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Early Life Disadvantage and Child Health

Early life disadvantage and adult adiposity: tests of sensitive periods during childhood and behavioural mediation in adulthood

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Abstract

Background: Early exposure to socioeconomic disadvantage is associated with obesity. Here we investigated how early, and conducted mediation analyses to identify behavioural factors in adulthood that could explain why.

Methods: Among 931 participants in the New England Family Study, we investigated the associations of family socioeconomic disadvantage measured before birth and at age 7 years with the following measures of adiposity in mid-adulthood (mean age = 44.4 years): body mass index (BMI), waist circumference and, among 400 participants, body composition from dual-energy X-ray absorption scans.

Results: In linear regressions adjusting for age, sex, race and childhood BMI Z-score, participants in the highest tertile of socioeconomic disadvantage at birth had 2.6 additional BMI units in adulthood [95% confidence interval (CI) = 1.26, 3.96], 5.62 cm waist circumference (95% CI = 2.69, 8.55), 0.73 kg of android fat mass (95% CI = 0.25, 1.21), and 7.65 higher Fat Mass Index (95% CI = 2.22, 13.09). Conditional on disadvantage at birth, socioeconomic disadvantage at age 7 years was not associated with adult adiposity. In mediation analyses, 10–20% of these associations were explained by educational attainment and 5–10% were explained by depressive symptoms.

Conclusions: Infancy may be a sensitive period for exposure to socioeconomic disadvantage, as exposure in the earliest years of life confers a larger risk for overall and central adiposity in mid-adulthood than exposure during childhood. Intervention on these two adult risk factors for adiposity would, if all model assumptions were satisfied, only remediate up to one-fifth of the excess adult adiposity among individuals born into socioeconomically disadvantaged households.

Key words: Socioeconomic disadvantage, adiposity, body mass index, fat mass, sensitive period, mediation, depressive symptoms, education

Key Messages

- This study examined socioeconomic disparities in anthropometric measures of obesity (body mass index and waist circumference) and measures of body composition from DXA scans (android fat mass, android: gynoid percent fat ratio, Fat Mass Index).
- Socioeconomic disadvantage around the time of birth was more strongly associated with adult obesity than disadvantage in childhood, resulting in higher body mass index, larger waist circumference and more android fat and total body fat.
- Educational attainment and depressive symptoms in adulthood were partial mediators (i.e. up to one-fifth) of the association between early life disadvantage and adult obesity; intervention on these factors might remediate a small portion of adult disparities.

Introduction

Socioeconomic disadvantage early in the life course is associated with excess risk of obesity, and this excess risk continues into adulthood.[1] However, it remains unclear when during childhood exposure to socioeconomic disadvantage first begins to elevate obesity risk. This information is needed to guide intervention strategies targeting early life risk factors for disparities in obesity.[2] As with any developmental process characterized by sensitive periods of heightened susceptibility to environmental influences, reducing the population prevalence of and disparities in obesity requires knowledge not only of risk factors but also of their developmental timing.

Participants in the Panel Study of Income Dynamics exposed to low family income during their first year of life had elevated body mass index (BMI) as adults; however, exposure to low family incomes after age 1 year had no lasting relationship with BMI in adulthood.[3] Interventions on income or mechanisms linked to income might therefore have no effect on obesity if not provided during the first year of life. Accordingly, the first aim of this study is to investigate sensitive periods of exposure to socioeconomic adversity during childhood—that is, times when exposure has a stronger association with adult adiposity.

