MAX PLANCK INSTITUTE
FOR DEMOGRAPHIC RESEARCH

Konrad-Zuse-Strasse 1 · D-18057 Rostock · Germany · Tel +49 (0) 3 81 20 81 - 0 · Fax +49 (0) 3 81 20 81 - 202 · www.demogr.mpg.de

MPIDR Working Paper WP 2023-016 I April 2023
https://doi.org/10.4054/MPIDR-WP-2023-016

The role of childhood obesity in socioeconomic inequalities in young adolescents' mental health: Differential exposure or differential impact?

M. Gueltzow I gueltzow@demogr.mpg.de
J. Oude Groeniger
M. J. Bijlsma
P. W. Jansen
T. A. J. Houweling
F. J. van Lenthe

This working paper has been approved for release by: Silvia Loi (loi@demogr.mpg.de), Deputy Head of the Laboratory of Population Health.

The role of childhood obesity in socioeconomic inequalities in young adolescents' mental health: Differential exposure or differential impact?

Gueltzow M[a,b]*, Oude Groeniger J*[b,c]*, Bijlsma MJ*[d,a]*, Jansen PW*[e,f,g]*, Houweling TAJ*[b]*, van Lenthe FJ*[b]

a. Max Planck Institute for Demographic Research, Rostock, Germany
b. Department of Public Health, Erasmus MC, University Medical Center Rotterdam, Rotterdam, the Netherlands
c. Department of Public Administration and Sociology, Erasmus University Rotterdam, Rotterdam, The Netherlands
d. Unit PharmacoTherapy, -Epidemiology, and -Economics (PTEE), Groningen Research Institute of Pharmacy, University of Groningen, the Netherlands
e. Department of Child & Adolescent Psychiatry/Psychology, Erasmus MC, University Medical Center, Rotterdam, The Netherlands
f. Generation R Study, Erasmus MC, University Medical Center, Rotterdam, The Netherlands.
g. Department of Psychology, Education & Child Studies, Erasmus University Rotterdam, Rotterdam, The Netherlands.

Abstract

We investigated to what extent socioeconomic inequalities in young adolescents' mental health are due to differential exposure to, or differential impact of obesity. We used data from 4,660 Generation R participants and defined mother's education and household income at child's age 5 as a disparity measure. We estimated the contribution of differential exposure to, and differential impact of, body fat percentage at age 9 to the total disparity in internalizing and externalizing symptoms at age 13. This was done through a four-way decomposition with interventional analogues using marginal structural models with inverse probability of treatment weighting. The total disparity in internalizing symptoms was 0.98 points (95%CI 0.35, 1.63) and 1.68 points (95%CI 1.13, 2.19), comparing children from least- and most-educated mothers, and lowest and highest income households, respectively. Of these total disparities in internalizing symptoms, 0.50 points (95%CI 0.15, 0.85) and 0.24 points (95%CI 0.09, 0.46) were due to differential exposure to obesity. We found no evidence for differential exposure or impact contributing to disparities in externalizing symptoms. Our results indicate that tackling the higher obesity prevalence in children from mothers with a low socioeconomic position may also reduce inequalities in internalizing symptoms in early adolescence.

Introduction

The majority of mental disorders have their onset before mid adolescence[1-3]. Early adolescence therefore presents itself as an important window of opportunity to prevent the onset of mental health problems[4].

Children who grow up in less privileged settings are more likely to have mental health problems than children who grow up in families with a high socioeconomic position (SEP).[5] This might be explained by the adverse social and physical contexts that can accompany low SEP, including higher odds of parental mental health problems and financial stress[5,6], and structural limitations such as lower access to mental health care[5] and neighborhoods with less advantageous conditions.[7] These factors may also create an environment with inadequate resources to cope with adversity and as such increase the risk of young adolescents' mental health problems.

This adversity in low socioeconomic groups may also contribute to higher levels of childhood obesity.[8,9] Indeed, there is evidence for higher comorbidity of obesity and adolescents' mental health problems in low socioeconomic settings.[10] In particular, obesity was shown to increase the risk for mental health problems.[11] This might be explained through biological pathways, such as stress or inflammatory response; behavioral pathways, such as low physical activity, sedentary behavior, poor diet or sleep;[12] or psychosocial pathways, such as discrimination based on weight[13,14] and negative self-image.[15] In early adolescence, the psychosocial pathway might be a particularly important contributor to the effect of obesity on mental health due to increased sensitivity to social evaluation.[4]

Getting insight into the underlying pathways of the role that obesity plays in socioeconomic inequalities in young adolescents' mental health will aid in understanding how these inequalities may be addressed. The co-occurrence of obesity and mental health problems in low socioeconomic settings[10] suggests that socioeconomic inequalities in young adolescents' mental health may be partially due to obesity being unevenly distributed across socioeconomic groups. Yet, the effect of obesity may also be more detrimental to mental health in specific socioeconomic groups, because of fewer resources to cope with the negative psychosocial effects of obesity. While the former can be defined as differential exposure, or mediation, the latter can be defined as differential impact, or effect modification.[16] We investigate to what extent differential exposure to and differential impact of obesity contribute to socioeconomic inequalities in young adolescents' mental health.

Methods

Data

We conducted our analysis in the Generation R Study[17]. Generation R is a multi-ethnic population-based prospective cohort study, based in Rotterdam, the Netherlands, that spans from fetal life until young adulthood. Pregnant women with expected delivery between April 2002 and January 2006 were invited to participate of which 9,778 mothers enrolled in the study. These mothers gave birth to 9,749 children of which 7,893 children enrolled in the study. We included children who had complete data on mental health at age 13 and maternal education (N=4,660) (Figure S.1). The Generation R Study was approved by the Medical Ethical Committee of Erasmus MC, University Medical Center Rotterdam. Participants (parents until age 12, parents and children from age 12) gave written consent for each phase of the study.

Exposure

We assessed socioeconomic status through mother's highest educational attainment and household income. Maternal education was measured at age 5 of the child and assessed with a self-reported questionnaire and categorized into low (primary school or lower vocational education, ISCED 0-2), medium (intermediate vocational education, ISCED 3-4), or high (higher vocational education or university, ISCED 5-7), in accordance with the International Standard Classification of Education (ISCED).[18] Household income was reported by the mother at age 5 of the child as the monthly household net income from work, benefits and/or assets in Euro and divided into "<3,200", "3,200 to 4,800", or ">4,800".

Outcome

We assessed emotional and behavioral problems at the of age 13 years with the validated, parent-reported Child Behavior Checklist (CBCL/6-18[19]). The checklist consists of 112 items that assess problem behavior, which can be divided into internalizing (syndrome scales: anxious/depressed, withdrawn/depressed, somatic complaints) and externalizing problem subscales (syndrome scales: rule-breaking behavior, aggressive behavior).[19,20] Because the link between SEP and mental health may differ between externalizing symptoms and internalizing problems,[5,21] we ran the analysis for the internalizing and externalizing problem subscales separately.

Mediator

Fat mass percentage provides a more accurate estimate of obesity than body mass index.[22] We calculated the body fat percentage at age 9 based on total fat mass, measured through dual X-ray absorptiometry (DXA), and body weight, measured with light clothing using a mechanical personal scale. To aid the analysis, we categorized body fat percentage into quartiles (Q1: <21.1%, Q2: 21.1-25.2%, Q3: 25.3-30.6%, Q4: >30.6%). Q4 correlates strongly with overweight and obesity as calculated using body mass index (Supplementary Figure). For subgroup analysis, we calculated gender-specific body fat percentage quartiles (Girls: Q1: <23.8%, Q2: 23.8 to 27.4%, Q3: 27.4% to 32.4%, Q4: >32.4%; Boys: Q1: <18.9%, Q2: 18.9 to 22.4%, Q3: 22.4% to 27.4%, Q4: >27.4%).

Confounders

We defined SEP as a disparity measure and are therefore only interested in confounders of the mediator-outcome pathway (see next section). Gender of the child and birth weight were obtained from hospital/midwife registries. Maternal age was recorded at intake. Child's migration background (Dutch, western, non-western; based on classifications provided by Statistics Netherlands[23]) was reported by the mother at baseline. Partnership status (married/registered partnership/living with partner, no partner/not living with partner), family functioning, and child mental health (to control for reverse causation; assessed with the CBCL/1.5-5) were measured at age 5. We assessed family functioning with the 12-item subscale General Functioning of the Family Assessment Device[24] and categorized the sum score (ranging from 0-4) into unhealthy family functioning (>2.17) or healthy family functioning (<2.17).[25] Mother's depressive symptoms health, financial stress and school problems were assessed at age 9. Mother's mental health was based on the 6-item depression subscale of the Brief Symptom Inventory (BSI), which is a 53-item self-report symptom inventory that assess psychological symptoms.[26,27] We determined financial stress by whether the mother reported trouble paying for food, rent or electricity (no trouble, a little trouble, a lot of trouble). We measured school problems by whether (yes/no) the child has any academic or other problems at school. We controlled for children's age at the time the outcome is measured (around age 13).

Statistical Analysis

We assessed to what extent differential exposure to or differential impact of obesity explain socioeconomic inequalities in young adolescents' mental health with the four-way decomposition approach described by VanderWeele.[28] VanderWeele's approach assumes a causal effect of the exposure on the outcome. Because we are interested in how intervening on obesity would affect

inequalities in young adolescents' mental health, we defined SEP as a disparity measure.[29] Maternal education and household income may still be considered causes of obesity and mental health. However, in the context of this study, we were not interested in estimating their causal effects. Instead, we aimed to describe the total disparity in mental health between groups defined by maternal education and household income, and to what extent these disparities could be reduced by eliminating socioeconomic differences in exposure to, and the impact of, obesity. Specifically, we defined total disparity (TD) as the absolute difference in internalizing and externalizing symptoms between SEPs expressed as

$$TD = E[Y_a - Y_{a^*}]$$

Where Y is internalizing or externalizing symptoms, a is either low or middle maternal education or a household income of either less than 800-3200 EUR or 3200-4800 EUR and a^* is high maternal education or a household income of >4800 EUR.

