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Potentially modifiable mediators for socioeconomic disparities in childhood obesity in the United States

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Abstract

Objective: The aim of this study was to examine modifiable mediators for socioeconomic disparities in childhood obesity in the United States.

Methods: This study used the data of 1,211 mother-child dyads from a US national birth cohort from pregnancy to 6 years post partum. Socioeconomic status was indicated by maternal education (college graduate vs. less) and family income (>185% vs. ≤185% of the poverty line). Single- and multiple-factor mediation analyses were conducted for socioeconomic disparities in childhood obesity at 6 years, adjusting for demographics.

Results: The confounder-adjusted relative risk of childhood obesity was 1.79 for low maternal education and 1.42 for low family income. Low-maternal-education-related obesity was individually mediated by maternal preconception BMI (percentage of indirect effect, 8.8%), smoking during pregnancy (7.0%), infant weight gain (14.4%), child sleep duration (11.4%), and TV viewing during weekdays at 6 years (4.9%). Low-family-income-related obesity was mediated by maternal preconception BMI (18.5%), smoking during pregnancy (6.3%), child sleep

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AUTHOR CONTRIBUTIONS

Xiaozhong Wen conceived of the study, obtained the data, designed the data analytic plan, and wrote the initial draft of the manuscript. Baibing Mi cleaned the data, conducted data analysis, generated tables and figures, and contributed to study design, interpretation of the data, and revision of the manuscript. Youfa Wang contributed to study design, interpretation of the data, and revision of the manuscript. Elsie M. Taveras contributed to study design, interpretation of the data, and revision of the manuscript. Maksym Bartashevskyy contributed to study design, interpretation of the data, and revision of the manuscript. All authors approved the final manuscript as submitted and agree to be accountable for all aspects of the work.

SUPPORTING INFORMATION

Additional supporting information may be found in the online version of the article at the publisher's website.

CONFLICT OF INTEREST

The authors declared no conflict of interest.

duration (12.8%), and the home learning environment at 6 years (26.2%). In multiple-mediator analysis, significant mediators together mediated 54.0% of maternal-education-related or 39.4% of family-income-related disparities.

Conclusions: Maternal preconception BMI, smoking during pregnancy, infant weight gain, child sleep, TV viewing, and the home learning environment substantially mediated socioeconomic disparities in childhood obesity in the United States.

INTRODUCTION

Childhood obesity is a major public health issue in the United States (US) and worldwide (1–3). The 2017–2018 National Health and Nutrition Examination Survey (NHANES) showed that 19.3% of US children had obesity and another 16.1% had overweight (4). Among other social determinants (e.g., race and ethnicity, neighborhood, transportation, media use, food access, schools) (5), there are large socioeconomic disparities in the prevalence of childhood obesity in the US (6) and many other developed countries (7). Children from socioeconomically disadvantaged families (e.g., low parental education [25% vs. 7%] (6) and/or low family income [26% vs. 16%] (6)) are particularly vulnerable to obesity.

There is an increasing interest in using mediation analyses to identify the potential determinants for socioeconomic disparities in childhood obesity. Existing research has yielded fairly consistent evidence on insufficient breastfeeding, parental body mass index (BMI), and TV viewing time; mixed evidence on maternal age, smoking during pregnancy, and child birth weight; and limited evidence on day care attendance, parenting practices, maternal depression, and alcohol consumption (8,9). However, only two published studies in this field were conducted among US children. A US study found maternal depression and permissive parenting style partially mediated the association between low socioeconomic status (SES) and BMI gain from age 2 to 11 years (10). The contribution of this study to the literature is limited by missed infancy growth outcomes and a narrow scope of mediators. Another US study found that the associations between low SES and childhood obesity at age 2 years were mainly mediated by nonrecommended infant feeding practices, including predominant formula feeding, early introduction of solid foods, and putting the child to bed with a bottle (11). A major limitation of this study was the relatively young age (2 years) for childhood obesity outcome, which did not allow for examining other important mediators in later life, especially the child's own lifestyles such as eating, physical activities, and sleep. In addition, neither US study built a causal network (i.e., a conceptual framework to clarify the network of interrelations among multiple causal factors or mediators [e.g., smokers are less likely to breastfeed]) with time series and bidirectional relations being considered (12). Causal network research with a comprehensive list of potential mediators is much needed to advance our poor knowledge of the underlying determinants of socioeconomic disparities in childhood obesity in the US.

This study aimed to examine the potentially modifiable root mediators for socioeconomic disparities in obesity among US children. We built a causal network of multiple mediators through structural equation modeling (SEM). Our list of potential mediators covers the

whole early-life period: preconception (e.g., maternal obesity); pregnancy (e.g., maternal smoking); delivery (e.g., cesarean delivery); infancy (e.g., feeding); and early childhood (e.g., sleep). We chose to focus on potentially modifiable factors because they had straightforward implications for intervention.

METHODS

Study design and participants

We analyzed existing data from the Infant Feeding Practices Study II (IFPS II, n = 3,033 newborns) from May 2005 through June 2007 (13) and its Year 6 Follow-Up (Y6FU, n = 1,542 children) at 6 years in 2012 (14). The IFPS II was conducted by the US Food and Drug Administration (FDA) in collaboration with the Centers for Disease Control and Prevention (CDC). This longitudinal study followed mother-child dyads from late pregnancy (~7 months of pregnancy) through 6 years post partum via mailed survey questionnaires or, sometimes, phone interviews, if needed. The sampling frame for the IFPS II was a nationally distributed consumer opinion panel of >500,000 households (13). Within the panel, all pregnant women in the third trimester were included in the initial sample. Questionnaires were then mailed to them over 8 months to achieve the desired sample size. Among 14,017 potentially eligible pregnant women, a total of 4,902 (35.0%) completed questionnaires and others either refused (46) or did not respond (9,069). The total study sample consisted of 4,902 adult pregnant women aged 18 years or older and 3,033 full-term or nearly full-term newborns (gestational age ≥ 35 complete weeks). Additional criteria for eligible newborns included the following: 1) lack of medical conditions in the mother-infant dyad that would affect feeding; 2) birth weight ≥ 5 lb; 3) singleton; and 4) not staying in neonatal intensive care for >3 days. After birth, a total of 2,095 mother-child dyads were followed to 6 months, 1,807 were followed to 12 months, and 1,542 were followed to 6 years. Mothers received a small gift (<$3 value) for completing each regular IFPS II questionnaire, $10 cash incentive for the dietary history questionnaire, and $10 for the Y6FU questionnaire. The study protocols were approved by the Research Involving Human Subjects Committee of the FDA. Mothers provided signed or oral consent for their own and their child's participation. Details on the study design have been published elsewhere (13,14).

For the purpose of this analysis, we restricted the total eligible sample to those 1,211 mother-child dyads with complete data on the following: 1) at least one of the two SES measures of our interest, including maternal education and family income (exposures); and 2) child weight and height to calculate BMI at age 6 years (outcomes). As shown in Supporting Information Table S1, mothers in the analytic sample had higher education, family income, and mean age at pregnancy and they were more likely to be of non-Hispanic White race and married compared with their counterparts in the excluded sample. This secondary data analysis used deidentified public-use data from the CDC and was approved by the State University of New York at Buffalo Institutional Review Board.