The second aim is to investigate whether the consequences of childhood socioeconomic disadvantage on adult obesity might be mitigated by reducing exposure to adult risk factors. In other words, long after sensitive periods have passed, can the socioeconomic gradient in obesity be reduced? We conduct mediation analyses to estimate how much excess adiposity among adults exposed to disadvantage during childhood could be averted via intervention on six adult risk factors: educational attainment,[4,5] physical activity, fruit and vegetable consumption,[6] alcohol consumption,[7–9] cigarette smoking[10,11] and depressive symptoms.[12,13]

Methods

Sample

Participants were selected from the New England Family Study cohort, which comprises the adult offspring born 1959–66 to participants in the Boston and Providence sites of the Collaborative Perinatal Project (CPP). Between 2005 and 2007, 618 (68.8% of those selected) CPP offspring participated in a study of the pathways linking educational attainment to health;[14] between 2010 and 2011, 400 (76.6% of those selected) CPP offspring participated in a study of the early life origins of ageing in mid-life that included dual-energy X-ray absorption (DXA) scans.[15,16] There were 87 individuals who participated in both projects, resulting in a combined study sample of 931. Anthropometric measures of adiposity were investigated in the full sample, whereas measures derived from DXA scans were investigated in the subsample of 400 participants.

Measures

Socioeconomic disadvantage at birth and age 7

Responses to social history interviews administered when CPP mothers were enrolled during pregnancy and again at the child's 7-year assessment were used to construct composite measures of socioeconomic disadvantage.[17] Each measure had multiple components that were given a score of 0 (no or low disadvantage), 0.5 (medium disadvantage) or 1 (high disadvantage). The components were summed to produce a composite score categorized as low, medium or high, based on tertiles of their distribution in the study sample. The composite score included parental education (greater than high school, high school, less than high school), parental income (greater than 150% of the US poverty threshold, 100–150% of the poverty threshold, less than the poverty threshold), parental occupation (non-manual, manual, unemployed), family structure (two parents, one parent and parent divorced, separated or widowed), and household crowding (<1 person per room, 1–1.5 persons per room, >1.5 persons per room).

Adiposity

BMI in adulthood was derived from weight and height obtained from participants wearing light clothing without shoes, using a calibrated stadiometer and weighing scale operated by trained research technicians. Waist circumference was assessed by the smallest horizontal circumference between the participant's ribs and iliac crest at the end of a normal expiration. Three measures of adiposity were derived from DXA scans: android fat mass (measuring centrally located fat), android-gynoid percent fat ratio[18–20] (measuring central to hip-area body fat distribution) and total fat mass.[21–24] Fat Mass Index was corrected for height by computing the ratio of total fat (kg)/height raised to the power of −0.5 (determined from a log-log regression of fat mass on height in the study sample).[25,26] In childhood, weight and height at age 7 years were used to derive BMI Z-scores based on Centers for Disease Control and Prevention (CDC) growth charts.[27]

Hypothesized mediators of the association between early life disadvantage and adult adiposity measured in adulthood

Education was measured in years. Depressive symptoms were assessed with the 10-item Center for Epidemiologic Studies Depression Scale (CES-D).[28] Participants reported the number of cigarettes smoked per day. Physical activity was assessed using the International Physical Activity Questionnaire Short Form[29] and analysed as mean metabolic equivalent of task (MET) min per day spent engaging in moderate or vigorous physical activity. Mean daily fruit and vegetable consumption was assessed using a 25-item Food Frequency Questionnaire.[30] Average daily alcohol consumption was assessed via self-report that measured consumption of beer, wine and liquor.

Analytic methods

To address the study's first aim (identification of sensitive periods in childhood), we analysed socioeconomic disadvantage at birth alone and then together with disadvantage at age 7 years in linear regression models of adiposity. A stronger association of disadvantage at birth with adiposity than disadvantage at 7 years (adjusting for disadvantage at birth) would support a sensitive period effect of disadvantage in infancy.[31] At the time the CPP was conducted, disadvantage was associated with lower BMI in childhood; analyses of childhood socioeconomic disadvantage therefore adjusted for BMI Z-score at 7 years (and therefore are interpreted relative to the change in adiposity from childhood to adulthood). In theory this brings results in alignment with contemporary cohorts in which an early disadvantage–lower BMI association is not present; in practice it focuses interpretation on factors related to disadvantage that lead to more rather than less adiposity. Adjusting for childhood BMI in the mediation analyses also addresses potential confounding by childhood growth of the association between behavioural factors in adulthood and adiposity. Based on evidence that early life conditions have stronger effects on adult obesity in females than males,[1] we tested sex-by-disadvantage cross-product interactions in each model. Linear regression models for BMI and waist circumference included random intercepts for each of 113 sibling sets. As there were only 13 sibling sets in the DXA sample, a linear model with the ordinary least square estimator was used for the analyses of android fat mass, android-gynoid percent fat ratio and Fat Mass Index.

