



## POPULATION STUDY ARTICLE

# Adverse childhood experiences are associated with an increased risk of obesity in early adolescence: a population-based prospective cohort study

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**OBJECTIVE:** To determine whether adverse childhood experiences were associated with weight gain and obesity risk in adolescence.

**METHODS:** We analyzed data from 6942 adolescents followed between 9 and 13 years of age in the Growing Up in Ireland cohort study. The main exposures were 14 adverse childhood experiences, 4 of which were included in the Adverse Childhood Experience (ACE) study. The primary outcome was incident overweight and obesity at 13 years. Secondary outcomes included prevalent overweight/obesity and weight gain.

**RESULTS:** More than 75% of the youth experienced an adverse experience and 17% experienced an ACE-specific experience before 9 years. At 13 years, 48% were female and 31.4% were overweight or obese. After adjusting for confounding, exposure to any adverse experience was associated with prevalent overweight/obesity (aOR: 1.56; 1.19–2.05) and incident overweight/obesity (adjusted IRR: 2.15; 95% CI: 1.37–3.39), while exposure to an ACE-specific exposure was associated weight gain (BMI Z score change = 0.202; 95% CI: 0.100–0.303). A significant interaction between income and adverse childhood experiences was observed for both incident overweight/obesity and weight gain (BMI Z change: –0.046; 95% CI: –0.092 to 0.000).

**CONCLUSIONS:** Adverse childhood experiences and low income interact and independently predict obesity risk in early adolescence.

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## INTRODUCTION

As many as one third of adolescents in developed countries live with overweight or obesity.<sup>1</sup> Most experts acknowledge that obesity is a complex condition<sup>2</sup>; however, the majority of current clinical and public health initiatives often prioritize proximal behaviors (i.e. diet and exercise)<sup>3</sup> over psychosocial factors.<sup>4</sup> Psychosocial factors, including low income,<sup>5</sup> income inequality and exposure to adverse experiences in childhood<sup>6</sup> play an important role in adolescent health. A better understanding of the role of these psychosocial factors in the development of obesity in adolescence may help guide future clinical or public health initiatives.

Adverse childhood experiences are critical social determinants of health.<sup>7</sup> Two systematic reviews published in the past 5 years examined the association between adverse experiences in childhood and obesity risk in adolescence.<sup>8,9</sup> These reviews revealed that the majority of studies published to date are cross-sectional in nature, and meta-analysis of the small number of prospective cohort studies yielded mixed results.<sup>10</sup> Pooled results suggested a weak association between adverse experiences and obesity (odds ratio: 1.12; 95% confidence interval (CI): 1.02–1.25), and only 2 of the 6 studies<sup>11–16</sup> observed a statistically significant association (see summary in Table s1 appendix). The lack of a consistent association between adverse childhood experiences and obesity risk into adolescence is likely explained by several methodological flaws in

previous cohort studies (Table s1 appendix). First, none of the cohort studies published to date capitalized on the prospective nature of the design to test for an association between adverse experiences in childhood and incident obesity or weight gain over time. Second, most cohorts were relatively small (<1000 adolescents). Third, only two smaller convenience cohorts adjusted for key proximal confounding variables. Finally, none of the studies tested for an interaction between poverty and exposure to adverse experiences in childhood on obesity risk in adolescence.

To overcome these limitations, we analyzed data from a large representative sample of children, followed prospectively, with information on key confounders, to test the hypothesis that exposure to adverse experiences before 9 years of age was associated with an increased risk of overweight and obesity, as well as weight gain, at 13 years of age, independent of dietary habits, activity and caregiver obesity. We also determined whether income and exposure to adverse experiences in childhood interacted to predict obesity risk at 13 years of age.