Child growth measures (outcomes)

In the Y6FU survey, mothers reported the child's weight and height as measured by trained health professionals at the child's most recent doctor's visit (Table 1). The mean child

age for these clinical anthropometric measures was 6.08 (SD 0.43) years. Child BMI was calculated as weight in kilograms divided by height in meters squared. Based on the CDC 2000 Growth Charts, we calculated child BMI percentile by sex (boys vs. girls) and age (monthly intervals) (15). Accordingly, we defined childhood obesity as BMI ≥95th percentile (16).

SES measures (exposures)

We focused on maternal education and family income as the key SES exposure measures because existing evidence has supported their strong influences on childhood obesity (17), although we recognized that other SES factors such as paternal education, parental occupation, and neighborhood quality also play roles (18).

In the IFPS II, mothers reported their highest educational attainment at enrollment (late pregnancy). The response options for maternal education included “1–7 years grade school,” “8 years grade school,” “1–3 years high school,” “high school graduate,” “1–3 years college,” “college graduate,” and “postgraduate.” There was a limited number of children stratified by the original categories of maternal education. Therefore, we grouped maternal education into two categories (3 years of college or less vs. college graduate or higher) to ensure a sufficient sample size for each final category and thus statistical power for mediation analysis. This binary classification of maternal education has been used in previous research on childhood obesity (19). Our decision on the cutoff point of maternal education was also supported by the striking gap in the prevalence of childhood obesity between “1–3 years college” (19.4%) and “college graduate” (11.3%) compared with the moderate gaps between “high school or lower” (23.1%) and “1–3 years college” (19.4%) or between “college graduate” (11.3%) and “postgraduate” (8.3%).

Mothers also reported family annual income at enrollment. Based on household size and income, a household-level poverty variable was created as the ratio of household income to the federal poverty line. We classified family income into two categories: ≤185% and >185% of the federal poverty line. This cutoff point was based on the income criterion for the Special Supplemental Nutrition Program for Women, Infants, and Children (WIC), a US social safety net program for low-income pregnant or postpartum women and their young children (20).

Mediator measures

We considered potentially modifiable early-life determinants for obesity reported in the literature that coexist with low SES as mediators for socioeconomic disparities in childhood obesity.

Preconception and prenatal mediators

Mothers reported their height, preconception weight, and total gestational weight gain (GWG). Maternal obesity was defined as preconception BMI ≥ 30.0 (21). We defined excessive GWG as total GWG greater than 18.0, 16.0, 11.5, and 9.0 kg for women with underweight (preconception BMI < 18.5), normal weight (18.5–24.9), overweight (25.0–29.9), and obesity (≥30.0), respectively (21). Mothers also reported whether the baby’s

father had overweight or obesity before conception. In late pregnancy, mothers self-reported the timing of their first prenatal visit, smoking status during pregnancy (yes vs. no; number of cigarettes smoked per day), and whether they had type 1, type 2, or gestational diabetes. Mothers' dietary intake (i.e., frequency and amount of foods, beverages, and supplements) in the past month was measured using Food Frequency Questionnaires repeatedly during late pregnancy and 3 months post partum, and we calculated the maternal Healthy Eating Index for each period (22).

Mediators at delivery and during infancy

Mothers reported their method of delivery, child's birth weight and length, and gestational age in the birth screener (phone interview) and neonatal survey. Large-for-gestational-age birth was defined as birth weight >90th percentile within a US reference population (23). Mothers reported weight, length, and age at their infant's recent doctor's visit in the 3-, 5-, 7-, and 12-month surveys (13,24). Mothers reported the infant's longest night's sleep duration and use of nonmaternal infant care (e.g., initial age and hours). Mothers reported their ever and current breastfeeding, breastfeeding duration, initial and current use of formula, and the timing of introduction of solid foods. In each IFPS II survey, mothers reported their infant's intake of 18 types of foods in the past 7 days, from which we derived infant dietary patterns using principal component analysis (24). Supporting Information Table S2 shows infant dietary patterns at 12 months of age. Maternal postnatal depression was measured with the Edinburgh Postnatal Depression Scale (25).

Early-childhood mediators

In the Y6FU, mothers reported the child's frequency of consuming 22 food and beverage groups (26), which was used to derive six dietary patterns (Supporting Information Table S3). Child food and eating environment was measured with four home-related (e.g., availability of fruits or vegetables) and two school-related items (e.g., salads and fast food from school cafeteria) (27). Mothers reported the child's number of days per week with at least 60 minutes of moderate or vigorous physical activity (28), number of hours per day the child watched TV or played video games (28), and nighttime sleep duration during weekdays and weekends (29). The home learning environment was measured with three items selected from the Home Observation for Measurement of the Environment-Short Form (HOME-SF) (30): the frequency of parents' reading aloud to the child, child participation in special lessons or organizations related to extracurricular activities, and attendance of musical or theatrical performances. Previous research has shown that a low HOME-SF score was associated with childhood obesity (31).

Confounders

We considered demographic and pregnancy characteristics as potential confounders, including maternal age in years, race and ethnicity, parity, marital status, child's sex, and child actual age at the Y6FU.

Statistical analysis

Based on the causal step method (32), we examined the mediating roles of potentially modifiable early-life factors in associations between SES measures and childhood obesity at 6 years in five steps. Step 1 was to examine the overall associations between SES measures (exposure) and childhood obesity (outcome) using a multivariable log-binomial regression model (Table 2) (33). Step 2 was to examine the associations between SES measures and early-life factors (mediators; Table 3). Step 3 was to examine the associations between early-life factors and childhood obesity (Table 3).

Step 4 was the single-mediator analysis to examine the mediation of each of the significant early-life factors in both Step 2 and Step 3 in the associations between SES measures and childhood obesity (Table 4). Specifically, the SAS procedure of CAUSALMED (SAS Institute Inc.) (34) was used to estimate the direct effects of low SES on risk of childhood obesity at 6 years and its indirect effect through each potential mediator. We chose the SAS CAUSALMED procedure over other existing approaches because it uniquely incorporates convenient estimations of the indirect effect as well as its 95% CI and percentage (i.e., indirect effect/[direct effect + indirect effect]).

Step 5 was the multiple-mediator analysis to examine the causal network of all significant mediators ($p < 0.05$) individually screened in Step 4. We considered all plausible interrelations among these mediators, based on prior literature and theoretical hypotheses. To allow the causal network to be inclusive, a higher cutoff point of p value (<0.10) was used for the final multiple-mediator model. Specifically, we built the causal network through the SEM using the “gsem” command in Stata (StataCorp LLC) with maximum likelihood estimation, log-transformation of non-normal variables, and Bayesian information criterion for the goodness of fit of models (35). SEM could handle multiple and time-varying mediators, reveal their complex relation, provide in-depth understanding on the causal chains with mediators at different levels (e.g., distant vs. proximal), and incorporate the measurement errors.

Note that adjustment for multiple comparisons might not be necessary in this study, as our hypothesis-driven statistical tests were independent from each other (36). Sample weights were not available from the CDC owing to the unrepresentative sampling frame of the IFPS II (13).

RESULTS

Sample characteristics

Among the 1,211 eligible mother-child dyads, 48.0% of mothers had a college degree or higher educational attainment, and 64.7% had a family income >185% of the poverty line (Table 2). Mean (SD) maternal age was 30.18 (5.36) years; 4.2% of mothers self-identified as Asian/Pacific Islander and others, 5.2% as Hispanic, 4.1% as non-Hispanic Black, and 86.5% as non-Hispanic White; 30.3% were nulliparous; and 83.3% were married. Among the children, 51.4% were boys, and the mean age at the Y6FU survey was 6.45 (0.19) years. The main reason for excluding other participants was missing data on child growth outcomes at 6 years due to nonresponse, loss of contact, or refusal in the Y6FU.