Mediation analyses were conducted to address the second aim by estimating the indirect effect of socioeconomic disadvantage through the adult adiposity risk factors that were associated with childhood disadvantage. Mediation analyses were implemented in Imai *et al.*'s *mediation* package in R which derives estimates of indirect effects under a counterfactual framework using nonparametric simulations; indirect effects are estimated from coefficients in two models, one for the mediator given exposures and confounders, and one for the outcome given mediators, exposures and confounders.[32–35] Given a three-level exposure

(Low, Medium and High Disadvantage), indirect effects are estimated for both the Medium vs Low and the High vs Low contrasts. For identified mediators we also estimated 'path specific' effects.[36–38] Analyses also controlled for age at adult interview, sex, and race (White vs Non-White).

Missing data across all study variables ranged from 1% to 7% (Supplementary Table 1, available as Supplementary data at *IJE* online); however, requiring the analysis sample to have complete data on all study variables would exclude nearly 20% of participants. Accordingly we imputed 100 complete datasets using fully conditional specification[39] implemented in IVEWare v0.3.[40] In addition to all analysis variables and interactions of sex with all analysis variables, the imputation models included auxiliary variables that were associated with the probability of missingness or likely predictive of the values of missing data (pregnancy and delivery complications and maternal smoking during pregnancy, offspring's birthweight, weeks of gestation at delivery and cognitive test scores during childhood). All analyses were conducted separately within each imputed dataset; point estimates were obtained by taking the average over the estimates from all imputed datasets, and the standard errors were obtained by combining the within imputation variance and the between imputation variance.[41]

Results

Characteristics of the analysis sample ($n = 931$) and the DXA subsample ($n = 400$) are presented in Table 1, which shows the distributions of socioeconomic disadvantage at the time of participants' birth and at age 7 years. Though these were moderately correlated ($r = 0.56$), 44% of participants were in different categories of disadvantage at birth and age 7. Table 1 also shows the distributions of sex (58% female), race (75% White) and age at interview (mean = 44.4 years). The mean adult BMI for the sample was 29.9 km/m^2, higher than the US average of approximately 26.5 and close to the cut-point of 30 for obesity.[42]

Table 1. Characteristics of participants in the New England Family Study project on early life disadvantage and adult adiposity[a]

	Full sample ($n = 931$) Percent (n) or mean (SE)	DXA sample ($n = 400$) Percent (n) or mean (SE)
Socioeconomic disadvantage at birth		
High	33.5 (313)	48.0 (194)
Medium	39.1 (363)	36.7 (145)
Low	27.5 (255)	15.3 (61)
Socioeconomic disadvantage at age 7 years		
High	34.5 (321)	45.5 (182)
Medium	32.1 (300)	31.3 (125)
Low	33.4 (310)	23.4 (93)
Sex		
Male	41.7 (388)	43.3 (173)
Female	58.3 (543)	56.7 (227)
Race		
White	74.8 (696)	65.0 (260)
Non-White	25.2 (140)	35.0 (140)
Mean (SE) Age at Interview	44.4 (0.1)	47.0 (0.1)
Adiposity in childhood and adulthood, mean (SE)		
BMI Z-Score at age 7	0.2 (0.03)	0.2 (0.05)
Adult BMI	29.9 (0.3)	30.3 (0.4)
Adult waist circumference, cm	97.4 (0.6)	98.7 (0.9)
Android fat mass, kg		3.1 (0.1)
Android-gynoid percent fat ratio		107.0 (2.6)
Fat Mass Index		39.6 (0.9)
Hypothesized disadvantage-adiposity mediators, mean (SE)		
Years of education	13.6 (0.1)	13.3 (0.1)
Moderate and vigorous physical activity (MET)	3046.9 (108.8)	2447.9 (162.7)
Fruits and vegetables per day	2.4 (0.7)	2.3 (0.1)
Drinks of alcohol per month	15.8 (1.0)	17.3 (1.7)
Cigarettes smoked per day	4.4 (0.3)	4.9 (0.4)
CESD scale of depressive symptoms	16.6 (0.2)	17.7 (0.3)