## METHODS

## Study design and sampling

The Growing Up in Ireland Child cohort enrolled 8568 9-year-old children and their primary caregiver, randomly selected from a

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total of 56,497 9-year-olds residing in the Republic of Ireland between 2007 and 2008<sup>17</sup> with plans to follow them until 18 years of age (2016/2017). Children with birthdates between 1 November 1997 and 31 October 1998 were eligible for the original sampling. The sampling was done in a two-stage clustered design.<sup>17</sup> The first stage identified a random sample of 1105 Irish primary schools from a national total of 3200 and 910 schools agreed to participate. In the second stage of sampling, 40 eligible children per school were randomly selected and 57% of children selected went on to participate in the study. Schools with disadvantaged status were less likely to participate to begin with, and at the household level those families with lower social class or caregiver educational attainment were less likely to return consent forms to be contacted for the study.<sup>18</sup>

Recruitment in Wave 2 for follow-up at age 13 years was done through home contact between 2010 and 2011. Of the original 8568 children and their caregivers involved in Wave 1, 7423 (87%) participated in data collection at Wave 2. Completion rates were lower in those with low primary caregiver education (81.4 vs 92.2%) and low family equivalized income (81.6 vs 90.6%) compared to caregivers with a degree and high family income, respectively. There were no exclusion criteria for participation in the study. Parents consented and adolescents assented to the study during the home visits by research staff. All stages of the Growing Up in Ireland project were approved by the Health Research Board's standing Research Ethics Committee based in Dublin, Ireland and these analyses were approved by the Health Research Ethics Board at the University of Manitoba.

#### Variables

**Primary exposure.** The primary exposure was an adverse experience before 9 years of age. Within the cohort, 14 separate adverse experiences were reported by the child's primary caregiver during the first wave of data collection when the child was aged 9 years (Table 1). The questions were dichotomous (yes/no) and administered by a research assistant/interviewer. Four of these events were identical to those included in the original Adverse Childhood Experiences (ACEs) study<sup>19</sup>: divorce, parent in prison, parent with drug/alcohol abuse, and parent with a mental health disorder. These four events were treated as a composite secondary exposure of ACEs. The additional ten experiences included death of a parent, death of a close family member, death of a close friend, moving house, moving country, a stay in a foster home, serious illness for the child, serious illness for a family member, conflict between parents and "other disturbing event" (Table 1). These events were adapted from those included in the National Longitudinal Survey of Children and Youth.<sup>20</sup> These adverse experiences were included in the study design as the investigator team felt they "could lead to social disadvantage and exclusion, educational difficulties, ill health and deprivation".<sup>21</sup>

**Main outcome measures.** The main outcome measure was a binary outcome of incident overweight or obesity at 13 years of age using sex-specific body mass index (BMI) criteria established by the World Health Organization.<sup>22,23</sup> We chose a categorical measure of obesity as it is the most commonly reported, and clinically relevant, measure of weight status in the current pediatric literature. In addition to these two categorical outcomes, we also included a continuous measure of weight gain over time. Weight gain between 9 and 13 years of age was estimated from the change in BMI Z score over that time. BMI Z score was selected as it provides a measure of weight normalized for age and sex. BMI Z scores are also commonly reported; however, these are less commonly used in clinical or public health sectors. Age- and sex-specific Z scores were created with the LMS table from the 2014 WHO growth charts. Overweight status was defined as a BMI between the 85th and 97.7th centile for age and gender, which is equivalent to BMI Z score of 1–<2. Obese status was defined as a