Socioeconomic disparities in childhood obesity

There was an inverse dose-response association between maternal education and childhood obesity (Supporting Information Table S4). When classified as a binary variable, low maternal education (i.e., not a college graduate) was associated with a high risk of childhood obesity (20.5% vs. 10.5%; relative risk [RR]: 1.95 [95% CI: 1.46–2.60]; $p < 0.001$; Table 2). Low family income (i.e., ≤185% of poverty line) was also associated with a high risk of childhood obesity (22.5% vs. 12.6%; RR: 1.78 [95% CI: 1.38–2.30]; $p < 0.001$). Adjustment for demographic and pregnancy confounders attenuated the RR of childhood obesity for low family income to 1.42 (95% CI: 1.03–1.97), but it did not substantially change the RR for low maternal education (1.79 [95% CI: 1.31–2.46]).

Single-mediator analysis of socioeconomic disparities in childhood obesity

As shown in Table 3, a considerable number of potential mediators were associated with both SES measures (exposure) and childhood obesity at 6 years (outcome) and were therefore eligible for the single-mediator analysis. The following mediators remained significant in the single-mediator analysis (Table 4) for low-maternal-education-related childhood obesity: maternal preconception BMI (percentage of indirect effect, 8.8%); maternal smoking during pregnancy (yes vs. no, 7.0%; number of cigarettes smoked per day, 4.8%); infant weight gain from birth to 7 months (14.4%); child sleep duration at 6 years (11.4%); and TV viewing during weekdays at 6 years (4.9%). In addition, the association between low family income and childhood obesity was substantially mediated by maternal preconception BMI (18.5%), maternal number of cigarettes smoked per day during pregnancy (6.3%), child sleep duration at 6 years (12.8%), and the home learning environment at 6 years (26.2%).

Multiple-mediator analysis of socioeconomic disparities in childhood obesity

Figure 1 shows the proposed causal network for multiple mediators in the association between maternal education and risk of childhood obesity at 6 years, adjusting for confounders. The mediators that remained significant in the final SEM included maternal preconception BMI, maternal smoking during pregnancy, infant weight gain from birth to 7 months, and child sleep duration at 6 years. In addition, we identified associations between some mediators: maternal preconception BMI → child sleep duration at 6 years; and maternal smoking during pregnancy → child sleep duration at 6 years. The five pathways of indirect effects together mediated 54.0% of the total effect of maternal education on childhood obesity.

Figure 2 shows the proposed causal network for multiple mediators in the association between family income and risk of childhood obesity at 6 years. The mediators in the final SEM included maternal preconception BMI, maternal number of cigarettes smoked per day during pregnancy, and child sleep duration at 6 years, with an extra mediator of the home learning environment at 6 years. We also identified the following associations between some mediators: maternal preconception BMI → child sleep duration at 6 years; maternal number of cigarettes smoked per day during pregnancy → child sleep duration at 6 years; maternal number of cigarettes smoked per day during pregnancy → the home learning environment at 6 years; and the home learning environment at 6 years → child sleep duration at 6 years.

The seven pathways of indirect effects together mediated 39.4% of the total effect of family income on childhood obesity.

DISCUSSION

Within a US prebirth cohort, we confirmed that both low maternal education and low family income were associated with a high risk of childhood obesity. We also made unique contributions to the science by identifying several modifiable mediators in early life that might explain these disparities among young US children. They included maternal preconception BMI, smoking during pregnancy, infant weight gain, child sleep, the home learning environment, and child TV viewing. In single-mediator analysis, each of them could explain a considerable proportion (range: 4.8%−26.2%) of SES-related disparities in childhood obesity. In multiple-mediator analysis, all significant mediators together mediated a substantial proportion of the maternal-education-related (54.0%) and the family-income-related (39.4%) disparities in childhood obesity. Our novel findings can inform effective intervention to narrow socioeconomic disparities in childhood obesity in the US and possibly other developed countries.

Maternal preconception BMI

In our sample, preconception BMI consistently mediated the associations between both SES measures (i.e., maternal education and family income) and childhood obesity. Similarly, two previous studies have found that maternal preconception BMI largely mediated the association between low SES and early-childhood weight gain (37,38). Although it is challenging to intervene preconception weight because of its multifactorial determinants, there is some pioneering research on preconception or interpregnancy weight-loss intervention through behavioral changes (39).

Maternal smoking during pregnancy

Maternal smoking during pregnancy also consistently mediated the effects of both SES measures on childhood obesity. Our result was supported by two previous studies (37,38) in which maternal smoking during pregnancy largely mediated the association between low SES and rapid infant weight gain from birth to age 1 year. It is effective and safe to use behavioral, pharmaceutical, and economic interventions to assist pregnant women to stop smoking (40). For example, our own smoking cessation intervention achieved a 63.3% smoking abstinence rate through a multicomponent intervention (41). In addition, we found that intervention-assisted maternal smoking cessation, especially if quitting occurred before 27 weeks, could substantially reduce the risk of rapid infant BMI gain (42). However, maternal smoking cessation during pregnancy remains an opportunity neglected in existing childhood obesity interventions.

Infant weight gain

In our analysis, infant weight gain only mediated the effects of maternal education on childhood obesity, but not the effect of family income. One possible reason might be that infant weight gain is more subject to maternal influences such as infant feeding practices, infant daily activities, monitoring infant growth trajectories, and adhering to well-child

visits. There are some intervention programs that have been tested to prevent rapid infant weight gain, but the results have been mixed (43,44).

Child sleep

Our research might be the first study, to our knowledge, to observe that short sleep duration could largely (>10% of total effect) mediate the effects of both SES measures on risk of childhood obesity. In the multiple-mediator analysis, child sleep also mediated some effects of maternal preconception BMI, smoking during pregnancy, and the home learning environment on childhood obesity. Altogether, child sleep seemed to play a crucial role in the causal network between low SES and childhood obesity, which warrants further intervention research. There have been some existing intervention programs that could effectively improve child sleep duration and quality (45).

The home learning environment

An unexpected finding in this analysis was that the home learning environment mediated the largest percentage (26.2%) of the effect of low family income on childhood obesity. It should be noted that two of the three HOME-SF items used to measure the home learning environment in our analysis (i.e., special lessons or organizations related to extracurricular activities and attendance of musical or theatrical performances) might be intertwined with family income, as these activities often require financial and time resources. Other less resource-dependent mediators related to the home learning environment, including alternative cognitive reinforcers to food (e.g., library books, chess, board games), warrant further investigation and may have broader implications. Compared with conventional early-life factors for obesity, the home learning environment, including cognitive stimulation, is a relatively new direction for childhood obesity (31). We were not aware of any existing childhood obesity intervention programs that have specifically focused on the home learning environment.

Other potential mediators

TV viewing was a significant and moderate mediator in our single-mediator analysis for the maternal-education-related disparity in childhood obesity, but it became nonsignificant in the multiple-mediator analysis. This suggested that the effect of TV viewing might overlap with other stronger mediators such as child sleep duration. We could not replicate the finding from a previous US study, in which some nonrecommended infant feeding practices (e.g., predominant formula feeding, early introduction of solid foods) mediated the association between low SES and childhood obesity at age 2 years (11). This inconsistency suggested that the potential mediation effects of these infant feeding practices on socioeconomic disparities in childhood obesity might diminish with age. Similarly, we did not find any significant mediation by child diet or moderate or vigorous physical activity at 6 years. A possible reason was low accuracy of maternal retrospective recalls of child diet and physical activity, especially with simplified items in the Y6FU.