SE, standard error.

[a]Characteristics shown are based on the average of 100 multiply imputed datasets.

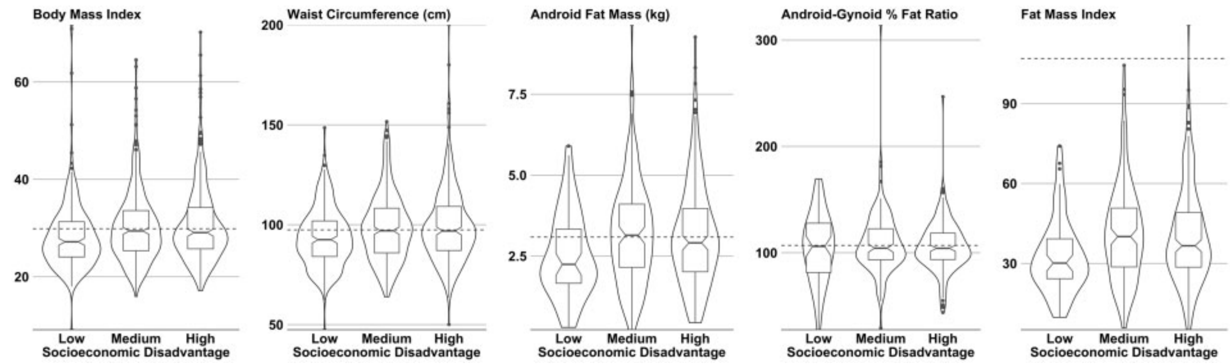

Figure 1. Distributions of adult adiposity according to socioeconomic disadvantage at birth. Violin plots show outlines of kernel density plots with box plots inside. Body mass index and waist circumference (cm) were measured in the full sample ($n = 931$); android fat mass (kg), android-gynoid percent fat ratio and fat mass index were measured in the DXA subsample ($n = 400$).

Table 2. Associations of socioeconomic disadvantage at birth and age 7 years with body size and composition in adulthood in the New England Family Study[a]