**Table 1.** Rates of adverse experiences before 9 years of age among adolescents in Ireland

	Sample	Healthy weight	Overweight/ obese
Death of a parent	2.3% (2–2.7)	2.1% (1.7–2.5)	2.8% (2.1–3.5)
Death of close family member	42.9% (41.8–44.1)	41.6% (40.2–43)	45.9% (43.8–47.9)
Death of close friend	5.9% (5.3–6.4)	5.4% (4.8–6)	6.8% (5.8–7.9)
Moving house	41.4% (40.2–42.5)	42% (40.6–43.4)	39.9% (37.9–42)
Moving country	9.6% (8.9–10.3)	10.1% (9.3–11)	8.4% (7.2–9.6)
Stay in foster home/ residential care	1.3% (1–1.5)	1.2% (0.9–1.5)	1.4% (0.9–1.9)
Serious illness/injury	4.7% (4.2–5.2)	4.7% (4.1–5.3)	4.7% (3.8–5.6)
Serious illness/injury of a family member	13.5% (12.7–14.3)	13.1% (12.2–14.1)	14.2% (12.7–15.7)
Conflict between parents	11.7% (11–12.5)	11.5% (10.6–12.4)	12.2% (10.9–13.6)
Other disturbing event	1.9% (1.6–2.2)	1.8% (1.5–2.2)	2% (1.4–2.6)
ACE events			
Parent in prison	0.7% (0.5–0.9)	0.5% (0.3–0.7)	1.3% (0.8–1.7)
Mental disorder in immediate family	3.4% (3–3.9)	3.5% (2.9–4)	3.4% (2.6–4.1)
Divorce/separation of parents	13.7% (12.9–14.5)	13.6% (12.6–14.6)	13.9% (12.5–15.4)
Drug taking/alcoholism in immediate family	3.2% (2.8–3.6)	3.3% (2.8–3.8)	3.1% (2.4–3.8)
Any adversity	78.3% (77.3–79.3)	77.3% (76.1–78.5)	80.5% (78.8–82.2)

Rates presented are weighted. Data are expressed as a percent of each category with 95% confidence intervals in brackets

BMI greater than or equal to the ≥97.7th centile for age and gender or a BMI Z score of ≥2.<sup>24</sup> Prevalent overweight or obesity was also a secondary outcome and was defined as being overweight or obese at 13 years. These anthropometric measures were calculated from objective measures of height and weight performed on the day of the household interview. Height was recorded to the nearest millimeter using a Leicester portable height stick with a range of 0–2.07 m. Weight was recorded using a Class III medically approved SECA 761 flat mechanic scale and reported to the closest 0.1 kg. BMI was calculated as the child's weight (kg)/(child's height m)<sup>2</sup> and expressed in kg/m<sup>2</sup>.

**Confounding/descriptive variables.** Potential confounders were chosen based on known determinants of overweight and obese status in this cohort and measured at the same time as the

exposure variables at the age 9 year visit.<sup>18</sup> These included caregiver BMI, household income, and household social class, as well as measures of physical activity and dietary intake. The height and weight of the primary caregiver were measured objectively using the methods described above and stratified into categories of underweight, healthy weight, overweight, and obese. Household income was self-reported and the equalized disposable income was calculated as the total income of a household, after tax and other deductions, that is available for spending or saving, divided by the number of household members converted into equalized adults; household members are equalized or made equivalent by weighting each according to their age, using the so-called modified OECD equivalence scale.<sup>25,26</sup> Daily physical activity was estimated by a question posed to the primary caregiver regarding the number of days of hard exercise in the past 2 weeks for their child and was categorized as minimal (0–2 days), moderate (3–5 days), and high (6+ days). To control for diet, we relied on a single measure consumption of non-diet soft drinks in the past 24 h within a short food frequency questionnaire, as it is one of the best markers in sensitivity analyses.

**Missing data.** No/low levels (<2%) of missing covariate values were found in most areas. Equalized household income had a high number ( $N = 626$ , 7.3%) of missing values. Thirty-three study children were missing all of the adverse experience variables. Children with missing adverse experience data were excluded from the primary analyses giving an effective cohort of 6942 children and their caregivers for these analyses. Multiple imputation using multivariate normal distribution was used to impute missing income data. Missing income data were imputed from multiple simulations ( $n = 5$ ; random seed = 50,000) using caregiver-reported measures of employment type, unemployment status, income support, and disability care. We did not impute data for youth who were lost to follow-up. They were excluded from the analyses.

