child's BMI differ for children growing up with parents with different levels of education. It is likely that what is considered to be a suitable environment for children to play in, varies by level of education and the sex of the child. The difference in effects of environment on BMI that we found between boys and girls are consistent with those found in other studies.[30,35]

Even though we found significant relations between changes of environment and changes of BMI of the children, the size of the change of BMI is small (ranging from 0.02 to 0.06 kg/m^2 per decile increase). To provide some perspective, the mean difference between the normal weight group and the overweight/obese group is 5.5 kg/m^2. Although we showed that a change in level of deprivation leads to a change in BMI, the clinical and societal relevance of this change is small. The model of weight status illustrates the limited effect of environment on weight status, and corroborates the lack of clinical relevance of the linear model findings. The only effect was that a decrease of crime slightly reduces the odds of overweight for boys or children from higher educated parents; but even this finding was not robust to our sensitivity analysis, suggesting there may be other mechanisms at play.

Ours is the first study that exploits repeat measures on environment and childhood BMI, and therefore allows us to better estimate the causal relationship between the two. The study provided enough power to evaluate the effect of changes in environment on BMI. However, the results have to be interpreted in light of its limitations. At the second MCS sweep (age three) access to a garden was evaluated for every family. Unfortunately, this was not assessed at subsequent surveys. We therefore employed the amount of gardens in the LSOA as opposed to the actual access to a garden. Furthermore, both the level of crime and the level of deprivation of neighbourhoods are based on the 2004 assessment of these variables.[32] This means that changes in the nature of areas between 2004 and 2011/2012 (the last sweep used for this study) have not been taken into account. Instead, our measures of change are driven by family moves.

CONCLUSION

Previous studies showed a moderate relation between environment and a child's BMI or level of physical activity. Our results suggest that it is less likely that these relationships are causal. Our findings instead suggest that environmental variables such as the amount of parks, recreational facilities or the level of multiple deprivation of a neighbourhood may be driven by selection. That is, those families that are less likely to have overweight children are more likely to choose to live in greener areas. We found an association between the level of crime and amount of gardens in the child's neighbourhood and their BMI. However, the size of change could be deemed of limited clinical and societal relevance, and did not translate into changes in weight status.

Based on our findings, future studies might do well to revisit assumptions about the ways in which environments can independently impact children's activity.

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ETHICS STATEMENT

The South West and London Multi-Centre Research Ethics Committees approved data collection for MCS sweeps 1-4 and the Northern and Yorkshire REC approved MCS sweep 5 data collection.[23]

AUTHORS CONTRIBUTIONS

BZ contributed to study design, data analysis, data interpretation, literature search, generation of tables, writing of the manuscript and led the writing of the manuscript. AS contributed to study design, data analysis, data interpretation, literature search, generation of tables and writing of the manuscript. GN and PE contributed to study design, data interpretation and writing of the manuscript. LP contributed to study design, data collection, data analysis, data interpretation and writing of the manuscript. All authors read and approved the final manuscript.

CONFLICT OF INTERREST

The authors declare that they have no competing interests.