The total disparity is comparable to the total effect, but requires no assumptions about the absence of exposure-outcome or exposure-mediator confounding.[30,31] The resulting conceptual framework can be found in Figure 1.

For the four-way-decomposition of the total disparity measure, we calculated the interventional analogues of those four components, as described by Jackson and VanderWeele[29]. In contrast to the original four-way-decomposition approach[28], we do not estimate the natural effects, but estimate the interventional analogues by fixing the mediator for each individual to a randomly drawn level from the distribution of the mediator amongst those with a particular exposure[32]. While this gives a somewhat weaker causal interpretation, these interventional analogues can be defined as effects that could in principle be achieved through intervening on the mediator, in our case obesity, under the assumption of no unmeasured mediator-outcome confounding.[32] We decomposed the TDs into: (I) the residual disparity across education or income groups if no one were obese (analogue to controlled direct effect (CDE)); (II) the product between the additive interaction of obesity with education or income and mean obesity levels among those with high educated mothers or high household income (analogue of referent interaction (INT_{ref}), (III) the product between the additive interaction of obesity with education or income and the disparity in obesity across education or income (analogue of mediated interaction (INT_{med}); (IV) the change in young adolescents' mental health among children with low educated mothers or low household income if they would have had the obesity prevalence of children with high educated mothers or high household income (analogue of the pure indirect effect (PIE)).[29]

We calculated differential exposure as the sum of the PIE and INT_{med}, and differential impact as the sum of INT_{ref} and INT_{med}, as proposed by Diderichsen et al.[16] Differential exposure indicates to what extent educational or income inequalities in young adolescents' mental health could be reduced by eliminating unequal exposure to obesity. Differential impact indicates to what extent the total disparity in young adolescents' mental health could be reduced by eliminating the interaction between education or income and childhood obesity. We calculated the relative contribution of differential exposure or differential impact to the TD by dividing each estimate by the TD. The relative difference may be below 0% or above 100%, which is the result of any of the four components being the opposite sign to the total disparity so they partially cancel each other out.

To calculate the interventional analogues of the four above described components (CDE, INT_{ref}, INT_{med}, PIE), we fit marginal structural models with inverse probability of treatment weighting for the mediator (which enabled us to accurately adjust for mediator-outcome confounders even if these are themselves affected by maternal education or household income[31,33]), controlling for the confounders listed above. We used the CMAverse R package developed by Shi et al.[34], but adapted the code to omit exposure weighting to estimate the TD, introduced Monte Carlo error reduction (60 iterations) for the simulation step, and calculated differential exposure and differential susceptibility. We used multiple imputation by chained equations (M=50) to impute missing data on body fat percentage and confounders. We used 399 bootstrap iterations to obtain the 95% confidence intervals. We performed subgroup analysis by gender.

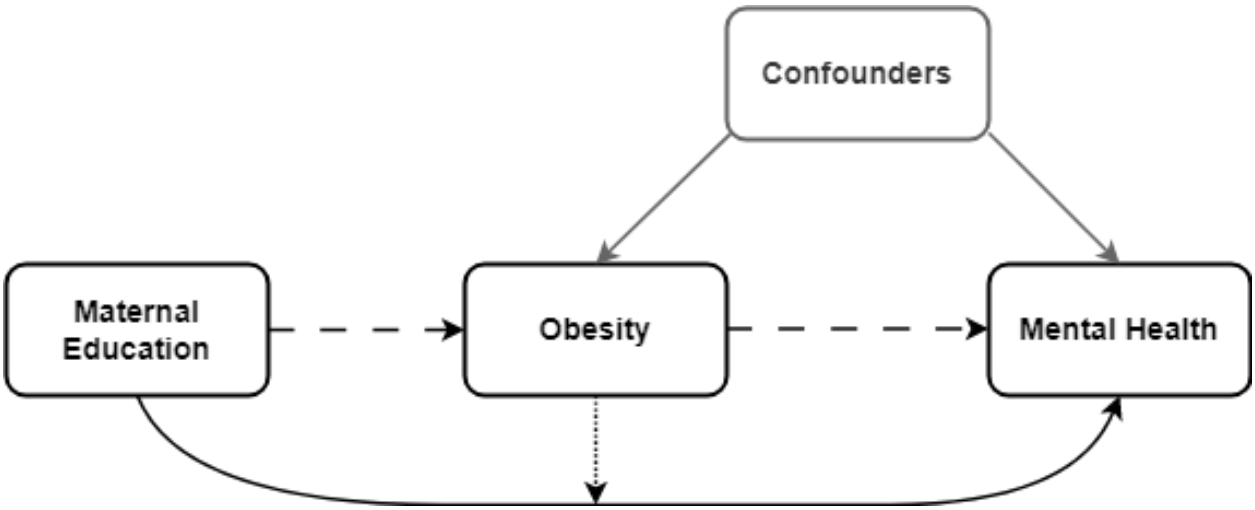

Figure 1 Conceptual Framework. Dashed arrows represent differential exposure and the dotted arrow indicates differential impact. Confounders: gender, child's migration background, mother's age at intake, birth weight, mother's mental health, family functioning, marital status, financial stress, school problems, CBCL/1.5-5. We omit exposure-outcome and exposure-mediator confounding because education and income are defined as a disparity measure.

Sensitivity analysis

While there is evidence for a causal effect of obesity on mental health, mental health might also affect obesity.[32,33] We investigated whether differential exposure to or differential impact of internalizing or externalizing symptoms contribute to socioeconomic inequalities in young adolescents' obesity. We used high body fat percentage at age 13 as the outcome and the cut-off for the clinical range of internalizing or externalizing symptoms at age 9 as the mediator, controlling for BMI at age 5. We categorized internalizing and externalizing symptoms into normal range (<60), borderline clinical (60-63) and clinical range (>63) based on the T-scores for internalizing and externalizing symptoms.[19] T-scores were age- and sex-standardized with a mean of 50 and standard deviation of 10 to allow for comparisons across groups.[35]

Results

Sample characteristics by maternal education and household income can be found in Table 1. Most children had mothers with high educational attainment and a household income of more than 4,800 Eur/month. The high education and high-income group were mostly of Dutch origin (74.4%), whereas the low education and low-income group mostly had a non-Western migration background (56.9% and 52.7%). The low education and low-income groups had a higher prevalence of high body fat percentage and higher mean internalizing and externalizing symptoms scores at age 13 than the high education and income groups.

Table 1 Sample characteristics by maternal education and household income.

	Maternal Education			**Household Income**		
	high	middle	low	>=4,800	3,200 to 4,800	<3,200
N	2843	1323	494	1577	1516	930
Girl N(%)	1420 (49.9)	667 (50.4)	254 (51.4)	791 (50.2)	767 (50.6)	459 (49.4)
Migration background N(%)						
Dutch	2114 (74.4)	773 (58.5)	185 (37.8)	1299 (82.4)	1064 (70.2)	355 (38.2)
Western	315 (11.1)	85 (6.4)	26 (5.3)	149 (9.5)	150 (9.9)	84 (9.0)
Non-Western	413 (14.5)	463 (35.0)	279 (56.9)	128 (8.1)	302 (19.9)	490 (52.7)
Body fat percentage at age 9 N(%)						
<21%	741 (29.2)	241 (20.2)	58 (13.6)	430 (30.4)	337 (24.0)	172 (20.4)
21 to 25%	713 (28.1)	242 (20.3)	84 (19.6)	398 (28.1)	359 (25.6)	170 (20.1)
25 to 30.6%	607 (23.9)	333 (28.0)	99 (23.1)	367 (25.9)	337 (24.0)	198 (23.5)
>30.6%	478 (18.8)	375 (31.5)	187 (43.7)	220 (15.5)	370 (26.4)	304 (36.0)
CBCL score at age 13 (mean(SD))						
Internalizing symptom score	5.27 (5.6)	6.06 (5.8)	6.23 (6.7)	4.66 (4.99)	5.82 (5.86)	6.37 (6.23)
Externalizing symptom score	3.96 (5.0)	4.57 (5.4)	4.65 (6.4)	3.61 (4.73)	4.25 (4.97)	4.88 (5.90)
Confounders						
Age at CBCL measurement (mean (SD))	13.53 (0.4)	13.55 (0.4)	13.60 (0.4)	13.52 (0.35)	13.51 (0.36)	13.57 (0.38)
Age of mother at intake (mean (SD))	32.50 (3.9)	29.90 (5.1)	29.73 (5.9)	33.15 (3.37)	31.39 (4.53)	29.81 (5.46)
Birth weight in grams (mean (SD))	3481 (569)	3348 (601)	3340 (549)	3516 (553)	3417 (582)	3340 (599)
No partner/not living with partner N(%)	217 (7.6)	220 (16.7)	117 (24.0)	24 (1.5)	47 (3.1)	380 (41.0)
CBCL at age 5 (mean (SD))	17.27 (14.25)	20.15 (15.9)	24.07 (19.3)	15.98 (13.58)	18.74 (14.61)	23.22 (18.24)

School problems N(%)	560 (26.0)	273 (32.0)	74 (29.6)	294 (23.9)	357 (31.0)	179 (29.6)
Problematic family functioning N(%)	89 (3.4)	58 (5.0)	39 (11.0)	39 (2.5)	47 (3.1)	88 (9.9)
Trouble paying for food, rent, electricity bill N(%)						
No trouble	2223 (89.1)	829 (76.6)	238 (67.8)	1344 (95.3)	1141 (84.4)	498 (64.4)
A little trouble	246 (9.9)	219 (20.2)	97 (27.6)	63 (4.5)	189 (14.0)	237 (30.7)
A lot of trouble	26 (1.0)	34 (3.1)	16 (4.6)	3 (0.2)	22 (1.6)	38 (4.9)
Depressive symptoms of the mother at age 9 (mean (SD))	0.16 (0.3)	0.22 (0.4)	0.24 (0.4)	0.13 (0.27)	0.18 (0.35)	0.29 (0.50)

Figure 2 shows the mean scores for internalizing (upper panels) and externalizing (lower panels) symptoms per quartile of body fat percentage, stratified by maternal education (left panels) or household income (right panels). It provides a descriptive illustration of the association between body fat and internalizing and externalizing symptoms within each education or income group (represented by the height of the bars; indicative for differential impact) as well as the prevalence of body fat percentage within each education or income group (represented by the width of the bars; indicative of differential exposure). This Figure indicates that children in the highest body fat percentage quartile had more internalizing and externalizing symptoms if they live in a family with a lower maternal education or income level. Furthermore, children in the highest body fat percentage quartile more often lived in families with a lower maternal education or income level.