Study limitations

The study limitations included the following: 1) although the IFPS II sample was geographically national (44 states and the District of Columbia), it did not represent the total US population because the sample was not randomly obtained from the general population and overrepresented well-educated, middle-income, employed, non-Hispanic White, nonsmoking, low-parity, and breastfeeding mothers (13), which could limit the generalizability of our results; 2) survey-based data were subject to recall bias, including the mother-reported child's weight and height as measured at the child's most recent doctor's visit; 3) lack of information on other potential mediators such as food security, parenting, and neighborhood social and built environment, which might explain why there was still a large direct effect of SES on childhood obesity unexplained by our multiple-mediator models, especially for the family-income-related disparities (~60%); 4) a potential violation of positivity, especially in the multiple-mediator analysis; 5) inclusion of 6-year mediators (e.g., child sleep, TV viewing) was subject to risk of reverse causality; 6) our findings should be interpreted as associational rather than causal; 7) we did not examine the potential effect modification by child sex or race and ethnicity because of insufficient statistical power; 8) we did not include postpartum maternal smoking in the mediation analysis because of the concern of its high correlation (multicollinearity) with maternal smoking during pregnancy; 9) we did not examine disparities by other important SES indicators, including paternal education and parental employment/occupation; (18) and 10) the relatively old data (the last follow-up in 2012) might impact the implications to current practice.

CONCLUSION

In the US, socioeconomic disparities in childhood obesity could be substantially mediated by several potentially modifiable early-life factors, including maternal preconception BMI, smoking during pregnancy, infant weight gain, child sleep, the home learning environment, and child TV viewing. Further research in external cohorts is needed to confirm our novel findings and to further test potential differences in other age groups and in other countries. Effective intervention targeting these significant modifiable mediators holds promise to improve obesity-related health equity among socioeconomically disadvantaged children.

Supplementary Material

Refer to Web version on PubMed Central for supplementary material.

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Study Importance

What is already known?

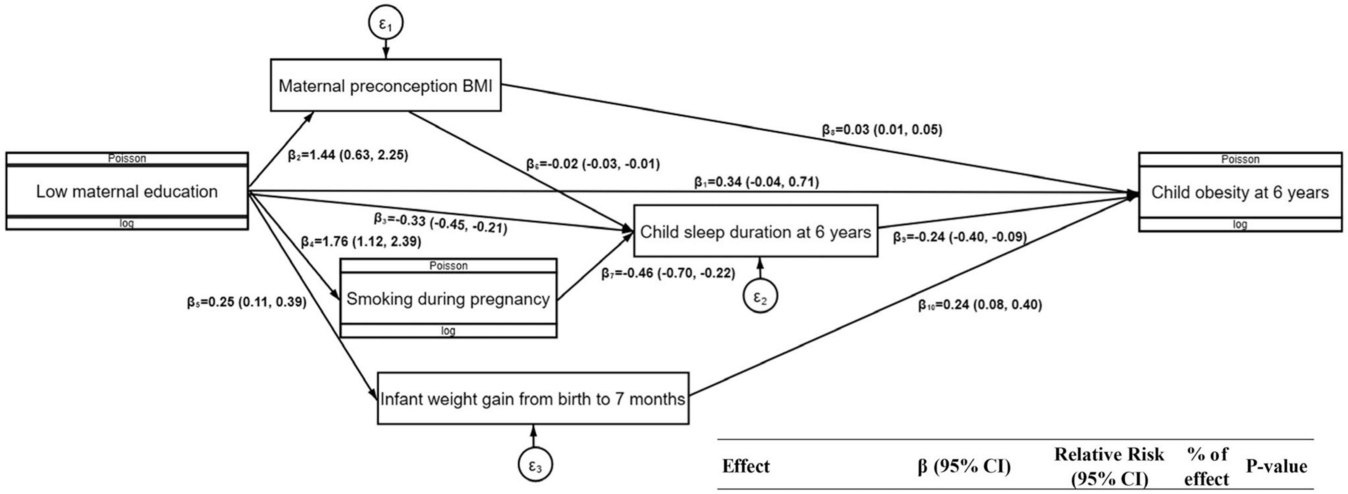
- There are large socioeconomic disparities in the prevalence of childhood obesity in the United States and many other developed countries.

What does this study add?

- Maternal preconception BMI, smoking during pregnancy, infant weight gain, child sleep, the home learning environment, and child TV viewing substantially mediated socioeconomic disparities in childhood obesity in the United States.

How might these results change the direction of research or the focus of clinical practice?

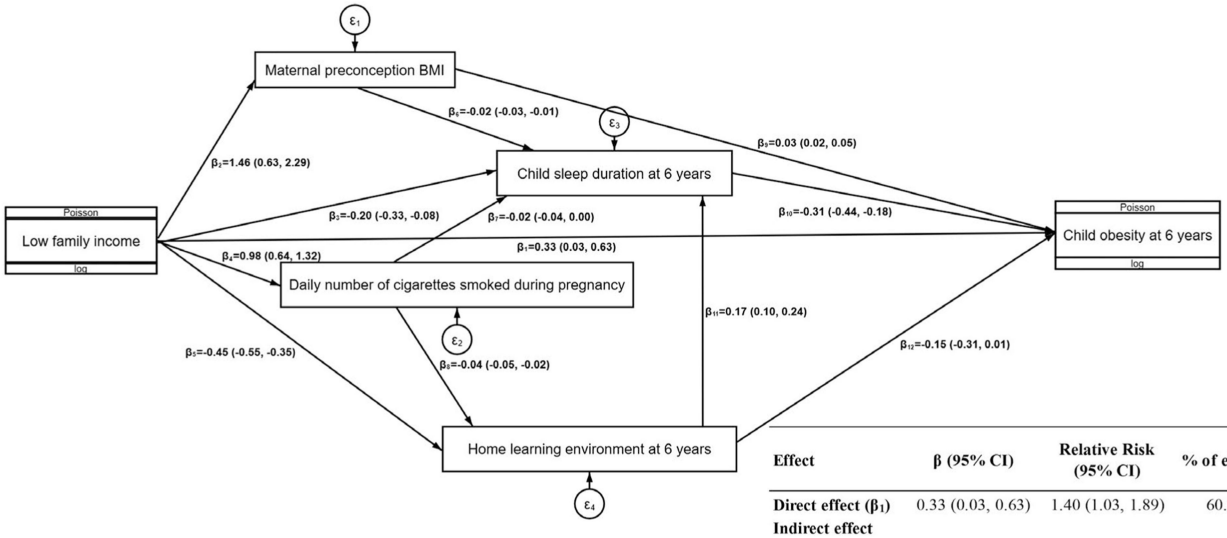
- Effective intervention targeting these significant modifiable mediators holds promise to improve obesity-related health equity among socioeconomically disadvantaged children.