EXCLUSIVE LICENCE

REFERENCES

1. NCD Risk Factor Collaboration (NCD-RisC) L, Abdeen ZA, Hamid ZA, et al. Worldwide trends in body-mass index, underweight, overweight, and obesity from 1975 to 2016: a pooled analysis of 2416 population-based measurement studies in 128·9 million children, adolescents, and adults. *Lancet (London, England)*. 2017;390(10113):2627-2642. doi:10.1016/S0140-6736(17)32129-3.
2. Singh AS, Mulder C, Twisk JWR, van Mechelen W, Chinapaw MJM. Tracking of childhood overweight into adulthood: a systematic review of the literature. *Obes Rev*. 2008;9(5):474-88. doi:10.1111/j.1467-789X.2008.00475.x.
3. Guh DP, Zhang W, Bansback N, Amarsi Z, Birmingham CL, Anis AH. The incidence of co-morbidities related to obesity and overweight: a systematic review and meta-analysis. *BMC Public Health*. 2009;9:88. doi:10.1186/1471-2458-9-88.
4. Katan MB, Ludwig DS. Extra calories cause weight gain--but how much? *JAMA*. 2010;303(1):65-6. doi:10.1001/jama.2009.1912.
5. Han JC, Lawlor DA, Kimm SYS. Childhood obesity. *Lancet (London, England)*. 2010;375(9727):1737-48. doi:10.1016/S0140-6736(10)60171-7.
6. Birch LL, Ventura AK. Preventing childhood obesity: what works? *Int J Obes*. 2009;33:S74-S81. doi:10.1038/ijo.2009.22.
7. Bell JF, Wilson JS, Liu GC. Neighborhood greenness and 2-year changes in body mass index of children and youth. *Am J Prev Med*. 2008;35(6):547-53. doi:10.1016/j.amepre.2008.07.006.
8. Casey R, Oppert JM, Weber C, et al. Determinants of childhood obesity: what can we learn from built environment studies? *Food Qual Prefer 31(1)*. 2011:164-172. doi:10.1016/j.foodqual.2011.06.003.
9. Epstein LH, Raja S, Daniel TO, et al. The built environment moderates effects of family-based childhood obesity treatment over 2 years. *Ann Behav Med*. 2012;44(2):248-58. doi:10.1007/s12160-012-9383-4.
10. Sanders T, Feng X, Fahey PP, Lonsdale C, Astell-Burt T. Green Space and Child Weight Status: Does Outcome Measurement Matter? Evidence from an Australian Longitudinal Study. *J Obes*. 2015;2015:194838. doi:10.1155/2015/194838.
11. Ding D, Sallis JF, Kerr J, Lee S, Rosenberg DE. Neighborhood environment and physical activity among youth a review. *Am J Prev Med*. 2011;41(4):442-55. doi:10.1016/j.amepre.2011.06.036.
12. McCormack GR, Shiell A. In search of causality: a systematic review of the relationship between the built environment and physical activity among adults. *Int J Behav Nutr Phys Act*.

2011;8(1):125. doi:10.1186/1479-5868-8-125.

13. Droomers M, Jongeneel-Grimen B, Kramer D, et al. The impact of intervening in green space in Dutch deprived neighbourhoods on physical activity and general health: results from the quasi-experimental URBAN40 study. *J Epidemiol Community Health*. 2016;70(2):147-54. doi:10.1136/jech-2014-205210.
14. Brodersen NH, Steptoe A, Williamson S, Wardle J. Sociodemographic, developmental, environmental, and psychological correlates of physical activity and sedentary behavior at age 11 to 12. *Ann Behav Med*. 2005;29(1):2-11. doi:10.1207/s15324796abm2901_2.
15. Gómez JE, Johnson BA, Selva M, Sallis JF. Violent crime and outdoor physical activity among inner-city youth. *Prev Med (Baltim)*. 2004;39(5):876-81. doi:10.1016/j.ypmed.2004.03.019.
16. Gordon-Larsen P, McMurray RG, Popkin BM. Determinants of adolescent physical activity and inactivity patterns. *Pediatrics*. 2000;105(6):E83.
17. Lovasi GS, Schwartz-Soicher O, Quinn JW, et al. Neighborhood safety and green space as predictors of obesity among preschool children from low-income families in New York City. *Prev Med (Baltim)*. 2013;57(3):189-93. doi:10.1016/j.ypmed.2013.05.012.
18. Bauman AE, Reis RS, Sallis JF, Wells JC, Loos RJF, Martin BW. Correlates of physical activity: why are some people physically active and others not? *Lancet*. 2012;380(9838):258-71. doi:10.1016/S0140-6736(12)60735-1.
19. Schmidt SC, Sleddens EFC, de Vries SI, Gubbels J, Thijs C. Longitudinal association of neighborhood variables with Body Mass Index in Dutch school-age children: The KOALA Birth Cohort Study. *Soc Sci Med*. 2015;135:99-108. doi:10.1016/j.socscimed.2015.04.018.
20. Schalkwijk AAH, van der Zwaard BC, Nijpels G, Elders PJM, Platt L. The impact of greenspace and condition of the neighbourhood on child overweight. *Eur J Public Health*. 2017. doi:10.1093/eurpub/ckx037.
21. Foster S, Hooper P, Knuiman M, Christian H, Bull F, Giles-Corti B. Safe RESIDential Environments? A longitudinal analysis of the influence of crime-related safety on walking. *Int J Behav Nutr Phys Act*. 2016;13:22. doi:10.1186/s12966-016-0343-4.
22. Mitchell R, Popham F. Effect of exposure to natural environment on health inequalities: an observational population study. *Lancet (London, England)*. 2008;372(9650):1655-60. doi:10.1016/S0140-6736(08)61689-X.
23. Connelly R, Platt L. Cohort Profile: UK Millennium Cohort Study (MCS). *Int J Epidemiol*. 2014;43(6):1719-1725. doi:10.1093/ije/dyu001.
24. Plewis I. *The Millennium Cohort Study: Technical Report on Sampling Centre for Longitudinal Studies*. London; 2007. Available at: http://www.cls.ioe.ac.uk/library-

media/documents/Technical_Report_on_Sampling_4th_Edition.pdf. Accessed July 19, 2017.