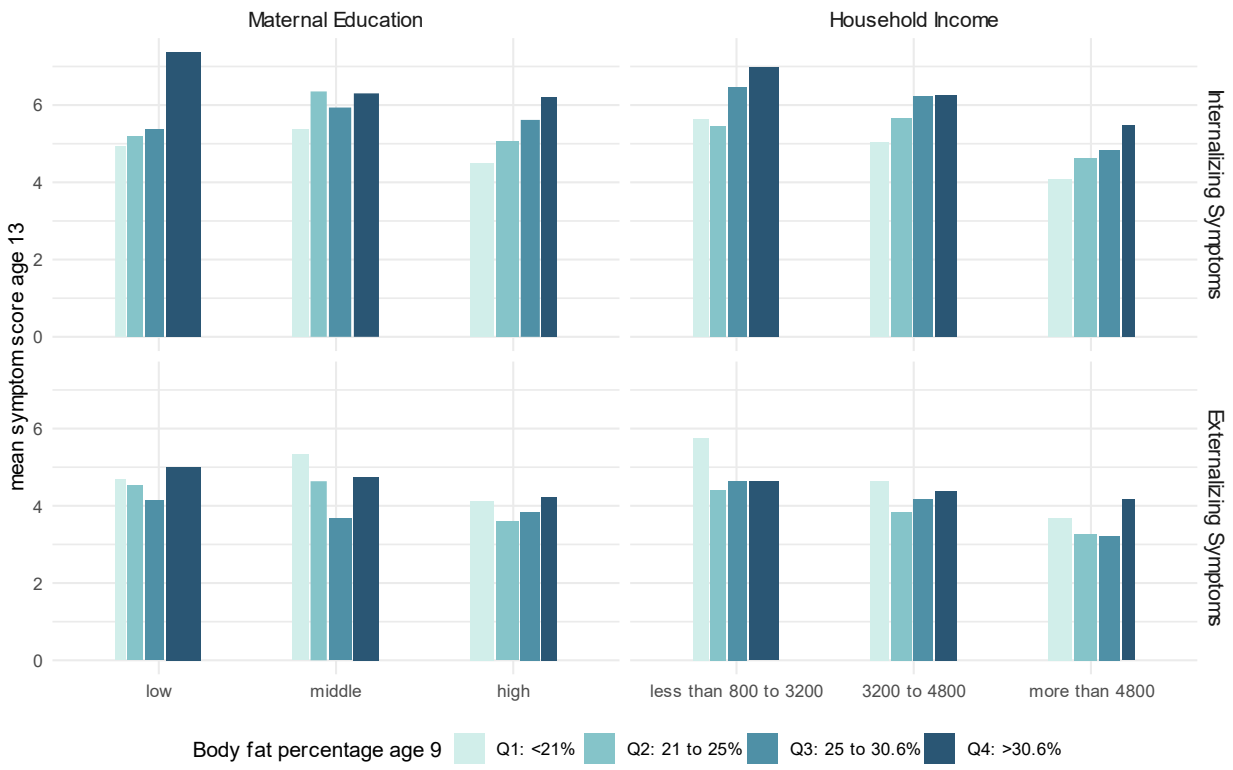

Figure 2 Descriptive mean internalizing and externalizing symptom score at age 13 by body fat percentage quartiles at age 9, stratified by maternal education and household income. The bar width represents the relative group size of each body fat percentage quartile in relation to the other quartiles, within each education or income group.

Main results by maternal education and household income can be found in Figure 3 and supplementary Table S.1. For maternal education, we estimated a total disparity in internalizing symptoms of 0.98 (95%CI 0.35, 1.63) points for low compared to high maternal education and 0.81 (95%CI 0.40, 1.23) points for middle compared to high education. For externalizing symptoms, we found a total disparity of 0.61 (95%CI 0.08, 1.14) points for low compared to high and of 0.64 (95%CI 0.27, 1.01) points for middle compared to high maternal education, respectively. Further, 0.50 (95%CI 0.15, 0.85) points or 51% of the total disparity in internalizing symptoms can be accounted for by differential exposure to high body fat percentage in the low compared to high education group. Our results indicate that -0.62 (95%CI -1.41 to 0.17) or 64% of this disparity in internalizing symptoms can be accounted for by differential impact, though confidence intervals are wide and include the null.

For household income, we found a total disparity in internalizing symptoms of 1.68 (95%CI 1.13, 2.19) points and 1.18 (95%CI 0.81, 1.56) points for low and middle versus high income. The total

disparity in externalizing symptoms was 1.25 (95%CI 0.8, 1.69) points and 0.68 (95%CI 0.34, 1.04) points in low and middle compared to high income. 0.24 (95%CI 0.09, 0.46) points and 0.09 (95%CI 0.02, 0.19) points of the total disparity in internalizing symptoms in the low compared to high and middle compared to high income group can be attributed to differential exposure, corresponding to 14% and 8% respectively. Further, our findings indicate that 0.54 points (95%CI -0.05, 1.14) or 43% of the disparity in externalizing symptoms between low and high income is due to differential impact, though confidence intervals include the null.

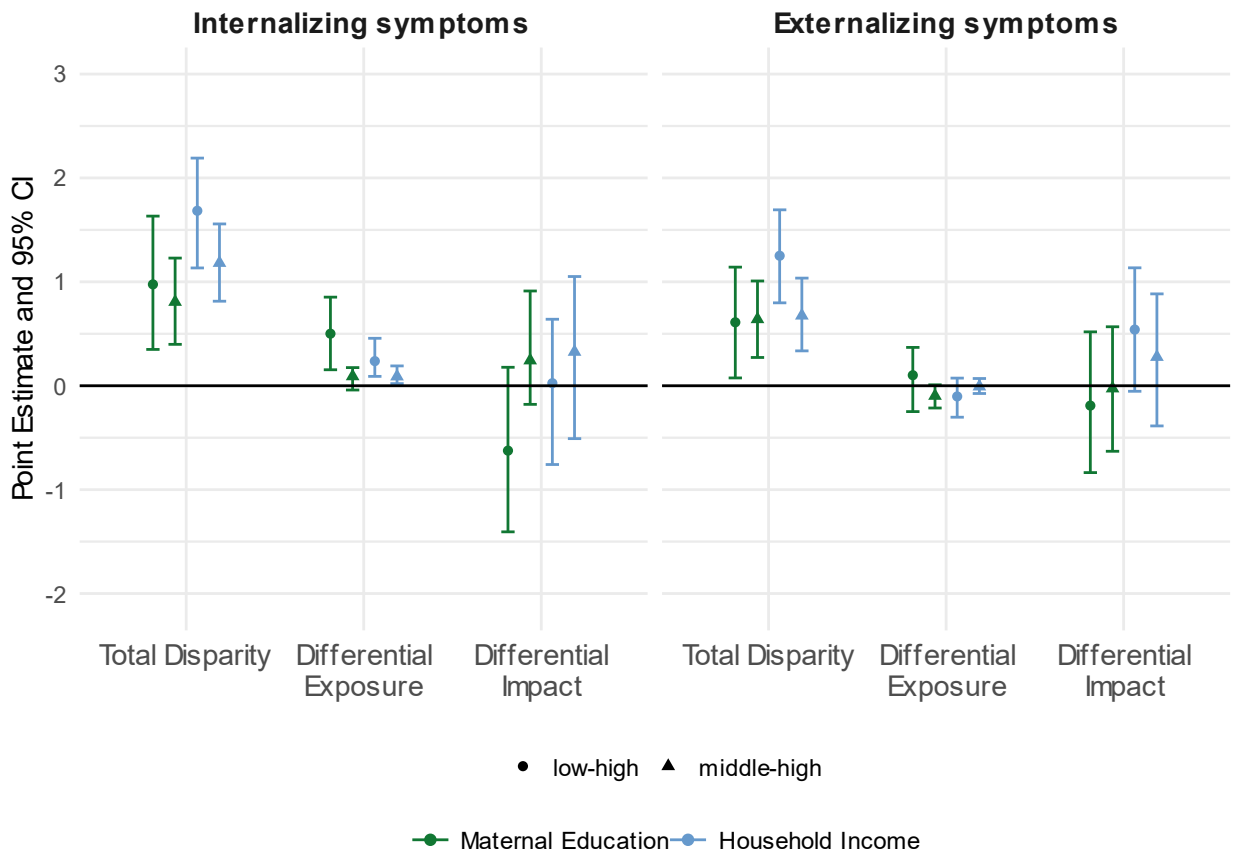

Figure 3 Total disparity in internalizing and externalizing symptoms by maternal education and household income, and the contribution of differential exposure to or impact of high body fat percentage to these disparities.