**Statistical methods**

Analyses were carried out in R version 3.0 ([www.R-project.org](http://www.R-project.org)). Standardized weights were used for the weighted analysis, created by dividing the inverse-probability survey weights by the mean of the weights from the actual sample. Differences in demographic variables across youth stratified by weight status at 13 years were assessed using chi-square tests and analysis of variance for categorical and continuous variables, respectively. A series of multiple logistic and Poisson regression analyses were conducted to determine the odds of overweight/obesity and incident rate ratios according to exposure to any adverse experiences and ACE-specific adverse experiences before 9 years of age. A series of multiple linear regression analyses were also used to test for an association between adverse childhood experiences and the change in BMI Z score between 9 and 13 years of age after adjusting for confounding. All regression analyses were adjusted for the following confounders: caregiver BMI (ordinal), household income (continuous), exercise level of the child (ordinal), and soft-drink by the child (binary). An interaction term for adverse childhood experiences and income was added to all multivariate logistic and linear regression analyses to determine whether these two exposures were synergistic predictors of obesity at 13 years of age and weight gain between and 13 years of age. Statistical significance was set at a two-tailed  $\alpha = 0.05$ .

**RESULTS**

**Participant characteristics**

Of the original cohort of 8568 9-year-old children and their primary caregivers, 7423 pairs returned for follow-up (87% retention) in 2011 when children were aged 13 years. Of the 1145 child–primary caregiver pairs who did not return for follow-

up, 103 moved out of country or were deceased, 668 declined to participate, 218 were unable to be contacted, and 156 had other family-specific reasons to decline such as recent family bereavement. Completion rates were lower in households with a primary caregiver that completed high school (81.4 vs 92.2%) and lived below the median for income (81.6 vs 90.6%).

Of the 7423 adolescent–caregiver pairs who returned for follow-up, complete data were available for 6942 pairs. Adolescent BMI (20.6 vs 21.1 kg/m<sup>2</sup>,  $p = 0.006$ ) was significantly higher among those with missing data. At 13 years of age, 48% were female, 31.4% were overweight or obese, 83.4% lived in two-parent households, and 46% lived in a household with a parent working as a professional (Table 2). Compared to healthy weight youth, overweight and obese youth were more likely to live in a household with a single parent (18.7 vs 15.6%,  $p < 0.01$ ) and a lower equalized income (15,500€/person vs 17,700€/person,  $p < 0.01$ ), have an overweight or obese parent (60 vs 44%), less frequently performed hard activity in the 14 days prior to being surveyed (69 vs 77% participated >6 days), and were more likely to consume sugar sweetened beverages (50 vs 56%) (Table 2). The distribution of exposure to adverse experiences and ACE-specific experiences are presented in Figure 1. More than 75% ( $n = 5435$ ) of youth in the cohort experienced at least 1 of the 14 adverse experiences and 17% ( $n = 1182$ ) experienced at least one ACE-specific experience and 2.3% of the cohort experienced  $\geq 2$  ACE-specific experiences before 9 years of age (Table 1; Fig. 1). Children were exposed to  $1.6 \pm 1.3$  adverse experiences before 9 years of age.

**Exposure to adverse experiences in childhood and risk of obesity in adolescence**

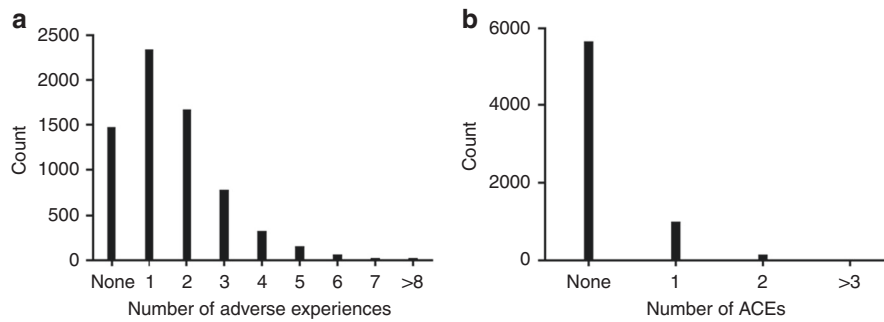
At 9 years of age, 33.5% ( $n = 2300$ ) of the cohort was overweight or obese. Among the 4565 children who were of healthy weight at 9 years of age, 11.8% ( $n = 541$ ) developed overweight or obesity by 13 years of age. At 13 years of age, the prevalence of overweight/obesity was 31% ( $n = 2176$ ). In the fully adjusted model, exposure to any adverse experience (adjusted odds ratio: 1.56; 95% CI: 1.19–2.05) was associated with prevalent overweight/