	Body mass index	Waist circumference	Android fat mass, kg	Android-gynoid percent fat ratio	Fat Mass Index
Model 1					
Socioeconomic disadvantage at birth					
High	2.61 (1.26, 3.96)	5.62 (2.69, 8.55)	0.73 (0.25, 1.21)	3.19 (−7.95, 14.33)	7.65 (2.22, 13.09)
Medium	2.23 (0.98, 3.48)	5.22 (2.39, 7.76)	0.75 (0.27, 1.23)	6.06 (−5.96, 18.07)	8.63 (3.22, 14.04)
Low	Reference	Reference	Reference	Reference	Reference
F (df = 2), P^b	8.5 (<0.001)	9.1 (<0.001)	5.2 (0.005)	0.6 (0.579)	5.0 (0.007)
BMI Z-score, age 7	2.56 (1.99, 3.13)	4.59 (3.36, 5.81)	0.44 (0.27, 0.61)	2.41 (−2.27, 7.10)	5.45 (3.49, 7.41)
Model 2					
Socioeconomic disadvantage at birth					
High	1.76 (0.19, 3.33)	3.78 (0.37, 7.18)	0.53 (−0.05, 1.12)	1.81 (−11.24, 14.85)	4.92 (−1.65, 11.49)
Medium	1.71 (0.35, 3.07)	4.19 (1.27, 7.11)	0.59 (0.03, 1.15)	5.97 (−6.64, 18.57)	6.26 (0.02, 12.51)
Low	Reference	Reference	Reference	Reference	Reference
F (df = 2), P^b	3.4 (0.034)	4.1 (0.017)	2.2 (0.115)	0.6 (0.544)	1.9 (0.147)
Socioeconomic disadvantage at age 7					
High	1.56 (0.10, 3.03)	3.56 (0.40, 6.72)	0.30 (−0.19, 0.79)	2.84 (−10.50, 16.17)	3.95 (−1.59, 9.50)
Medium	0.84 (−0.49, 2.17)	1.19 (−1.69, 4.07)	0.24 (−0.25, 0.72)	−2.40 (−13.25, 8.45)	3.85 (−1.63, 9.33)
Low	Reference	Reference	Reference	Reference	Reference
F (df = 2), P^b	2.2 (0.109)	2.6 (0.071)	0.7 (0.488)	0.5 (0.611)	1.1 (0.327)
BMI Z-score, age 7	2.59 (2.02, 3.16)	4.66 (3.34, 5.89)	0.44 (0.27, 0.61)	2.59 (−2.21, 7.38)	5.46 (3.49, 7.42)

[a]Linear regression coefficients and 95% confidence intervals from models of body mass index ($n = 931$), waist circumference ($n = 931$) android fat mass ($n = 400$), android-gynoid percent fat ratio ($n = 400$) and fat mass index ($n = 400$) also controlling for age at interview, sex and race/ethnicity.

[b]F tests and P-values correspond to the joint significance of High and Medium disadvantage.

The mean waist circumference was 97.4 cm, and in the DXA subsample, participants had on average 3.1 kg of android fat. Distributions of adult adiposity according to disadvantage at birth are presented in Figure 1 (and in Supplementary Figure 1 for males and females separately). These show, for all measures of adult adiposity except android-gynoid percent fat ratio, distributions that are shifted up with higher childhood disadvantage at birth.

In linear regression analyses of anthropometric measures of adiposity (Table 2, Model 1), high socioeconomic disadvantage at birth (relative to low disadvantage) was associated with an increase of 2.61 BMI units (95% CI: 1.26, 3.96) and 5.62 cm (95% CI: 2.69, 8.55) of waist circumference between childhood and adulthood. Children in disadvantaged households at birth had 0.7 kg (95% CI: 0.25, 1.21) more android fat in adulthood as well as 7.65 additional Fat Mass Index units (95% CI: 2.22, 13.09). No positive linear trend between disadvantage and adiposity was observed; rather, adults in the Medium and High categories of childhood disadvantage had similarly higher adiposity as adults in the Low category of disadvantage. There were no significant interactions identified between childhood disadvantage and sex.

Conversely, disadvantage at age 7 years was not strongly associated with change in adiposity since childhood, except possibly for waist circumference (Model 2, Table 2; see Supplementary Figure 2 for plots of the coefficients for disadvantage at birth and disadvantage at 7 years, to compare the strength of their associations with adult adiposity). Given the weight of evidence pointing to disadvantage at birth as the relevant period of exposure for development of adiposity in adulthood, we assessed mediated effects only for disadvantage at birth.

Socioeconomic disadvantage at birth was associated with four of the six risk factors examined for adult adiposity: education, fruit and vegetable consumption, cigarette smoking and depressive symptoms (but not physical activity or alcohol consumption). Those in the High category of disadvantage had 2.25 fewer years of education (95% CI: −2.71, −1.79), consumed 1.13 fewer daily servings of fruits and vegetables (95% CI: −1.50, −0.77), smoked 5.14 more cigarettes per day (95% CI: 3.66, 6.62), and scored 2.12 points higher on the CESD-10 scale of depressive symptoms (95% CI: 1.09, 3.14) than those with Low disadvantage (Table 3). Accordingly, mediation analyses focused on these four risk factors.