Subgroup analysis

Stratified by gender, we found disparities in internalizing and externalizing symptoms in both girls and boys (Figure 4, supplementary Table S.2). For girls, 0.62 (95%CI 0.06, 1.25) points or 57% of the total disparity in internalizing symptoms in the low compared to high education group can be accounted for by differential exposure to high body fat percentage. For boys, the TDs in

internalizing and externalizing symptoms are not accounted for by differential exposure. For household income, we found disparities among both girls and boys for both internalizing and externalizing symptoms, but differential exposure to body fat percentage did not seem to account for these disparities.

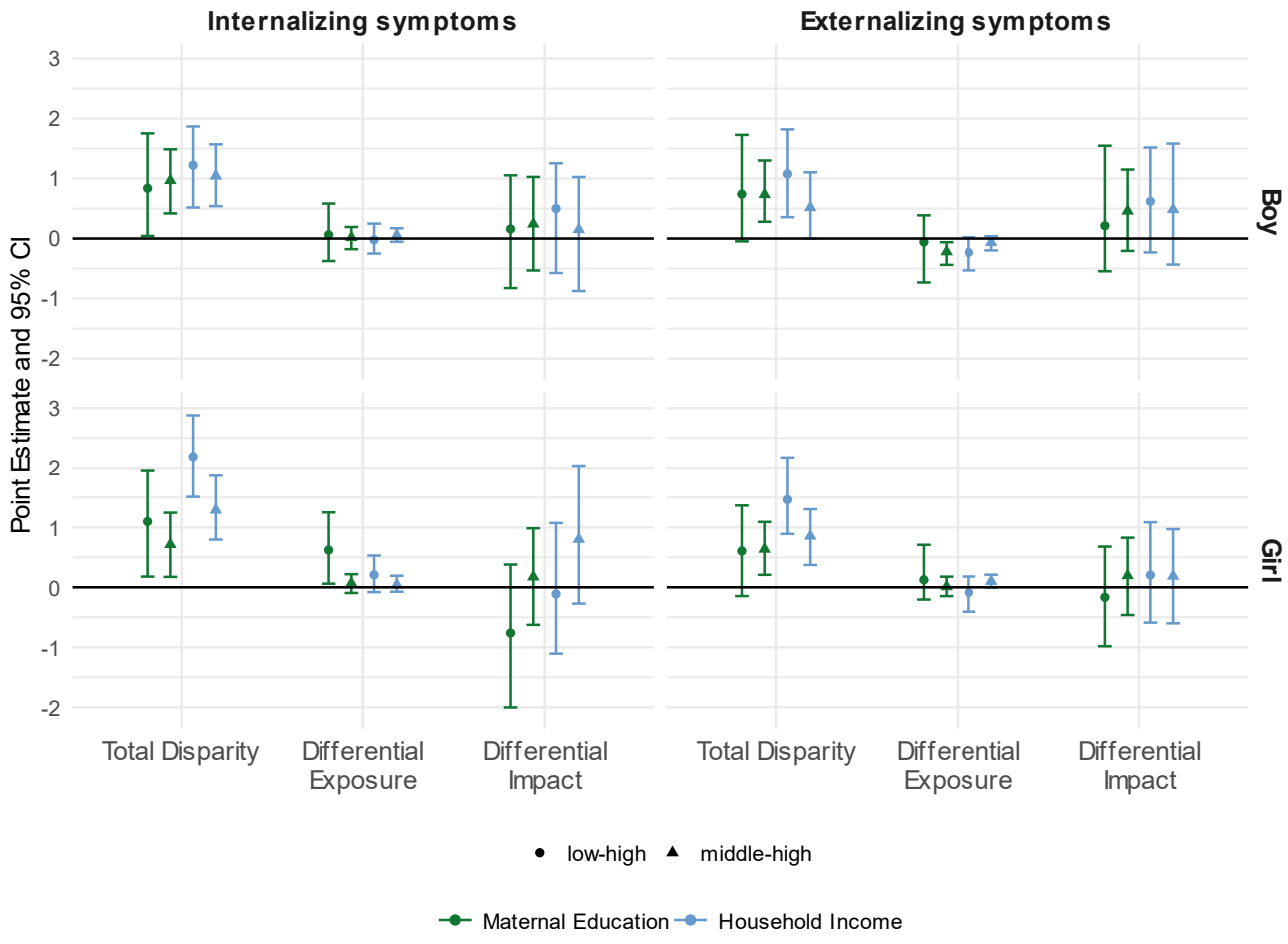

Figure 4 Total disparity in maternal education and household income and the contribution of differential exposure to or impact of high body fat percentage by gender.

Sensitivity analysis

We repeated the analyses with obesity as the outcome and internalizing or externalizing symptoms as the mediator (Supplementary Table S.4). We did not find evidence for differential exposure to or differential impact of internalizing or externalizing symptoms contributing to this disparity.

Discussion

Summary of findings

This study found educational and income inequalities in internalizing and externalizing symptoms in early adolescence. These inequalities are partly explained by socioeconomic inequalities in obesity at age 9. For internalizing symptoms, we estimated that 50% of the total disparity between low and high maternal education and 14% between low and high household income is due to differential exposure to high body fat percentage at age 9. For externalizing symptoms, we did not find evidence that a high body fat percentage explains part of the education or income inequalities. We found differences by gender, with high body fat percentage contributing to educational inequality in internalizing symptoms in girls only. Conversely, differential exposure to or impact of internalizing and externalizing symptoms at age 9 did not explain educational and income inequalities in high body fat percentage at age 13.

Strengths and limitations

This study has several advantages. First, we have objective measurements of fat mass, which allowed us to calculate body fat percentage. While BMI is commonly used to study the effects of obesity on various outcomes, BMI may underestimate the socioeconomic gradient in obesity.[36] Furthermore, fat mass is a more accurate measure of body composition than BMI.[22] Second, this is the first study (to our knowledge) that performs a 4-way-decomposition where the exposure, namely education or income, is considered as a disparity measure. This offers a unique opportunity to assess underlying mechanisms that explain how intervening on obesity can decrease socioeconomic inequalities in young adolescents' mental health.

This paper has a number of limitations that we would like to highlight. First, the Generation R Study is higher educated and healthier than the underlying study population.[37] Furthermore, mental health of the child at age 13 was only available for about 40% of the participants that were included at the start of the Generation R Study (supplementary Figure S.1). Hence, the already quite healthy selection of the underlying sample might also suffer from selection bias whereby mainly children with worse mental health dropped out. This selection bias may differ by educational or income groups[36] which affects the interpretation of our results: we might have underestimated the true socioeconomic gradient in young adolescents' mental health in the Rotterdam region[21], which biases the differential exposure and impact towards the null. Second, based on the large confidence intervals surrounding our differential impact estimates, we believe

there is too much uncertainty to conclude to what extent differential impact to high body fat percentage explains educational or income inequality in internalizing or externalizing symptoms. Hence, while we do report our findings on differential impact, these should be interpreted with caution because it seems we lacked sufficient statistical power to detect the interaction effects. This indicates that an even larger sample size than was available to us is needed to have sufficient statistical power to perform the four-way-decomposition with interventional analogues. Third, our analysis assumes no unmeasured confounding of the obesity-mental health relationship. Obesity and mental health share a number of risk factors and even though we carefully selected relevant confounders, other factors not considered in this analysis might play a role. Not including these factors may lead to an overestimation of the causal effect of obesity on mental health.

Comparison with previous literature

We found evidence that a higher body fat percentage in low compared to high education and income groups explains part of the total disparity in internalizing symptoms. Obesity is more strongly associated with internalizing symptoms than with externalizing symptoms[38,39], which might explain why we find contributions of differential exposure in internalizing symptoms only. While it was reported before that obesity and mental health problems more often co-occur among households with a low as compared to high SEP[10], our study is novel in that it finds evidence for the mediating role of obesity on socioeconomic inequalities in internalizing symptoms. The fact that differential exposure to obesity might explain the socioeconomic inequality in internalizing symptoms in childhood was indirectly suggested by Zhou et al.[39] and Patalay et al.[40] who found an attenuation of the link between obesity and internalizing symptoms after controlling for SEP and concluded that SEP is a shared origin for both. We add to this finding by quantifying the actual contribution of differential exposure to high body fat percentage to socioeconomic inequalities in young adolescents' mental health. Stratified by gender, we found that differential exposure of obesity contributes to socioeconomic inequalities in internalizing symptoms in girls only. Our results suggest that reducing the prevalence of high body fat percentage among girls with low educated mothers to the same level as that of girls of highly educated mothers would result in a 57% decrease in the total disparity in internalizing symptoms. This is supported by previous findings of a larger socioeconomic gradient in obesity in women than in men[41,42], whereas the evidence among children and adolescents is mixed.[9,43]

Overall, our results suggest that differential exposure to obesity may be more important in explaining educational than income inequalities in internalizing symptoms. It was reported before that there may be different underlying mechanisms at play when attempting to explain socioeconomic inequalities (e.g.[44,45]). Our study supports these findings by showing that obesity plays a more important role in educational as opposed to income inequalities in young adolescents' mental health.