Effect	β (95% CI)	Relative Risk (95% CI)	% of effect	P-value
Direct effect (β_1)	0.34 (-0.04, 0.71)	1.40 (0.96, 2.04)	46.0	0.081
Indirect effect				
$\beta_2*\beta_8$	0.05 (0.01, 0.09)	1.05 (1.01, 1.09)	6.6	0.013
$\beta_2*\beta_6*\beta_9$	0.01 (0.00, 0.01)	1.01 (1.00, 1.01)	1.0	0.040
$\beta_3*\beta_9$	0.08 (0.02, 0.14)	1.08 (1.02, 1.15)	11.1	0.008
$\beta_4*\beta_7*\beta_9$	0.20 (0.02, 0.37)	1.22 (1.02, 1.45)	27.0	0.030
$\beta_5*\beta_{10}$	0.06 (0.01, 0.11)	1.06 (1.01, 1.12)	8.3	0.022
Total effect	0.73 (0.33, 1.13)	2.07 (1.39, 3.09)	100.0	<0.001

FIGURE 1.

Proposed causal network for multiple mediators in the association between maternal education and risk of childhood obesity at 6 years. The parameters were estimated from structural equation modeling, adjusting for confounders including maternal age, race and ethnicity, parity, marital status, child sex, and child's actual age at the 6-year follow-up



Effect	β (95% CI)	Relative Risk (95% CI)	% of effect	P-value
Direct effect (β_1)	0.33 (0.03, 0.63)	1.40 (1.03, 1.89)	60.6	0.030
Indirect effect				
$\beta_2*\beta_9$	0.05 (0.01, 0.08)	1.05 (1.01, 1.09)	8.5	0.010
$\beta_2*\beta_6*\beta_{10}$	0.01 (0.00, 0.02)	1.01 (1.00, 1.02)	1.6	0.017
$\beta_3*\beta_{10}$	0.06 (0.02, 0.11)	1.07 (1.02, 1.12)	11.6	0.009
$\beta_4*\beta_7*\beta_{10}$	0.01 (0.00, 0.01)	1.01 (1.00, 1.01)	1.1	0.090
$\beta_4*\beta_8*\beta_{11}*\beta_{10}$	0.00 (0.00, 0.00)	1.00 (1.00, 1.00)	0.3	0.015
$\beta_5*\beta_{11}*\beta_{10}$	0.02 (0.01, 0.04)	1.02 (1.01, 1.04)	4.3	0.002
$\beta_5*\beta_{12}$	0.07 (-0.01, 0.14)	1.07 (0.99, 1.15)	12.2	0.078
Total effect	0.55 (0.26, 0.84)	1.73 (1.30, 2.32)	100.0	<0.001

FIGURE 2.

Proposed causal network for multiple mediators in the association between family income and risk of childhood obesity at 6 years. The parameters were estimated from structural equation modeling, adjusting for confounders including maternal age, race and ethnicity, parity, marital status, child sex, and child's actual age at the 6-year follow-up

TABLE 1

List of outcomes, exposures, covariates, and mediators

	Time point at data collection	Method of data collection
Child growth (outcomes)		
Child weight	Age 6	Doctor's visit (reported by mother)
Child height	Age 6	Doctor's visit (reported by mother)
Child BMI	Age 6	Calculated; BMI = weight in kg/height in m^2
Child obesity	Age 6	Calculated; BMI ≥ 95th percentile
SES measures (exposures)		
Maternal education	Late pregnancy (~7 months; enrollment)	Paper survey via mailed questionnaires
Family income (US dollars)	Late pregnancy	Paper survey via mailed questionnaires
Family income (percentage of poverty line)	Late pregnancy	Calculated; percentage = family income/federal poverty line
Covariates		
Maternal age at pregnancy (y)	Late pregnancy	Paper survey via mailed questionnaires
Maternal race and ethnicity	Late pregnancy	Paper survey via mailed questionnaires
Parity	Late pregnancy	Paper survey via mailed questionnaires
Marital status	Late pregnancy	Paper survey via mailed questionnaires
Child sex	1 month post natal (neonatal)	Paper survey via mailed questionnaires
Child age at 6-year follow-up (y)	Age 6	Calculated; child age = survey date - date of birth
Mediators		
Maternal height (m)	Late pregnancy	Paper survey via mailed questionnaires
Maternal preconception weight (kg)	Late pregnancy	Paper survey via mailed questionnaires
Maternal preconception BMI (kg/m^2)	Late pregnancy	Paper survey via mailed questionnaires
Paternal preconception weight status	Late pregnancy	Paper survey via mailed questionnaires
GWG (kg)	1 month post natal	Paper survey via mailed questionnaires
Prenatal Healthy Eating Index	Late pregnancy	Paper survey via mailed questionnaires (Food Frequency Questionnaire)
Gestational age at first prenatal visit (wk)	Late pregnancy	Paper survey via mailed questionnaires
Maternal smoking during pregnancy	Late pregnancy	Paper survey via mailed questionnaires
Maternal number of cigarettes smoked per day during pregnancy	Late pregnancy	Paper survey via mailed questionnaires
Gestational diabetes	Late pregnancy	Paper survey via mailed questionnaires
Method of delivery	1 month post natal	Paper survey via mailed questionnaires

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	Time point at data collection	Method of data collection
Date of birth	Birth	Phone interview
Gestational age at birth (wk)	Birth	Calculated; gestational age = date of birth - last menstrual period
Birth weight (kg)	Birth	Phone interview
Large-for-gestational-age birth	Birth	Calculated; birth weight > 90th percentile by sex and gestational age
Birth length (cm)	1 month post natal	Paper survey via mailed questionnaires
Edinburgh postnatal depression score	2 months post natal	Paper survey via mailed questionnaires
Postnatal Healthy Eating Index	3 months post natal	Paper survey via mailed questionnaires (Food Frequency Questionnaire)
Breastfeeding duration (wk)	1–12 months post natal	Paper survey via mailed questionnaires
Exclusive breastfeeding duration (wk)	1–12 months post natal	Paper survey via mailed questionnaires
Timing of formula initiation (wk)	1–12 months post natal	Paper survey via mailed questionnaires
Timing of introduction of solid foods (wk)	1–12 months post natal	Paper survey via mailed questionnaires
Infant dietary pattern adherence score	12 months post natal	Paper survey via mailed questionnaires
Child sleep duration at 1 year (h)	12 months post natal	Paper survey via mailed questionnaires
Nonmaternal infant care at 1 year	12 months post natal	Paper survey via mailed questionnaires
Infant weight gain (kg)	3, 7, and 12 months post natal	Calculated; infant weight gain = postnatal weight at doctor's visit - birth weight
Child sleep duration at 6 years (h)	Age 6	Paper survey via mailed questionnaires or phone interview if needed
Child dietary pattern adherence score	Age 6	Paper survey via mailed questionnaires or phone interview if needed
Score of child food and eating environment	Age 6	Paper survey via mailed questionnaires or phone interview if needed
Score of child home learning environment	Age 6	Paper survey via mailed questionnaires or phone interview if needed
Number of days per week with ≥60 minutes of child MVPA	Age 6	Paper survey via mailed questionnaires or phone interview if needed
Child TV viewing per day on weekdays (h)	Age 6	Paper survey via mailed questionnaires or phone interview if needed
Child TV viewing per day on weekends (h)	Age 6	Paper survey via mailed questionnaires or phone interview if needed

Abbreviations: GWG, gestational weight gain; MVPA, moderate or vigorous physical activity; SES, socioeconomic status.