Education and depressive symptoms were identified as mediators of the associations of early life disadvantage with adult BMI and waist circumference (Table 4). The magnitude of the indirect effects should be viewed relative to the estimates of total effects in Table 2. For example, Medium (vs Low) disadvantage at birth was associated with a 2.23 higher mean BMI (Table 2); 0.37 (95% CI: 0.08, 0.70) of that increase was mediated by lower educational attainment, and 0.20 (95% CI: 0.04, 0.40) of that increase was mediated by higher depressive symptoms in adulthood. Corresponding indirect effects for the High (vs Low) category of disadvantage (which had a total effect of 2.61) were 0.55 for education (95% CI: 0.12, 1.02) and 0.27 for depressive symptoms (95% CI: 0.07, 0.52). The indirect effect estimates for education were 10–20% of the magnitude of the total effect of disadvantage on adult BMI and 15–22% on adult waist circumference; for depressive symptoms, they were nearly 5–10% of the total effects (see Supplementary Table 2 for estimates and 95% confidence intervals of the proportions of total effects mediated).

The indirect effects of depressive symptoms controlling for participants' attained education ('path specific' effects) were substantially reduced but still non-zero. For BMI, the path-specific effects of high and medium disadvantage through depressive symptoms were 0.15 (95% CI: 0.01, 0.34) and 0.11 (95% CI: 0.001, 0.28), respectively; for waist circumference, they were 0.38 (95% CI: 0.06, 0.85) and 0.29 (95% CI: 0.02, 0.69), respectively.

Among the behavioural risk factors, only cigarette smoking emerged as a mediator of the effects of disadvantage at birth on body composition. The indirect effects of cigarette smoking carried a negative sign (−1.42 for high and −0.87 for medium disadvantage); therefore, adjusting for smoking unmasks the even larger (direct) effect of disadvantage.

Discussion

This study posed two questions regarding the association between socioeconomic disadvantage during childhood and adult adiposity: (i) when during childhood is the association strongest?; and (ii) can the association be mitigated in part by reducing exposure to adult risk factors for obesity?

We addressed the first question through analyses of socioeconomic disadvantage measured before participants' birth and again when they were 7 years old. Disadvantage before birth was associated with higher BMI in adulthood, higher waist circumference, higher android fat mass and higher Fat Mass Index; these associations were generally stronger than those of disadvantage at age 7 conditional on disadvantage at birth. The prenatal period and infancy may therefore be a sensitive period for exposure to socioeconomic disadvantage; this suggests that the increase in

Table 3. Associations of socioeconomic disadvantage at birth with behavioural factors in adulthood[a]

Dependent variable	Medium vs low disadvantage	High vs low disadvantage	F, df = 2 (*P*)
Mean (SD) years of education	−1.51 (−1.93, −1.09)	−2.25 (−2.71, −1.79)	47.5 (<0.001)
Moderate and vigorous physical activity (MET)	489.9 (−37.6, 1017.3)	326.2 (−250.8, 903.1)	1.7 (0.193)
Fruits and vegetables per day	−0.51 (−0.84, −0.18)	−1.13 (−1.50, −0.77)	18.6 (<0.001)
Drinks of alcohol per month	0.20 (−4.59, 4.99)	−4.38 (−9.61, 0.84)	2.1 (0.123)
Cigarettes smoked per day	2.34 (0.99, 3.69)	5.14 (3.66, 6.62)	23.3 (<0.001)
CESD scale of depressive symptoms	1.60 (0.66, 2.53)	2.12 (1.09, 3.14)	8.9 (<0.001)

SD, standard deviation.

[a]Results of linear regression models for hypothesized adult mediators also adjusting for sex, race, BMI Z-score at age 7, and age at adult interview ($n = 931$). Regression coefficients and 95% confidence intervals shown.