We are not able to make any substantiated inferences about the extent to which differential impact to obesity contributes to educational or income inequality in internalizing and externalizing symptom scores. While there is some evidence that obesity may affect health outcomes more strongly in low socioeconomic groups[46,47], evidence on whether this is the case for internalizing and externalizing symptoms in young adolescents is still lacking. When looking at weight-related stigma and discrimination as one of the underlying pathways linking obesity to mental health, there is mixed evidence regarding the existence and direction of socioeconomic differences.[48,49] Nonetheless, addressing obesity in early adolescence may be particularly important due to the increased sensitivity to social evaluation[4] which may amplify consequences of weight-based stigma and discrimination and in turn negatively affect mental health. Future research that is able to draw on larger samples is needed to more thoroughly test this.

Mental health problems and obesity co-occur more often among low socioeconomic groups.[10] We found that while differential exposure to obesity does explain part of the educational and income inequalities in young adolescents' mental health, socioeconomic inequality in internalizing or externalizing symptoms do not explain socioeconomic inequalities in obesity. These inequalities in obesity might instead be more strongly driven by other factors that may accompany low SEP, such as financial stress and hardship at the family level, or structural factors like inadequate accessibility or affordability of sport facilities.[8]

Implications and recommendations

Our results indicate that tackling obesity in children from parents in low education and income groups will also decrease the existing educational and income inequalities in their mental health in early adolescence, specifically in girls. Often, interventions that aim to reduce obesity are targeted at individual behavior and with the main rationale that further weight gain may lead to health concerns in adulthood. These types of interventions are not always successful in reducing

socioeconomic inequalities because low socioeconomic groups are less likely to adhere[50] to or attend[51] such interventions. This might be driven by the fact that young adolescents with a low SEP have fewer resources and capabilities to respond to such interventions, and because such interventions are often too far detached from the life-worlds of lower SEP groups.[16,52] Hence, rather than introducing individual behavioral interventions, population-based (preventive) interventions targeted at multiple health and social dimensions might lead to the largest reduction in socioeconomic inequalities in both obesity and mental health. The co-occurrence of obesity and mental health may be partially explained by the fact that both outcomes share a number of risk factors[9] which are also more likely to be present among lower socioeconomic groups. These factors include family level factors such as financial stress and hardship, parental mental health problems, parenting, and more structural factors like inadequate access to facilities for physical activity, green space, and mental health care.[5,7,8,53] Tackling these root causes of both obesity and mental health problems in young adolescents offer a promising strategy to reduce health inequalities early in life.

Conclusion

Using a novel four-way-decomposition approach, we found that the larger prevalence of high body fat percentage in low compared to high education and income groups partly accounts for the higher internalizing symptom score in those groups, particularly among girls. Hence, reducing the prevalence of obesity or exposure to shared risk factors of mental health and obesity may contribute to tackling educational and income inequality in young adolescents' mental health.

References

1. Mulraney M, Coghill D, Bishop C, et al. A systematic review of the persistence of childhood mental health problems into adulthood. *Neuroscience and biobehavioral reviews.* 2021;129:182-205.
2. Solmi M, Radua J, Olivola M, et al. Age at onset of mental disorders worldwide: large-scale meta-analysis of 192 epidemiological studies. *Molecular Psychiatry.* 2022;27(1):281-295.
3. Kessler RC, Amminger Gp Fau - Aguilar-Gaxiola S, Aguilar-Gaxiola S Fau - Alonso J, Alonso J Fau - Lee S, Lee S Fau - Ustün TB, Ustün TB. Age of onset of mental disorders: a review of recent literature. (0951-7367 (Print)).
4. Dahl RE, Allen NB, Wilbrecht L, Suleiman AB. Importance of investing in adolescence from a developmental science perspective. *Nature.* 2018;554(7693):441-450.
5. Reiss F. Socioeconomic inequalities and mental health problems in children and adolescents: A systematic review. *Social Science & Medicine.* 2013;90:24-31.
6. Oude Groeniger J, Houweling TAJ, Jansen PW, et al. Social inequalities in child development: the role of differential exposure and susceptibility to stressful family conditions. *Journal of Epidemiology and Community Health.* 2023;77(2):74.
7. Alderton A, Villanueva K, O'Connor M, Boulangé C, Badland H. Reducing Inequities in Early Childhood Mental Health: How Might the Neighborhood Built Environment Help Close the Gap? A Systematic Search and Critical Review. *International Journal of Environmental Research and Public Health.* 2019;16(9).
8. Schreier HM, Chen E. Socioeconomic status and the health of youth: a multilevel, multidomain approach to conceptualizing pathways. *Psychol Bull.* 2013;139(3):606-654.
9. Wang Y, Lim H. The global childhood obesity epidemic and the association between socio-economic status and childhood obesity. *International Review of Psychiatry.* 2012;24(3):176-188.
10. Khanolkar AR, Patalay P. Socioeconomic inequalities in co-morbidity of overweight, obesity and mental ill-health from adolescence to mid-adulthood in two national birth cohort studies. *The Lancet Regional Health - Europe.* 2021;6:100106.
11. Tyrrell J, Mulugeta A, Wood AR, et al. Using genetics to understand the causal influence of higher BMI on depression. *International Journal of Epidemiology.* 2019;48(3):834-848.
12. Milaneschi Y, Simmons WK, van Rossum EFC, Penninx BW. Depression and obesity: evidence of shared biological mechanisms. *Mol Psychiatry.* 2019;24(1):18-33.
13. Puhl RM, Andreyeva T Fau - Brownell KD, Brownell KD. Perceptions of weight discrimination: prevalence and comparison to race and gender discrimination in America. *International Journal of Obesity.* 2008;32.
14. Puhl RM, Heuer CA. The Stigma of Obesity: A Review and Update. *Obesity.* 2009;17(5):941-964.
15. Reeves GM, Postolache TT, Snitker S. Childhood Obesity and Depression: Connection between these Growing Problems in Growing Children. *International journal of child health and human development : IJCHD.* 2008;1(2):103-114.
16. Diderichsen F, Hallqvist J, Whitehead M. Differential vulnerability and susceptibility: how to make use of recent development in our understanding of mediation and interaction to tackle health inequalities. *International Journal of Epidemiology.* 2019;48(1):268-274.
17. Kooijman MN, Kruithof CJ, van Duijn CM, et al. The Generation R Study: design and cohort update 2017. *Eur J Epidemiol.* 2016;31(12):1243-1264.
18. UNESCO Institute for Statistics. *International Standard Classification of Education ISCED 2011.* Montreal: UNESCO Institute for Statistics;2012.

19. Achenbach TM, Rescorla LA. *Manual for ASEBA School Age Forms & Profiles.* Burlington, VT: University of Vermont Research Center for Children, Youth and Families; 2001.
20. Maust D, Cristancho M, Gray L, Rushing S, Tjoa C, Thase ME. Chapter 13 - Psychiatric rating scales. In: Aminoff MJ, Boller F, Swaab DF, eds. *Handbook of Clinical Neurology.* Vol 106. Elsevier; 2012:227-237.
21. Houweling TAJ, Oude Groeniger J, Jansen PW, et al. Trajectories of socioeconomic inequality in early child development: a cohort analysis. *International Journal for Equity in Health.* 2022;21(1):79.
22. Prentice AM, Jebb SA. Beyond body mass index. *Obes Rev.* 2001;2(3):141-147.
23. Alders M. *Classification of the population with a foreign background in the Netherlands.* Paris: Statistics Netherlands;2001.
24. Byles J, Byrne C, Boyle MH, Offord DR. Ontario Child Health Study: reliability and validity of the general functioning subscale of the McMaster Family Assessment Device. *Family process.* 1988;27(1):97-104.
25. Henrichs J, Schenk JJ, Roza SJ, et al. Maternal psychological distress and fetal growth trajectories: The Generation R Study. *Psychological Medicine.* 2010;40(4):633-643.
26. Derogatis LR. *BSI brief symptom inventory: Administration, scoring, and procedures manual.* 4th ed. Minneapolis: MN: National Computer Systems; 1993.
27. De Beurs E. *Brief Symptom Inventory. Handleiding.* Leiden, The Netherlands2004.
28. VanderWeele TJ. A unification of mediation and interaction: a 4-way decomposition. *Epidemiology (Cambridge, Mass).* 2014;25(5):749-761.
29. Jackson JW, VanderWeele TJ. Intersectional decomposition analysis with differential exposure, effects, and construct. *Soc Sci Med.* 2019;226:254-259.
30. Naimi AI, Schnitzer ME, Moodie EEM, Bodnar LM. Mediation Analysis for Health Disparities Research. *American Journal of Epidemiology.* 2016;184(4):315-324.
31. Oude Groeniger J, de Koster W, van der Waal J. Time-varying Effects of Screen Media Exposure in the Relationship Between Socioeconomic Background and Childhood Obesity. *Epidemiology (Cambridge, Mass).* 2020;31(4):578-586.
32. VanderWeele TJ, Tchetgen Tchetgen EJ. Mediation analysis with time varying exposures and mediators. *Journal of the Royal Statistical Society Series B, Statistical methodology.* 2017;79(3):917-938.
33. VanderWeele TJ. Marginal structural models for the estimation of direct and indirect effects. *Epidemiology (Cambridge, Mass).* 2009;20(1):18-26.
34. Shi B, Choirat C, Coull BA, VanderWeele TJ, Valeri L. CMAverse: A Suite of Functions for Reproducible Causal Mediation Analyses. *Epidemiology (Cambridge, Mass).* 2021;32(5).
35. Lande MB, Adams H, Falkner B, et al. Parental assessments of internalizing and externalizing behavior and executive function in children with primary hypertension. *The Journal of pediatrics.* 2009;154(2):207-212.
36. van den Berg G, van Eijsden M, Vrijkotte TG, Gemke RJ. BMI may underestimate the socioeconomic gradient in true obesity. *Pediatric obesity.* 2013;8(3):e37-40.
37. Bouthoorn SH, Wijtzes AI, Jaddoe VWV, Hofman A, Raat H, van Lenthe FJ. Development of socioeconomic inequalities in obesity among Dutch pre-school and school-aged children. *Obesity.* 2014;22(10):2230-2237.
38. Bradley RH, Houts R, Nader PR, O'Brien M, Belsky J, Crosnoe R. The relationship between body mass index and behavior in children. *The Journal of pediatrics.* 2008;153(5):629-634.
39. Zhou N, Liang Y, Cao H, Chen Y, Lin X, Zhang J. Body mass index and internalizing symptoms from early childhood through early adolescence: Trend of codevelopment and directionality. *Journal of child psychology and psychiatry, and allied disciplines.* 2022;63(3):324-332.