TABLE 2

Sample characteristics and their associations with childhood obesity at 6 years (n = 1,211)

	***n* (%)/mean ± SD**[a]	**Risk of obesity, *n* (%)**	**RR of obesity (95% CI)**	***p* value**
SES measures				
Maternal education				
Low (3 years of college or less)	596 (52.0)	122 (20.5)	1.95 (1.46–2.60)	<0.001
High (college graduate or higher)	551 (48.0)	58 (10.5)	Reference	
Family income (percentage of the poverty line)	287.81 ± 205.97			
Low (≤185%)	427 (35.3)	96 (22.5)	1.78 (1.38–2.30)	<0.001
High (>185%)	784 (64.7)	99 (12.6)	Reference	
Covariates				
Maternal age at pregnancy (y)	30.18 ± 5.36		0.99 (0.96–1.01)	0.269
18–24	184 (15.2)	40 (21.7)	Reference	
25–29	374 (30.9)	51 (13.6)	0.63 (0.43–0.91)	0.015
30–34	388 (32.1)	59 (15.2)	0.70 (0.49–1.00)	0.052
≥35	264 (21.8)	45 (17.1)	0.78 (0.54–1.15)	0.212
Maternal race and ethnicity				
Asian/Pacific Islander and others	50 (4.2)	3 (6.0)	0.39 (0.13–1.19)	0.099
Hispanic	62 (5.2)	13 (21.0)	1.38 (0.83–2.28)	0.213
Non-Hispanic Black	48 (4.1)	17 (35.4)	2.33 (1.55–3.50)	<0.001
Non-Hispanic White	1025 (86.5)	156 (15.2)	Reference	
Parity				
Nulliparous	358 (30.3)	52 (14.5)	Reference	
1 previous birth	487 (41.2)	85 (17.5)	1.20 (0.88–1.65)	0.256
≥2 previous births	336 (28.5)	55 (16.4)	1.13 (0.80–1.60)	0.502
Marital status				
Married	956 (83.3)	127 (13.3)	Reference	
Unmarried	192 (16.7)	52 (27.1)	2.04 (1.54–2.71)	<0.001
Child sex				
Male	622 (51.4)	106 (17.0)	Reference	
Female	589 (48.6)	89 (15.1)	0.89 (0.69–1.15)	0.361

	n (%)/mean ± SD[a]	Risk of obesity, *n* (%)	RR of obesity (95% CI)	*p* value
Child age at the 6-year growth measurement (y)	6.08 ± 0.43		1.10 (0.57–2.12)	0.770
Child age at the Y6FU survey (y)	6.45 ± 0.19			

[a] For some variables, the sum of categories was not equal to the total because of missing data.

Abbreviations: RR, relative risk; SES, socioeconomic status; Y6FU, Year Six Follow-Up.

TABLE 3

Associations of potential mediators with SES measures and risk of obesity

Potential mediator	Total sample (*n* = 1,211) *n* (%)/mean ± SD[a]	RR of obesity at 6 years (95% CI)	Maternal education[b] Low (*n* = 596) *n* (%)/mean + SD	High (*n* = 551) *n* (%)/mean + SD	*p* value	Family income[b] Low (*n* = 427) *n* (%)/mean + SD	High (*n* = 784) *n* (%)/mean + SD	*p* value
Maternal height (m)	1.65 ± 0.07	2.60 (0.40–16.90)	1.65 ± 0.07	1.66 ± 0.07	0.701	1.65 ± 0.07	1.65 ± 0.07	0.975
Maternal preconception weight (kg)	73.45 ± 20.46	1.02 (1.01–1.02)	75.40 ± 21.75	71.58 ± 18.66	0.002	76.10 ± 22.44	72.02 ± 19.18	0.001
Maternal preconception BMI (kg/m^2)	26.76 ± 7.03	1.04(1.03–1.06)	27.49 ± 7.54	26.05 ±6.29	<0.001	27.71 ± 7.86	26.25 ± 6.49	<0.001
Underweight/normal weight (<25.0)	588 (49.2)	Reference	263 (44.8)	294 (53.9)	0.002	180 (43.0)	408 (52.5)	0.004
Overweight (25.0–29.9)	312 (26.1)	2.18 (1.57–3.03)	156(26.6)	139(25.5)		116 (27.7)	196(25.2)	
Obesity (>30.0)	296 (24.7)	2.44 (1.77–3.36)	168 (28.6)	112 (20.6)		123 (29.4)	173 (22.3)	
Paternal preconception weight status								
Normal weight	952 (86.0)	Reference	463 (85.4)	437(86.0)	0.782	324 (84.8)	628 (86.6)	0.411
Overweight/obesity	155 (14.0)	1.73 (1.26–2.38)	79 (14.6)	71 (14.0)		58 (15.2)	97 (13.4)	
GWG (kg)	13.70 ± 6.24	0.99 (0.97–1.02)	13.68 ± 6.89	13.63 ± 5.41	0.88	13.58 ± 7.02	13.76 ± 5.78	0.638
Inadequate	240 (20.8)	Reference	127 (22.4)	102 (19.3)	0.112	92 (22.8)	148 (19.8)	0.084
Adequate	370 (32.1)	0.70 (0.47–1.04)	168 (29.7)	187 (35.3)		113 (28.0)	257(34.3)	
Excessive	542 (47.1)	1.07 (0.77–1.50)	271 (47.9)	240 (45.4)		198 (49.1)	344 (45.9)	
Prenatal Healthy Eating Index	65.99 ±8.61	0.97 (0.94–1.00)	64.84 ± 9.17	67.36 ± 7.91	0.003	63.97 ± 9.25	66.78 ± 8.23	0.003
Gestational age at first prenatal visit (wk)								
≤4	137 (11.4)	Reference	74 (12.5)	51 (9.3)	0.007	50(11.7)	87(11.2)	<0.001
5–8	635 (52.7)	0.82 (0.56–1.19)	303 (51.1)	301 (54.9)		195 (45.8)	440 (56.6)	
9–12	320 (26.6)	0.70 (0.45–1.08)	148 (25.0)	159 (29.0)		117 (27.5)	203 (26.1)	
≥13	112 (9.3)	0.91(0.54–1.53)	68 (11.5)	37(6.8)		64 (15.0)	48 (6.2)	
Maternal smoking during pregnancy								
No	1,118 (92.5)	Reference	526 (88.4)	538 (98.0)	<0.001	370 (86.7)	748 (95.8)	<0.001
Yes	90 (7.5)	1.74 (1.21–2.52)	69 (11.6)	11 (2.0)		57(13.3)	33 (4.2)	
Maternal number of cigarettes smoked per day during pregnancy	0.68 ± 2.92	1.05 (1.02–1.08)	1.09 ±3.58	0.15 ± 1.50	<0.001	1.32 ±4.03	0.34 ± 2.00	<0.001
Gestational diabetes								
No	1,117 (92.2)	Reference	551 (92.4)	508 (92.2)	0.872	394 (92.3)	723 (92.2)	0.974