**Table 2.** Participant characteristics at 13 years of age

Variable	Healthy weight ( $n = 4759$ )	Overweight/obese ( $n = 2183$ )
Height Z score	0.17 (–0.49, 0.83)	0.44 (–0.19, 1.11)
Weight Z score	–0.03 (–0.6, 0.47)	1.44 (1, 1.89)
BMI Z score	–0.03 (–0.64, 0.45)	1.67 (1.31, 2.12)
<b>Parental characteristics</b>		
Equalized household income <sup>a</sup>	1.75 (1.22, 2.38)	1.66 (1.14, 2.24)
Delta income	–0.23 (–0.66, 0.13)	–0.23 (–0.62, 0.15)
Overweight/obese	2092 (44.0%)	1316 (60.3%)
2-parent household	4018 (84.4%)	1775 (81.3%)
<b>Hard exercise in the past 14 days</b>		
High (6+ days)	3668 (77.1%)	1512 (69.3%)
<b>Soft drink daily</b>		
Yes	2403 (50.5%)	1221 (55.9%)

Data in brackets are 95% confidence intervals for continuous measures and percentages within each weight strata for categorical variables (i.e. column)

<sup>a</sup>Equalized household income is calculated as the total income of a household, after tax and other deductions, that is available for spending or saving, divided by the number of household members converted into equalized adults



**Fig. 1** Distribution of exposure variables related to adverse experiences in childhood. **a** Distribution of the 14 experiences presented Table 1; **b** Distribution of ACE-specific adverse experiences

**Table 3.** Adverse experiences in childhood and prevalent overweight/obesity at 13 years of age

	Overweight/obese	Obese alone
Any adversity	1.56 (1.19–2.05)	1.74 (1.09–2.73)
Female gender	1.20 (1.08–1.34)	1.06 (0.90–1.26)
Daily soft drink	1.21 (1.08–1.34)	1.21 (1.02–1.44)
Hard exercise in the past 14 days	0.72 (0.64–0.82)	0.59 (0.50–0.71)
Parent overweight/obese	2.02 (1.80–2.26)	2.84 (2.36–3.44)
Equalized household income	1.07 (0.96–1.20)	1.02 (0.82–1.22)
Household income × adversity interaction	0.86 (0.76–0.98)	0.87 (0.70–1.09)

Prevalent overweight/obesity data are odds ratios and 95% confidence intervals  
ACE any of the following 4 adverse childhood experiences from the ACEs Study: divorce, parent in prison, parent with drug/alcohol abuse and parent with a mental health disorder, OW overweight

obesity at 13 years of age (Table 3). In the unadjusted model, exposure to any adverse experience but not ACE-specific experience was associated with an increased incidence of overweight or obesity at 13 years of age (Table 4). In the fully adjusted model, exposure to any adverse experience, but not ACE-specific experiences, were also significant predictors of incident overweight/obesity (incident rate ratio: 2.15; 95% CI: 1.37–3.39) at 13 years of age (Table 4). ACE-specific exposures were not associated with incident obesity but were associated with weight gain ( $\beta = 0.20$ ; 95% CI: 0.10–0.30) between age 9 and 13 years (Table 5).

**Interaction effects and sensitivity analyses**

Neither prevalent and nor incident overweight/obesity or obesity were associated with the four ACE exposures (Tables 3 and 4). When youth were categorized into the number of adverse experiences and ACE-specific experiences, we did not observe any difference in the incident rate ratio among those exposed to  $\geq 2$  adverse experiences, relative to those exposed to 1–2 experiences. In fully adjusted models, the interaction between exposure to any adverse experience and income was significantly associated with incident overweight/obesity and weight gain over time (Table 5). Specifically, the odds of overweight/obesity were greater among youth living in lower-income households, relative to those in higher-income households (Fig. 2).