25. University of London. Institute of Education. Centre for Longitudinal Studies, Millennium Cohort Study: First Survey, 2001-2003 [computer file]. 11th Edition. Colchester, Essex: UK Data Archive [distributor], December 2012. SN: 4683 , http://dx.doi.org/10.5255/UKDA-SN-4683-3.
26. University of London. Institute of Education. Centre for Longitudinal Studies, Millennium Cohort Study: Second Survey, 2003-2005 [computer file]. 8th Edition. Colchester, Essex: UK Data Archive [distributor], December 2012. SN: 5350 , http://dx.doi.org/10.5255/UKDA-SN-5350-3
27. University of London. Institute of Education. Centre for Longitudinal Studies, Millennium Cohort Study: Third Survey, 2006 [computer file]. 6th Edition. Colchester, Essex: UK Data Archive [distributor], December 2012. SN: 5795 , http://dx.doi.org/10.5255/UKDA-SN-5795-3
28. University of London. Institute of Education. Centre for Longitudinal Studies, Millennium Cohort Study: Fourth Survey, 2008 [computer file]. 4th Edition. Colchester, Essex: UK Data Archive [distributor], December 2012. SN: 6411 , http://dx.doi.org/10.5255/UKDA-SN-6411-3
29. University of London. Institute of Education. Centre for Longitudinal Studies. (2017). Millennium Cohort Study: Fifth Survey, 2012. [data collection]. 4th Edition. UK Data Service. SN: 7464, http://doi.org/10.5255/UKDA-SN-7464-4
30. Frederick CB, Snellman K, Putnam RD. Increasing socioeconomic disparities in adolescent obesity. *Proc Natl Acad Sci U S A*. 2014;111(4):1338-42. doi:10.1073/pnas.1321355110.
31. Office for National statistics (ONS). Super Output Area (SOA). Available at: http://www.ons.gov.uk/ons/guide-method/geography/beginner-s-guide/census/super-output-areas--soas-/index.html. Accessed January 27, 2016.
32. Office of the Deputy Prime Minister. *The English Indices of Deprivation 2004*. London; 2004. Available at: http://webarchive.nationalarchives.gov.uk/20120919132719/www.communities.gov.uk/documents/communities/pdf/131209.pdf. Accessed January 27, 2016.
33. Office of the Deputy Prime Minister. *Indices Summary*.; 2004. Available at: http://webarchive.nationalarchives.gov.uk/20100410180038/http://www.communities.gov.uk/documents/communities/pdf/131206.pdf. Accessed June 21, 2017.
34. Cole TJ, Bellizzi MC, Flegal KM, Dietz WH. Establishing a standard definition for child overweight and obesity worldwide: international survey. *BMJ*. 2000;320(7244):1240-3.
35. Ogden CL, Carroll MD, Kit BK, Flegal KM. Prevalence of childhood and adult obesity in the United States, 2011-2012. *JAMA*. 2014;311(8):806-14. doi:10.1001/jama.2014.732.

36. Timperio A, Giles-Corti B, Crawford D, et al. Features of public open spaces and physical activity among children: findings from the CLAN study. *Prev Med (Baltim)*. 2008;47(5):514-8. doi:10.1016/j.ypmed.2008.07.015.
37. Evenson KR, Scott MM, Cohen DA, Voorhees CC. Girls' perception of neighborhood factors on physical activity, sedentary behavior, and BMI. *Obesity (Silver Spring)*. 2007;15(2):430-45. doi:10.1038/oby.2007.502.
38. Mackenbach JD, Lakerveld J, van Lenthe FJ, et al. Exploring why residents of socioeconomically deprived neighbourhoods have less favourable perceptions of their neighbourhood environment than residents of wealthy neighbourhoods. *Obes Rev*. 2016;17 Suppl 1:42-52. doi:10.1111/obr.12375.
39. Kawachi I, Kennedy BP, Wilkinson RG. Crime: social disorganization and relative deprivation. *Soc Sci Med*. 1999;48(6):719-31.
40. De Bourdeaudhuij I, Van Dyck D, Salvo D, et al. International study of perceived neighbourhood environmental attributes and Body Mass Index: IPEN Adult study in 12 countries. *Int J Behav Nutr Phys Act*. 2015;12:62. doi:10.1186/s12966-015-0228-y.