Table 4. Indirect effect estimates from mediation analyses of the obesogenic effects of socioeconomic disadvantage at birth on adult body size and composition[a]

	Body mass index		Waist circumference (cm)	
	Medium vs Low disadvantage Indirect effect Estimate (95% CI)	High vs Low disadvantage Indirect effect Estimate (95% CI)	Medium vs Low disadvantage Indirect effect Estimate (95% CI)	High vs Low disadvantage Indirect effect Estimate (95% CI)
Years of education	0.37 (0.08, 0.70)	0.55 (0.12, 1.02)	0.84 (0.21, 1.56)	1.26 (0.32, 2.26)
Fruits and vegetables per day	−0.05 (−0.21, 0.09)	−0.10 (−0.40, 0.18)	−0.03 (−0.36, 0.28)	−0.07 (−0.70, 0.55)
Cigarettes smoked per day	−0.08 (−0.24, 0.06)	−0.17 (−0.50, 0.14)	0.002 (−0.31, 0.32)	0.005 (−0.67, 0.68)
Depressive symptoms	0.20 (0.04, 0.40)	0.27 (0.07, 0.52)	0.50 (0.15, 0.98)	0.69 (0.24, 1.27)

	Android fat mass (kg)		Android-gynoid percent fat ratio		Fat Mass Index	
	Medium vs Low Disadvantage Indirect effect Estimate (95% CI)	High vs Low Disadvantage Indirect effect Estimate (95% CI)	Medium vs Low Disadvantage Indirect effect Estimate (95% CI)	High vs Low Disadvantage Indirect effect Estimate (95% CI)	Medium vs Low Disadvantage Indirect effect Estimate (95% CI)	High vs Low Disadvantage Indirect effect Estimate (95% CI)
Years of education	0.09 (−0.08, 0.27)	0.12 (−0.10, 0.35)	1.03 (−3.50, 4.75)	1.35 (−4.58, 6.14)	0.57 (−1.36, 2.54)	0.75 (−1.78, 3.30)
Fruits and vegetables per day	−0.02 (−0.10, 0.04)	−0.04 (−0.16, 0.07)	0.27 (−1.66, 2.26)	0.48 (−2.80, 3.70)	−0.38 (−1.36, 0.35)	−0.67 (−2.15, 0.61)
Cigarettes smoked per day	−0.04 (−0.14, 0.03)	−0.07 (−0.21, 0.05)	0.14 (−1.66, 1.83)	0.22 (−2.64, 2.84)	−0.87 (−2.07, -0.02)	−1.42 (−3.06, -0.05)
Depressive symptoms	0.03 (−0.05, 0.12)	0.03 (−0.05, 0.13)	0.02 (−2.15, 1.63)	0.03 (−2.40, 1.80)	−0.03 (−0.96, 0.88)	−0.03 (−1.06, 0.98)

[a]Indirect effect estimates and corresponding 95% confidence intervals presented for the Medium and High categories of disadvantage at birth vs the Low disadvantage category adjusting for age at adult interview, sex, race and BMI Z-score at 7 years. Results based on a simulation-based approach in which models for the mediator and outcome were fitted and indirect effects were estimated after 10 000 simulations of the counterfactual outcomes for the Medium and High categories of the mediators.

adiposity from childhood to adulthood among individuals raised in socioeconomically disadvantaged households is due to pathways to obesity established during the first months of life. Whereas a previous report from the New England Family Study showed that disadvantage in childhood was associated with adult obesity, that study measured disadvantage cumulatively from birth through 7 years.[43] Here we identified infancy as the period when disadvantage was most strongly associated with participants' long-term risk of adiposity.