**DISCUSSION**

We found that exposure to adverse experiences before 9 years of age was associated with an elevated prevalence and incidence of

overweight or obesity at 13 years of age, as well as weight gain during that time frame, independent of measures of physical activity, dietary intake, parental obesity, and household income. In addition, we found that this association is stronger among adolescents living in households in the bottom quintile of income for the population. Finally, we found that this association was not limited to exposure to adverse experiences included in the ACEs study.

The results presented here support previous work in smaller cohorts of adolescents and extend them in several important ways. First, we support results from a recent systematic review<sup>8</sup> that exposure to a broad range of adverse experiences in childhood is associated with prevalent obesity in adolescence. We build on previous work by demonstrating that exposure to adverse experiences was also associated with weight gain and incident obesity in adolescence. Importantly, we also provide evidence that all of these associations were observed independent of caregiver weight status, as well as physical activity level and dietary habits of the child. Second, we found that the association between adverse experiences and obesity is more pronounced among youth living in low-income households. These observations reinforce the concept that social inequalities and environmental stressors are important determinants of obesity risk in early adolescence.

Adverse experiences in childhood are established independent predictors of health trajectories over the lifecourse.<sup>27</sup> In the current study, >75% of youth experienced one adverse experience and >15% were exposed to an ACE-specific adverse experience before 9 years of age. These rates are comparable to rates of ACE exposure in the US<sup>6,28</sup> and Europe.<sup>29</sup> Several previous cohort studies have examined this association with varying results.<sup>10</sup> Previous studies included a wide range of adverse experiences that ranged from poverty and food insecurity to death of a parent and those included in the original ACEs study (Table s1 appendix). As an important extension to previous prospective cohort studies, we found that exposure to adverse experiences in childhood, particularly adverse experiences not captured in the original ACEs study, were also associated with an increased the odds for overweight and obesity in early adolescence, independent of caregiver weight status and proximal behaviors (i.e. diet and physical activity). In addition, we found that exposure to adverse childhood experiences also predicted weight gain between 9 and 13 years and the odds of becoming obese. This is important as it suggests that exposure to adverse events early in life have lasting impacts on processes that lead to excessive weight gain, years after the exposure and throughout adolescence. Collectively, these data support the need to consider social determinants of health when developing behavioral strategies for promoting healthy weight status, particularly in early adolescence.

There is mounting evidence that obesity disproportionately affects children and adolescents living in low-income settings.<sup>30,31</sup> Adolescents living in low-income settings are more likely to be

**Table 4.** Incidence of overweight or obesity according to exposure to adverse childhood experiences

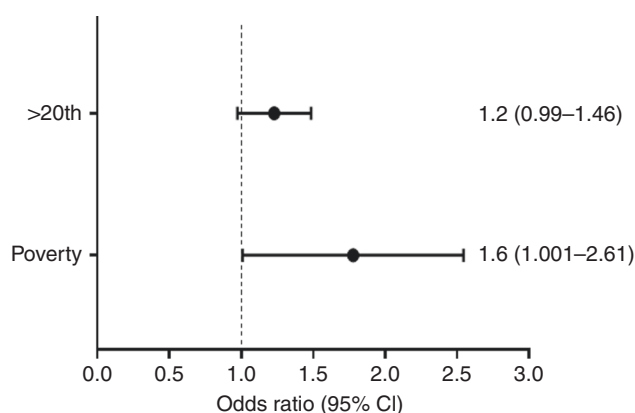
Variable	Sample	Incident overweight/obesity	Incident rate ratio (unadjusted)	Incident rate ratio (fully adjusted) <sup>a</sup>
No experiences	902	102	—	
Adverse experiences	3122	439	1.28 (1.03–1.59)	2.15 (1.37–3.39)
No ACEs	3317	432	—	
ACEs	707	109	1.19 (0.97–1.47)	1.23 (0.75–2.02)