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Potential mediator	Total sample (n = 1,211) n (%)/mean ± SD[a]	RR of obesity at 6 years (95% CI)	Maternal education[b] Low (n = 596) n (%)/mean + SD	Maternal education[b] High (n = 551) n (%)/mean + SD	p value	Family income[b] Low (n = 427) n (%)/mean + SD	Family income[b] High (n = 784) n (%)/mean + SD	p value
Yes	94 (7.8)	1.51 (1.02–2.23)	45 (7.6)	43 (7.8)		33 (7.7)	61 (7.8)	
Method of delivery								
Vaginal	849 (70.2)	Reference	419 (70.4)	390(70.8)	0.894	310(72.6)	539 (68.8)	0.172
Cesarean delivery	361 (29.8)	1.32 (1.01–1.72)	176 (29.6)	161 (29.2)		117 (27.4)	244 (31.2)	
Large-for-gestational-age								
No	1,075 (88.8)	Reference	535 (89.8)	478 (86.8)	0.112	382 (89.5)	693 (88.4)	0.574
Yes	136(11.2)	1.49 (1.06–2.10)	61 (10.2)	73 (13.2)		45 (10.5)	91(11.6)	
Gestational age at birth (wk)	39.32 ± 1.26	1.02 (0.91–1.14)	39.28 ± 1.29	39.34 ± 1.22	0.41	39.34 ± 1.31	39.31 ± 1.24	0.687
Birth weight (kg)	3.46 ± 0.50	1.33 (1.05–1.69)	3.44 ± 0.48	3.51 ± 0.51	0.018	3.44 ± 0.53	3.47 ± 0.48	0.26
Birth length (cm)	50.81 ±2.68	1.02 (0.96–1.07)	50.63 ±2.63	51.03 ± 2.70	0.001	50.58 ±2.67	50.93 ±2.68	0.029
Edinburgh postnatal depression score at 2 months	6.50 ± 4.47	1.03 (1.00–1.06)	6.75 ± 4.68	6.12 ±4.21	0.026	6.84 ±4.79	6.32 ± 4.28	0.074
Postnatal Healthy Eating Index at 3 months	64.42 ± 9.67	0.98 (0.96–1.00)	62.21 ± 9.73	66.64 ± 9.06	<0.001	62.78 ± 10.19	65.09 ± 9.38	0.007
Breastfeeding duration (wk)	30.68 ± 30.47	1.00(0.99–1.00)	25.03 ± 28.32	37.77 ± 30.86	<0.001	27.41 ± 29.86	32.43 ±30.67	0.007
Exclusive breastfeeding duration (wk)	4.84 ± 8.32	0.96 (0.97–1.01)	3.55 ± 6.86	6.63 ± 9.68	<0.001	4.31 ±8.09	5.13 ±8.44	0.141
Timing of formula initiation (wk)	10.24 ± 10.69	0.97(0.95–0.99)	8.34 ±8.49	13.09 ± 12.91	<0.001	8.87 ±9.51	11.01 ± 11.23	0.003
Timing of introduction of solid foods (wk)	26.66 ±8.15	0.97(0.95–0.99)	25.61 ± 9.06	27.78 ± 6.58	<0.001	25.47 ±8.55	27.29 ± 7.86	<0.001
Infant dietary pattern adherence score								
Infant guideline solids at 1 year	0.06 ± 1.00	0.79 (0.64–0.99)	-0.08 ± 0.99	0.18 ± 0.96	<0.001	-0.11 ± 1.02	0.14 ± 0.98	0.001
High sugar/fat/protein at 1 year	-0.09 ± 0.93	1.23 (1.08–1.40)	0.09 ± 0.95	-0.26 ± 0.78	<0.001	0.19 ± 1.19	-0.21 ± 0.74	<0.001
High dairy at 1 year	-0.05 ± 1.01	1.01 (0.85–1.20)	0.10 ± 1.00	-0.17 ± 1.01	<0.001	-0.03 ± 0.98	-0.05 ± 1.03	0.796
Formula/baby cereal at 1 year	0.03 ± 1.01	1.08 (0.94–1.25)	0.03 ± 1.05	-0.02 ± 0.94	0.486	0.05 ± 1.12	0.02 ± 0.96	0.679
Child sleep duration at 1 year (h)								
≥4	49 (5.4)	Reference	21(5.2)	27 (5.8)	<0.001	26 (9.0)	23 (3.7)	<0.001
5–6	129 (14.2)	0.70 (0.37–1.30)	66 (16.4)	56(12.0)		42 (14.5)	87 (14.1)	
7–8	159 (17.5)	0.85 (0.48–1.51)	85(21.1)	59 (12.6)		73 (25.3)	86(13.9)	
≥9	571 (62.9)	0.48 (0.28–0.82)	231 (57.3)	326 (69.7)		148 (51.2)	423 (68.3)	
Nonmaternal infant care at 1 year								

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Potential mediator	Total sample (n = 1,211) n (%)/mean ± SD[a]	RR of obesity at 6 years (95% CI)	Maternal education[b] Low (n = 596) n (%)/mean + SD	Maternal education[b] High (n = 551) n (%)/mean + SD	p value	Family income[b] Low (n = 427) n (%)/mean + SD	Family income[b] High (n = 784) n (%)/mean + SD	p value
No	435 (47.3)	Reference	175 (42.9)	238 (50.2)	0.03	177 (60.6)	307 (49.0)	0.001
Yes	484(52.7)	1.11 (0.81–1.52)	233 (57.1)	236 (49.8)		115 (39.4)	320(51.0)	
Infant weight gain (kg)								
From birth to 3 months	2.07 ± 0.77	1.12 (0.90–1.40)	2.10 ± 0.78	2.05 ± 0.76	0.291	2.03 ± 0.81	2.09 ± 0.75	0.232
From birth to 7 months	4.42 ± 1.08	1.37(1.19–1.57)	4.54 ± 1.17	4.29 ± 0.95	<0.001	4.40 ± 1.14	4.43 ± 1.04	0.625
From birth to 12 months	6.16 ± 1.24	1.29 (1.13–1.48)	6.19 ± 1.34	6.07 ± 1.11	0.147	6.09 ± 1.37	6.19 ± 1.18	0.291
Child sleep duration at 6 years (h)	9.71 ± 1.06	0.68 (0.62–0.75)	9.53 ± 1.11	9.93 ± 0.94	<0.001	9.49 ± 1.13	9.83 ± 0.99	<0.001
Child dietary pattern adherence score at 6 years								
Fast foods	0.02 ± 1.07	1.08 (1.00–1.16)	0.18 ± 1.31	-0.20 ± 0.63	<0.001	0.19 ± 1.49	-0.08 ± 0.72	<0.001
Guideline foods	0.01 ± 1.02	0.90 (0.78–1.02)	-0.07 ± 1.08	0.14 ± 0.94	<0.001	-0.01 ± 1.11	0.03 ± 0.97	0.525
Breakfast-type foods	0.00 ± 1.02	0.94 (0.79–1.12)	-0.06 ± 1.02	0.08 ± 0.96	0.014	-0.05 ± 1.01	0.03 ± 1.03	0.236
Staple foods	0.01 ± 1.05	1.01 (0.87–1.16)	-0.02 ± 1.13	0.03 ± 0.99	0.42	0.06 ± 1.20	-0.02 ± 0.96	0.193
Dairy foods	0.01 ± 1.03	0.94 (0.82–1.08)	0.03 ± 1.09	0.00 ± 0.97	0.625	0.00 ± 1.04	0.02 ± 1.03	0.841
Package foods	-0.01 ± 1.02	1.04 (0.92–1.19)	-0.01 ± 1.05	-0.03 ± 0.90	0.803	0.13 ± 1.14	-0.08 ± 0.93	<0.001
Score of child food and eating environment at 6 years	28.03 ± 2.41	0.98 (0.51–1.90)	27.92 ± 2.53	28.19 ±2.08	0.137	28.09 ±2.37	27.91 ± 2.48	0.378
Score of child home learning environment at 6 years	2.21 ± 0.86	0.77 (0.67–0.88)	2.01 ± 0.91	2.43 ± 0.75	<0.001	1.89 ± 0.93	2.38 ± 0.78	<0.001
Number of days per week with ≥60 minutes of child MVPAat 6 years	5.49 ± 1.60	0.95 (0.88–1.02)	5.54 ± 1.59	5.48 ± 1.55	0.51	5.46 ± 1.64	5.50 ± 1.58	0.706
Child TV viewing per day on weekdays at 6 years (h)	1.50 ± 1.15	1.18 (1.08–1.28)	1.68 ± 1.25	1.28 ± 0.96	<0.001	1.61 ± 1.26	1.44 ± 1.09	0.012
Child TV viewing per day on weekends at 6 years (h)	2.70 ± 1.64	1.08 (1.00–1.15)	2.95 ± 1.70	2.41 ± 1.43	<0.001	2.81 ± 1.72	2.64 ± 1.60	0.091

[a] For some variables, the sum of categories was not equal to the total because of missing data.