Our study demonstrates that the socioeconomic gradient in obesity, which has increased over time,[44] may have early childhood origins. Previous studies have also found sensitive periods for exposure to socioeconomic disadvantage during childhood but, as noted above, most of those studies did not examine disadvantage as early as infancy. There are several explanations for infancy being a sensitive period for exposure to disadvantage. First, obesity-related risk factors present during gestation could be more common among socioeconomically disadvantaged pregnancies. For example, Robinson *et al.*[2] reported that cumulative exposure to maternal obesity, excess gestational weight gain, smoking during pregnancy and low maternal vitamin D were associated with a higher risk of offspring obesity. Second, early growth has been shown to predict adult overweight;[45] thus, a sensitive period could reflect socioeconomic differences in growth during the earliest years of life. As our analyses adjusted for early growth, this explanation would imply that the sensitive period effect also involves factors connected to adiposity change between childhood and adulthood. Third, family-level adversities that are associated with risk for obesity may confer risk earlier than demonstrated in previous studies.[46]

We addressed the second aim of our study by conducting mediation analyses of four factors in adulthood that were associated with early life disadvantage: educational attainment, fruit and vegetable consumption, cigarette smoking and depressive symptoms. Two of these factors, education and depressive symptoms, had positive indirect effects between early life disadvantage and adult adiposity. Educational attainment is a reliable predictor of obesity.[4,47] However, quasi-experimental studies of education suggest that standard analyses such as ours may overstate the health benefits of expanding educational opportunities,[14] as educational inequalities in health may also be attributable to familial factors which increase risk of poor health before school entry. Depression and obesity are strongly related to one another in epidemiological studies.[48] Their association is bidirectional and likely includes a non-causal component due to shared risks.[49] Two additional factors, physical activity and alcohol consumption, were initially considered as potential mediators but were not pursued given that they were not associated with childhood disadvantage. Other factors unmeasured here that are important for understanding adiposity, such as caloric intake, need to be pursued in future research.

Socioeconomic disadvantage was measured in a cohort from 1959 to 1966. In the 1960s, poverty was associated with a higher risk of underweight, not overweight as it is today.[50] For that reason, we presented analyses adjusting for BMI Z-score at age 7 years. Because within a single birth cohort it is not possible to account for secular trends, we cannot establish whether or not our findings regarding sensitive periods and mediation would generalize to more recent cohorts. However, childhood disadvantage is associated with obesity in more recent generations[51–53] and our finding regarding a very early sensitive period for exposure to disadvantage is consistent with current thinking on the developmental origins of obesity.[54]

Socioeconomic disadvantage levels at birth and at age 7 years were moderately correlated with each other ($r = 0.56$), with 44% of the sample shifted into different categories of disadvantage at 7 years from their category at birth. However, the persistence of disadvantage during childhood might have presented a challenge in evaluating the relative strength of their influences on adiposity; whereas our results are consistent with a sensitive period in infancy, they do not exclude the possibility that both time points are important and thus could also support an accumulation model. In addition, with only two time points during childhood studied, we have provided only a partial test of sensitive periods. Evaluations of disadvantage at intermediary time points, as well as time points extending into adolescence, are needed.

The behavioural factors in adulthood that were used in mediation analyses were assessed concurrently with adiposity. This presents two issues: first, the temporality among the behavioural factors and adiposity could not be established; the two risk factors that emerged with indirect effects, education and depression, are known to be associated.[55] Second, current measures of the behavioural factors may not accurately reflect participants' cumulative history of them. This measurement error would likely bias mediation effects towards the null.

Conclusions

Socioeconomic disadvantage at the very beginning of life was associated with adult adiposity, based on anthropometric measures as well as by direct measures of central adiposity. If our findings regarding infancy being a 'disparity-sensitive period' for exposure to socioeconomic disadvantage are replicated, addressing disparities in obesity and related diseases will require interventions during infancy or even earlier. Our findings also need to be extended to cover a broader range of potential behavioural factors that could be targeted in adulthood. Nevertheless, if all assumptions were met regarding no unmeasured confounding, and if the temporality among education, depressive symptoms and adiposity is as our analyses assume, up to one-fifth of the excess adiposity linked with early childhood disadvantage would be averted.

Supplementary Data

Supplementary data are available at *IJE* online.

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