40. Patalay P, Hardman CA. Comorbidity, Codevelopment, and Temporal Associations Between Body Mass Index and Internalizing Symptoms From Early Childhood to Adolescence. *JAMA Psychiatry.* 2019;76(7):721-729.
41. Fan JX, Wen M, Li K. Associations between obesity and neighborhood socioeconomic status: Variations by gender and family income status. *SSM - Population Health.* 2020;10:100529.
42. Zhang Q, Wang Y. Socioeconomic inequality of obesity in the United States: do gender, age, and ethnicity matter? *Social Science & Medicine.* 2004;58(6):1171-1180.
43. Chung A, Backholer K, Wong E, Palermo C, Keating C, Peeters A. Trends in child and adolescent obesity prevalence in economically advanced countries according to socioeconomic position: a systematic review. *Obesity Reviews.* 2016;17(3):276-295.
44. Macintyre S, McKay L, Der G, Hiscock R. Socio-economic position and health: what you observe depends on how you measure it. *Journal of public health medicine.* 2003;25(4):288-294.
45. Geyer S, Hemström Ö, Peter R, Vågerö D. Education, income, and occupational class cannot be used interchangeably in social epidemiology. Empirical evidence against a common practice. *Journal of Epidemiology and Community Health.* 2006;60(9):804.
46. Burkert NT, Rásky É, Großschädl F, Muckenhuber J, Freidl W. The Influence of Socioeconomic Factors on Health Parameters in Overweight and Obese Adults. *PloS one.* 2013;8(6):e65407.
47. Minet Kinge J, Morris S. Socioeconomic variation in the impact of obesity on health-related quality of life. *Social Science & Medicine.* 2010;71(10):1864-1871.
48. Bernard M, Fankhänel T, Riedel-Heller SG, Luck-Sikorski C. Does weight-related stigmatisation and discrimination depend on educational attainment and level of income? A systematic review. *BMJ Open.* 2019;9(11):e027673.
49. Viner RM, Haines MM, Taylor SJC, Head J, Booy R, Stansfeld S. Body mass, weight control behaviours, weight perception and emotional well being in a multiethnic sample of early adolescents. *International Journal of Obesity.* 2006;30(10):1514-1521.
50. Lemstra ME, Rogers M. Mental health and socioeconomic status impact adherence to youth activity and dietary programs: a meta-analysis. *Obes Res Clin Pract.* 2021;15(4):309-314.
51. Puhl RM, Latner JD. Stigma, obesity, and the health of the nation's children. *Psychol Bull.* 2007;133(4):557-580.
52. Frohlich KL, Potvin L. Transcending the known in public health practice: the inequality paradox: the population approach and vulnerable populations. *American journal of public health.* 2008;98(2):216-221.
53. Peverill M, Dirks MA, Narvaja T, Herts KL, Comer JS, McLaughlin KA. Socioeconomic status and child psychopathology in the United States: A meta-analysis of population-based studies. *Clinical psychology review.* 2021;83:101933.

Supplement

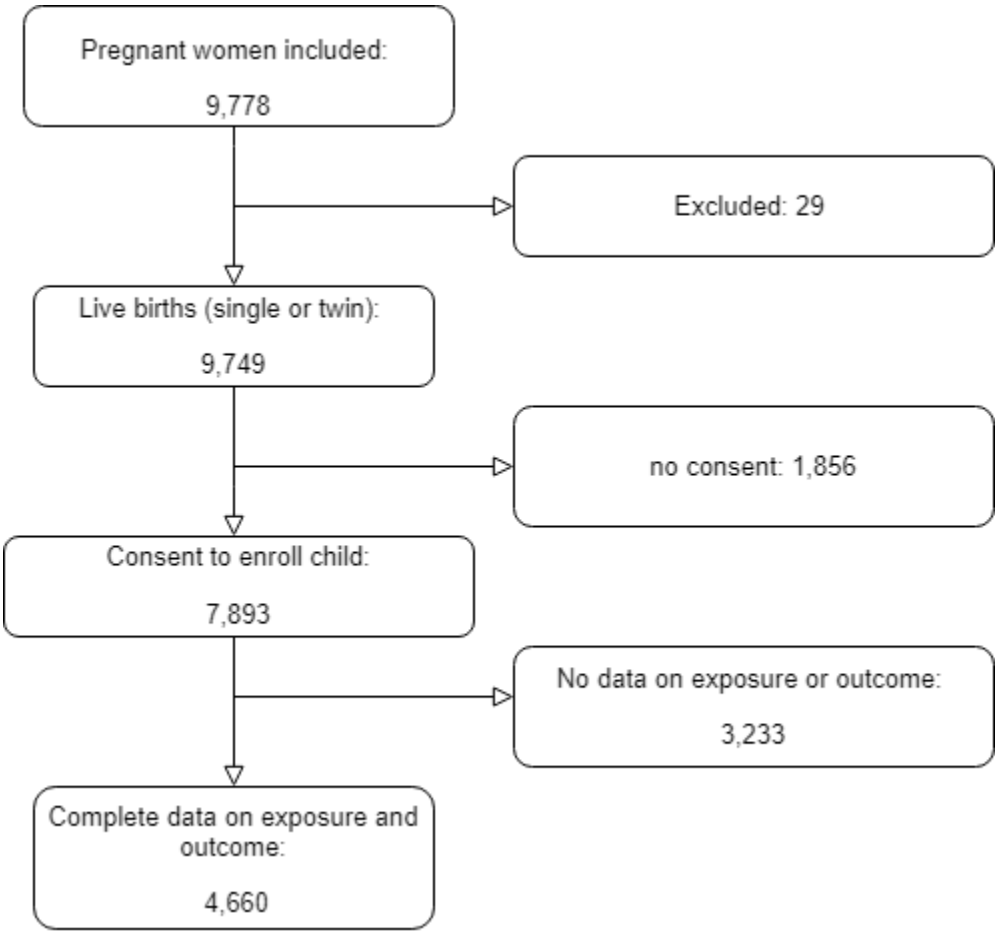

Figure S. 1 Flow chart sample selection

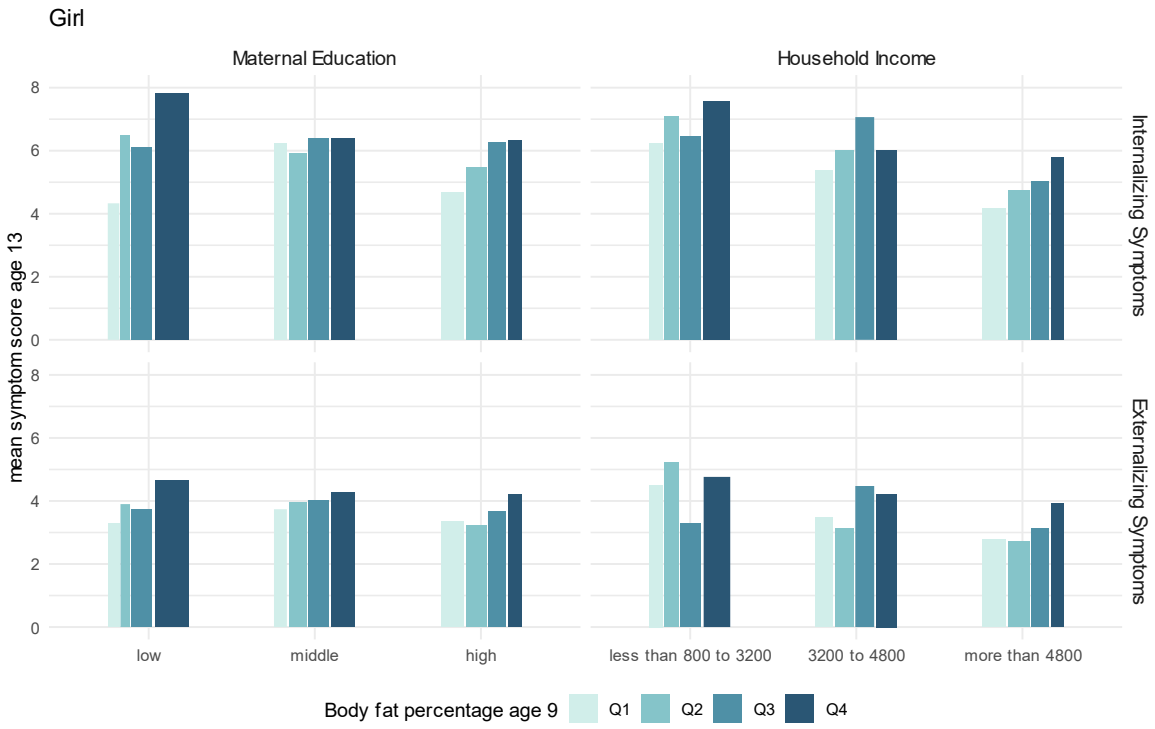

Figure S. 2 Descriptive mean internalizing and externalizing symptom score at age 13 by body fat percentage quartiles at age 9, stratified by maternal education and household income for girls. Bar width represents relative group size of body fat percentage categories.