[b] Low parental education was defined as 3 years of college or lower, and high education was defined as college graduate or higher; low family income was defined as ≤185% of the poverty line, and high family income was defined as >185% of the poverty line.

Abbreviations: GWG, gestational weight gain; MVPA, moderate or vigorous physical activity; RR, relative risk.

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TABLE 4

Single-mediator analysis for socioeconomic disparities in childhood obesity at 6 years

	Sample size (*n*)	Excess RR (95% CI)[a]			Percentage of indirect effect[b]
		Total effect	Direct effect	Indirect effect	
Maternal-education-related disparity in childhood obesity (low vs. high education)[c]					
Maternal preconception BMI (kg/m^2)	1,085	0.85 (0.28 to 1.41)	0.77 (0.21 to 1.34)	**0.07 (0.03 to 0.12)**	**8.8**
Prenatal Healthy Eating Index	394	1.21 (−0.05 to 2.48)	1.17 (−0.10 to 2.45)	0.04 (−0.04 to 0.12)	3.3
Postnatal Healthy Eating Index at 3 months	559	0.89 (0.06 to 1.73)	0.85 (0.00 to 1.69)	0.05 (−0.05 to 0.14)	5.3
Maternal smoking during pregnancy (binary, yes vs. no)	1,096	0.75 (0.19 to 1.30)	0.69 (0.13 to 1.25)	**0.05 (0.01 to 0.10)**	**7.0**
Maternal number of cigarettes smoked per day during pregnancy	1,096	0.88 (0.34 to 1.42)	0.84 (0.30 to 1.38)	**0.04 (0.02 to 0.07)**	**4.8**
Birth weight (kg)	1,099	0.80 (0.23 to 1.37)	0.83 (0.26 to 1.40)	−0.03 (−0.05 to 0.00)	N/A
Timing of formula initiation (wk)	871	1.08 (0.39 to 1.77)	1.01 (0.33 to 1.69)	0.07 (−0.01 to 0.16)	6.6
Timing of introduction of solid foods (wk)	977	0.67 (0.10 to 1.24)	0.63 (0.06 to 1.20)	0.04 (0.00 to 0.08)	5.8
Adherence score to infant guideline solids at 1 year	693	0.24 (−0.25 to 0.73)	0.19 (−0.30 to 0.67)	0.05 (−0.01 to 0.12)	22.6
Adherence score to high sugar/fat/protein at 1 year	693	0.26 (−0.28 to 0.80)	0.20 (−0.34 to 0.74)	0.06 (0.00 to 0.13)	23.5
Infant weight gain from birth to 7 months (kg)	854	0.82 (0.28 to 1.37)	0.71 (0.15 to 1.26)	**0.12 (0.05 to 0.19)**	**14.4**
Child sleep duration at 1 year (h)	831	0.41 (−0.08 to 0.89)	0.38 (−0.10 to 0.87)	0.03 (−0.01 to 0.06)	6.3
Child sleep duration at 6 years (h)	1,090	0.78 (0.21 to 1.34)	0.69 (0.13 to 1.25)	**0.09 (0.03 to 0.14)**	**11.4**
Score of child home learning environment at 6 years	1,096	0.75 (0.19 to 1.30)	0.69 (0.13 to 1.25)	0.06 (0.00 to 0.12)	7.7
Child TV viewing per day on weekdays at 6 years (h)	1,093	1.20 (0.60 to 1.80)	1.14 (0.54 to 1.74)	**0.06 (0.02 to 0.10)**	**4.9**
Child TV viewing per day on weekends at 6 years (h)	1,085	0.78 (0.21 to 1.35)	0.77 (0.20 to 1.34)	0.01 (−0.03 to 0.05)	1.2
Family-income-related disparity in childhood obesity (low vs. high income)[c]					
Maternal preconception BMI (kg/m^2)	1,087	0.51 (0.14 to 0.88)	0.42 (0.06 to 0.77)	**0.10 (0.04 to 0.15)**	**18.5**
Prenatal Healthy Eating Index	395	0.10 (−0.56 to 0.77)	0.05 (−0.62 to 0.71)	0.06 (−0.03 to 0.15)	55.9
Postnatal Healthy Eating Index at 3 months	560	0.37 (−0.25 to 0.99)	0.35 (−0.27 to 0.96)	0.03 (−0.02 to 0.07)	6.8
Maternal smoking during pregnancy (binary, yes vs. no)	1,098	0.39 (−0.05 to 0.83)	0.36 (−0.08 to 0.80)	0.03 (−0.01 to 0.06)	7.1
Maternal number of cigarettes smoked per day during pregnancy	1,098	0.73 (0.31 to 1.14)	0.68 (0.26 to 1.10)	**0.05 (0.02 to 0.08)**	**6.3**
Timing of formula initiation (wk)	873	0.85 (0.36 to 1.34)	0.84 (0.35 to 1.32)	0.01 (−0.02 to 0.04)	1.4
Timing of introduction of solid foods (wk)	979	0.55 (0.01 to 1.09)	0.53 (−0.01 to 1.07)	0.02 (−0.01 to 0.05)	3.6
Adherence score to infant guideline solids at 1 year	695	0.34 (−0.27 to 0.94)	0.29 (−0.31 to 0.89)	0.05 (−0.01 to 0.12)	15.3

	Sample size (*n*)	Excess RR (95% CI)[a]			Percentage of indirect effect[b]
		Total effect	Direct effect	Indirect effect	
Adherence score to high sugar/fat/protein at 1 year	695	0.28 (−0.31 to 0.87)	0.22 (−0.38 to 0.82)	0.06 (−0.01 to 0.12)	20.5
Child sleep duration at 1 year (h)	833	0.35 (−0.18 to 0.88)	0.33 (−0.21 to 0.86)	0.03 (−0.01 to 0.07)	7.4
Child sleep duration at 6 years (h)	1,092	0.70 (0.32 to 1.08)	0.61 (0.23 to 0.99)	**0.09 (0.02 to 0.16)**	**12.8**
Score of child home learning environment at 6 years	1,098	0.41 (−0.03 to 0.84)	0.30 (−0.13 to 0.73)	**0.11 (0.04 to 0.18)**	**26.2**
Child TV viewing per day on weekdays at 6 years (h)	1,095	0.43 (−0.01 to 0.87)	0.42 (−0.02 to 0.85)	0.02 (−0.01 to 0.04)	3.4

[a] Excess RR = RR − 1. Significant indirect effects are in bold ($p < 0.05$).

[b] Percentage of indirect effect = indirect effect/total effect.

[c] Low education was defined as 3 years of college or lower, and high education was defined as college graduate or higher; low family income was defined as ≤185% of the poverty line, and high family income was defined as >185% of the poverty line.

Abbreviation: RR, relative risk.