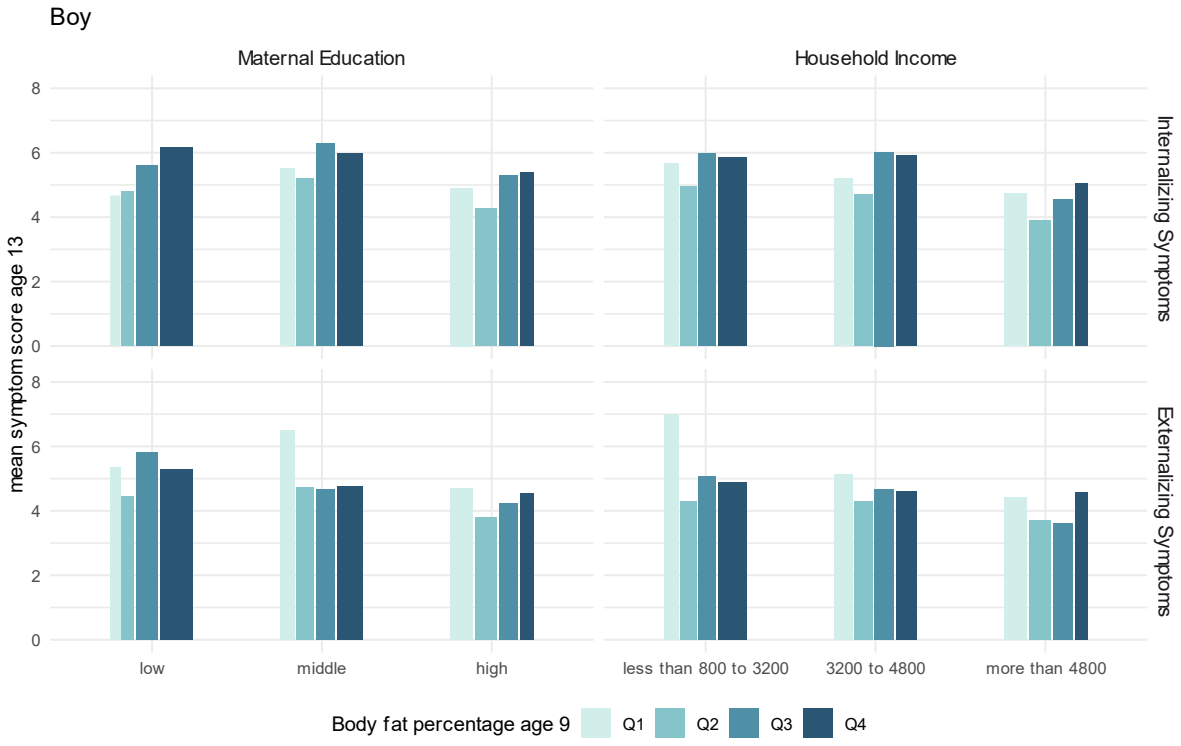

Figure S. 3 Descriptive mean internalizing and externalizing symptom score at age 13 by body fat percentage quartiles at age 9, stratified by maternal education and household income for boys. Bar width represents relative group size of body fat percentage categories.

Table S. 1 Estimated total disparity (TD) of education and household income, 4-way decomposition of TD, and contribution of differential impact or exposure to Q4 fat mass (>30%) to inequalities in internalizing and externalizing problems. CDE: controlled direct effect. INTmed: mediated interaction. INTref: reference interaction. PIE: pure indirect effect.

		comparison	Absolute difference (95%CI)		Relative difference
Maternal Education					
Internalizing	TD	low-high	0.98	(0.35, 1.63)	
		middle-high	0.81	(0.40, 1.23)	
	CDE	low-high	1.30	(0.04, 2.40)	133%
		middle-high	0.37	(-0.48, 0.97)	46%
	INTmed	low-high	0.20	(-0.20, 0.57)	20%
		middle-high	-0.10	(-0.27, 0.01)	-12%
	INTref	low-high	-0.82	(-1.89, 0.38)	-85%
		middle-high	0.34	(-0.16, 1.12)	42%
	PIE	low-high	0.30	(0.17, 0.47)	31%
		middle-high	0.19	(0.10, 0.28)	24%
	Differential exposure	low-high	0.50	(0.15, 0.85)	51%
		middle-high	0.09	(-0.04, 0.17)	11%
	Differential impact	low-high	-0.62	(-1.41, 0.18)	-64%
		middle-high	0.24	(-0.18, 0.91)	30%
Externalizing	TD	low-high	0.61	(0.08, 1.14)	61%
		middle-high	0.64	(0.27, 1.01)	64%
	CDE	low-high	0.79	(-0.26, 1.72)	130%
		middle-high	0.66	(-0.10, 1.36)	103%
	INTmed	low-high	0.09	(-0.30, 0.37)	15%
		middle-high	-0.11	(-0.24, 0.02)	-17%
	INTref	low-high	-0.28	(-1.15, 0.77)	-47%
		middle-high	0.08	(-0.60, 0.76)	12%
	PIE	low-high	0.01	(-0.10, 0.14)	2%
		middle-high	0.00	(-0.05, 0.08)	1%
	Differential exposure	low-high	0.10	(-0.25, 0.37)	17%
		middle-high	-0.10	(-0.21, 0.01)	-15%
	Differential impact	low-high	-0.19	(-0.84, 0.52)	-32%
		middle-high	-0.03	(-0.63, 0.57)	-4%
Household Income					
Internalizing symptoms	TD	low-high	1.68	(1.13, 2.19)	168%
		middle-high	1.18	(0.81, 1.56)	118%
	CDE	low-high	1.43	(0.57, 2.59)	85%

		middle-high	0.73	(-0.12, 1.75)	62%
	INTmed	low-high	0.00	(-0.19, 0.28)	0.3%
		middle-high	-0.04	(-0.14, 0.08)	-3%
	INTref	low-high	0.02	(-1.03, 0.81)	1%
		middle-high	0.36	(-0.60, 1.20)	31%
	PIE	low-high	0.23	(0.08, 0.38)	14%
		middle-high	0.13	(0.04, 0.23)	11%
	Differential exposure	low-high	0.24	(0.09, 0.46)	14%
		middle-high	0.09	(0.02, 0.19)	8%
	Differential impact	low-high	0.02	(-0.76, 0.64)	1%
		middle-high	0.33	(-0.51, 1.05)	28%
Externalizing symptoms	TD	low-high	1.25	(0.80, 1.69)	125%
		middle-high	0.68	(0.34, 1.04)	68%
	CDE	low-high	0.62	(-0.19, 1.44)	49%
		middle-high	0.37	(-0.41, 1.17)	54%
	INTmed	low-high	-0.20	(-0.43, 0.01)	-16%
		middle-high	-0.04	(-0.16, 0.06)	-6%
	INTref	low-high	0.74	(-0.05, 1.49)	59%
		middle-high	0.32	(-0.42, 1.01)	47%
	PIE	low-high	0.09	(-0.03, 0.23)	7%
		middle-high	0.03	(-0.03, 0.13)	5%
	Differential exposure	low-high	-0.10	(-0.30, 0.07)	-8%
		middle-high	0.00	(-0.07, 0.07)	-1%
	Differential impact	low-high	0.54	(-0.05, 1.14)	43%
		middle-high	0.28	(-0.39, 0.88)	41%

Table S. 2 Estimated total disparity (TD) of education and household income, 4-way decomposition of TD, and contribution of differential impact or exposure to Q4 fat mass (>30%) to inequalities in internalizing and externalizing problems by gender. CDE: controlled direct effect. INTmed: mediated interaction. INTref: reference interaction. PIE: pure indirect effect.

		comparison	Absolute difference (95%CI)		Relative difference	Absolute difference (95%CI)		Relative difference
			Girls			Boys		
Maternal Education								
Internalizing	TD	low-high	1.10	(0.18, 1.96)		0.84	(0.04, 1.75)	
		middle-high	0.71	(0.17, 1.25)		0.97	(0.42, 1.49)	
	CDE	low-high	1.62	(0.08, 3.39)	149%	0.55	(-0.54, 1.92)	66%
		middle-high	0.36	(-0.63, 1.39)	52%	0.66	(-0.28, 1.62)	68%
	INTmed	low-high	0.38	(-0.23, 1.06)	35%	-0.06	(-0.48, 0.49)	-7%
		middle-high	-0.11	(-0.33, 0.07)	-15%	-0.05	(-0.26, 0.18)	-5%
	INTref	low-high	-1.14	(-2.95, 0.52)	-106%	0.22	(-1.14, 1.41)	26%
		middle-high	0.29	(-0.72, 1.23)	38%	0.30	(-0.69, 1.26)	31%
	PIE	low-high	0.24	(0.04, 0.50)	22%	0.12	(-0.09, 0.28)	15%
		middle-high	0.18	(0.06, 0.33)	25%	0.07	(-0.07, 0.17)	7%
	Differential exposure	low-high	0.62	(0.06, 1.25)	57%	0.06	(-0.37, 0.58)	7%
		middle-high	0.07	(-0.09, 0.22)	10%	0.02	(-0.18, 0.19)	2%
	Differential impact	low-high	-0.76	(-2.00, 0.38)	-71%	0.16	(-0.83, 1.05)	19%
		middle-high	0.17	(-0.63, 0.98)	23%	0.24	(-0.53, 1.03)	25%
Externalizing	TD	low-high	0.61	(-0.15, 1.37)		0.74	(-0.05, 1.73)	
		middle-high	0.64	(0.21, 1.09)		0.73	(0.28, 1.30)	
	CDE	low-high	0.65	(-0.58, 1.95)	111%	0.61	(-0.79, 1.70)	83%
		middle-high	0.38	(-0.40, 1.19)	59%	0.31	(-0.52, 1.32)	42%
	INTmed	low-high	0.00	(-0.35, 0.51)	5%	0.02	(-0.67, 0.47)	4%
		middle-high	-0.05	(-0.23, 0.13)	-8%	-0.18	(-0.43, 0.04)	-25%

	INTref	low-high	-0.17	(-1.55, 0.96)	-37%	0.19	(-0.82, 1.98)	24%
		middle-high	0.25	(-0.56, 1.02)	39%	0.64	(-0.20, 1.56)	88%
	PIE	low-high	0.12	(-0.02, 0.32)	20%	-0.08	(-0.28, 0.12)	-11%
		middle-high	0.07	(-0.02, 0.16)	10%	-0.04	(-0.19, 0.08)	-5%
	Differential exposure	low-high	0.13	(-0.20, 0.71)	25%	-0.06	(-0.73, 0.39)	-7%
		middle-high	0.01	(-0.15, 0.18)	2%	-0.22	(-0.44, -0.06)	-30%
	Differential impact	low-high	-0.17	(-0.98, 0.68)	-32%	0.21	(-0.54, 1.55)	28%
		middle-high	0.20	(-0.46, 0.83)	30%	0.46	(-0.21, 1.15)	63%
Household Income								
Internalizing	TD	low-high	2.19	(1.51, 2.88)		1.22	(0.52, 1.87)	
		middle-high	1.29	(0.80, 1.87)		1.04	(0.54, 1.57)	
	CDE	low-high	2.10	(0.74, 3.60)	96%	0.64	(-0.45, 1.82)	52%
		middle-high	0.38	(-1.01, 1.69)	29%	0.85	(-0.26, 2.13)	82%
	INTmed	low-high	0.00	(-0.34, 0.37)	0%	-0.10	(-0.43, 0.23)	-9%
		middle-high	-0.07	(-0.28, 0.09)	-6%	0.01	(-0.15, 0.18)	1%
	INTref	low-high	-0.12	(-1.40, 1.31)	-5%	0.60	(-0.84, 1.67)	50%
		middle-high	0.87	(-0.33, 2.25)	68%	0.14	(-1.06, 1.15)	13%
	PIE	low-high	0.20	(-0.02, 0.46)	9%	0.08	(-0.12, 0.30)	7%
		middle-high	0.11	(0.01, 0.26)	9%	0.04	(-0.06, 0.17)	4%
	Differential exposure	low-high	0.21	(-0.08, 0.53)	9%	-0.02	(-0.25, 0.25)	-2%
		middle-high	0.04	(-0.07, 0.19)	3%	0.05	(-0.05, 0.17)	5%
	Differential impact	low-high	-0.11	(-1.11, 1.07)	-5%	0.50	(-0.57, 1.25)	41%
		middle-high	0.80	(-0.27, 2.04)	62%	0.15	(-0.87, 1.03)	14%
Externalizing	TD	low-high	1.46	(0.89, 2.17)		1.08	(0.36, 1.82)	
		middle-high	0.85	(0.37, 1.30)		0.52	(0.00, 1.10)	
	CDE	low-high	1.08	(-0.03, 2.20)	73%	0.47	(-0.87, 1.66)	44%
		middle-high	0.58	(-0.45, 1.60)	68%	0.04	(-1.27, 1.11)	8%
	INTmed	low-high	-0.26	(-0.62, 0.04)	-18%	-0.22	(-0.62, 0.08)	-20%
		middle-high	0.01	(-0.14, 0.14)	2%	-0.06	(-0.22, 0.10)	-11%
	INTref	low-high	0.47	(-0.59, 1.68)	33%	0.84	(-0.24, 2.07)	78%

		middle-high	0.17	(-0.74, 1.15)	20	0.54	(-0.51, 1.76)	105%
	PIE	low-high	0.18	(0.02, 0.32)	12	-0.01	(-0.21, 0.24)	-1%
		middle-high	0.09	(0.01, 0.20)	10	0.00	(-0.14, 0.13)	-2%
	Differential exposure	low-high	-0.09	(-0.41, 0.18)	-6	-0.23	(-0.53, 0.02)	-22%
		middle-high	0.10	(-0.01, 0.21)	12	-0.06	(-0.20, 0.04)	-13%
	Differential impact	low-high	0.20	(-0.59, 1.09)	14	0.62	(-0.23, 1.52)	57%
		middle-high	0.19	(-0.60, 0.97)	21	0.48	(-0.43, 1.58)	93%

Table S. 3 Estimated total disparity (TD) of education and household income, 4-way decomposition of TD, and contribution of differential impact or exposure to clinical internalizing or externalizing symptoms to Q4 fat mass (>30%). RR: risk ratio. ERR: relative risk ratio. Proportions are calculated as ERR/(RR_TD-1). CDE: controlled direct effect. INTmed: mediated interaction. INTref: reference interaction. PIE: pure indirect effect.

		Comparison	Absolute difference (95%CI)		Relative difference
Internalizing symptoms					
Maternal education[a]					
Q4 fat mass	TD (RR)	low-high	2.40	(2.09, 2.78)	
		middle-high	1.72	(1.51, 1.96)	
	CDE (ERR)	low-high	1.64	(1.03, 2.73)	117%
		middle-high	0.49	(0.03, 1.27)	67%
	INTmed (ERR)	low-high	0.00	(-0.02, 0.05)	0%
		middle-high	0.00	(-0.01, 0.02)	0%
	INTref (ERR)	low-high	-0.25	(-1.16, 0.40)	-18%
		middle-high	0.22	(-0.53, 0.65)	32%
	PIE (ERR)	low-high	0.00	(-0.01, 0.02)	0%
		middle-high	0.00	(0.00, 0.01)	0%
	Differential exposure (ERR)	low-high	0.01	(-0.02, 0.06)	0%
		middle-high	0.00	(-0.01, 0.02)	0%
	Differential impact (ERR)	low-high	-0.25	(-1.12, 0.39)	-17%
		middle-high	0.23	(-0.54, 0.65)	32%
Household income[b]					
Q4 fat mass	TD (RR)	low-high	2.18	(1.91, 2.47)	
		middle-high	1.53	(1.32, 1.78)	
	CDE (ERR)	low-high	1.68	(0.77, 2.38)	143%
		middle-high	0.92	(0.13, 1.40)	175%
	INTmed (ERR)	low-high	0.04	(-0.02, 0.08)	3%
		middle-high	0.01	(-0.02, 0.04)	3%
	INTref (ERR)	low-high	-0.52	(-1.16, 0.38)	-44%
		middle-high	-0.40	(-0.83, 0.39)	-77%
	PIE (ERR)	low-high	-0.02	(-0.03, 0.02)	-2%
		middle-high	0.00	(-0.02, 0.02)	-1%
	Differential exposure (ERR)	low-high	0.02	(-0.02, 0.06)	2%
		middle-high	0.00	(-0.01, 0.03)	1%
	Differential impact (ERR)	low-high	-0.48	(-1.08, 0.36)	-41%
		middle-high	-0.39	(-0.80, 0.38)	-74%
Externalizing symptoms					
Maternal education[c]					
Q4 fat mass	TD (RR)	low-high	2.35	(2.06, 2.71)	
		middle-high	1.72	(1.51, 1.92)	
	CDE (ERR)	low-high	0.88	(-0.33, 2.23)	65%

		middle-high	0.96	(-0.31, 1.91)	133%
	INTmed (ERR)	low-high	0.00	(-0.03, 0.02)	0%
		middle-high	0.00	(-0.01, 0.01)	0%
	INTref (ERR)	low-high	0.48	(-0.79, 1.76)	36%
		middle-high	-0.24	(-1.15, 0.89)	-33%
	PIE (ERR)	low-high	0.00	(-0.01, 0.01)	0%
		middle-high	0.00	(0.00, 0.01)	0%
	Differential exposure (ERR)	low-high	0.00	(-0.03, 0.02)	0%
		middle-high	0.00	(-0.01, 0.01)	0%
	Differential impact (ERR)	low-high	0.48	(-0.81, 1.78)	35%
		middle-high	-0.24	(-1.13, 0.88)	-33%
Household income[d]					
Q4 fat mass	TD (RR)	low-high	2.22	(1.93, 2.52)	
		middle-high	1.57	(1.33, 1.79)	
	CDE (ERR)	low-high	1.37	(0.36, 2.87)	112%
		middle-high	0.68	(-0.37, 1.84)	119%
	INTmed (ERR)	low-high	0.00	(-0.03, 0.05)	0%
		middle-high	0.00	(-0.02, 0.01)	0%
	INTref (ERR)	low-high	-0.15	(-1.59, 0.82)	-12%
		middle-high	-0.11	(-1.20, 0.95)	-19%
	PIE (ERR)	low-high	0.00	(-0.02, 0.02)	0%
		middle-high	0.00	(-0.01, 0.02)	0%
	Differential exposure (ERR)	low-high	0.00	(-0.02, 0.04)	0%
		middle-high	0.00	(-0.01, 0.01)	0%
	Differential impact (ERR)	low-high	-0.15	(-1.56, 0.80)	-12%
		middle-high	-0.12	(-1.20, 0.96)	-19%

Number of children N(%) with clinical internalizing or externalizing symptoms in each education or income group:
[a] low: 34(10%), middle: 71(7%), high: 167(7%)
[b] low: 79(11%), middle: 100(7%), high: 66(5%)
[c] low: 12(4%), middle: 38(4%), high: 85(3%)
[d] low: 42(6%), middle: 46(3%), high: 37(3%)