ACE adverse childhood experiences  
<sup>a</sup>Adjusted for gender, equivalized household income, soft drink intake, hard exercise in the previous 14 days, parental overweight/obesity and the interaction of adverse experiences and income

**Table 5.** Adverse experiences in childhood and weight gain between 9 and 13 years of age

	Change in BMI Z score	Change in BMI Z score
Any adversity	0.101 (–0.003 to 0.204)	—
ACE adversity	—	0.202 (0.100 to 0.303)
Female gender	0.124 (0.082 to 0.167)	0.121 (0.078 to 0.164)
Daily soft drink	0.019 (–0.024 to 0.062)	0.017 (–0.026 to 0.060)
Regular vigorous exercise	0.019 (–0.030 to 0.068)	0.016 (–0.033 to 0.065)
Parent overweight/obese	–0.020 (–0.063 to 0.022)	–0.019 (–0.062 to 0.024)
Equivalized household income	0.012 (–0.031 to 0.055)	–0.015 (–0.033 to 0.003)
Household income × adversity interaction	–0.046 (–0.092 to 0.000)	–0.075 (–0.128 to –0.023)

Incident overweight data are odds ratios and 95% confidence intervals  
 Change in BMI Z score reflect coefficient estimates and 95% confidence intervals  
 ACE any of the following four adverse childhood experiences from the ACEs study: divorce, parent in prison, parent with drug/alcohol abuse, and parent with a mental health disorder, BMI body mass index, OW overweight



**Fig. 2** Interaction between poverty and adverse experiences in childhood for the odds of overweight/obesity at age 13 years. Data represent the odds of overweight/obesity for adolescents at 13 years of age living in households with income >20th centile (top plot) for the cohort and those living below the 20th centile (“poverty” bottom plot)

exposed to adverse experiences early in life<sup>32,33</sup> and the combination alters health trajectories into adulthood.<sup>34</sup> It is well established that the combination of material deprivation and adverse experiences unfavorably alters adolescent development.<sup>35</sup> We extend these observations by revealing that the association between adverse childhood experiences and weight status in early adolescence is accentuated in youth living in low-income households. The chronic “toxic” physiological stress (i.e. allostatic load) that accompanies poverty and exposure to adverse experiences, particularly elevated inflammatory and immune responses, alters behavioral choices, brain growth, and

developmental trajectories.<sup>36,37</sup> While data on child or adolescent stress were not available in this cohort, it is possible that these two exposures act synergistically to elicit chronic toxic stress, leading to increased weight gain over time.

The observations made here have implications for future interventions and clinical initiatives for adolescent obesity. The observation that adverse experiences are more common among obese adolescents suggests that they could become part of the intake/screening process for future initiatives. Accordingly, strategies could be developed to address them and incorporated in weight management programs.<sup>38</sup> For example, self-regulation or temperament training could be used to moderate the impact of adverse experiences on overweight/obese adolescents. Lastly, the observation that adverse experiences in childhood are more impactful on obesity risk for youth living in poverty suggests that targeted approaches, potentially addressing food security, may be warranted for this specific population of overweight/obese adolescents. Future interventions and public policies should consider the role of adverse experiences in childhood, poverty, and underlying chronic stress in their designs to address adolescent obesity.

This study has several limitations. The prospective cohort design employed here provides an important temporal association between adverse experiences and obesity risk; however, it limits our ability to draw a causal link between the two. The study is also limited by loss to follow-up and incomplete responses to questionnaires. Specifically, there were differences in key demographics between those who remained in the cohort and those who were lost to follow-up. This not only limits the generalizability of our findings but also introduces potential selection bias, which would likely have an unpredictable influence on the associations reported. In addition, the self-reported nature of adverse experiences by the caregivers was retrospective and is at risk of recall bias. Furthermore, several of the events included in the

landmark ACE study<sup>19</sup> including childhood neglect, or physical, emotional, or sexual abuse were not included in the survey and would be important to include in future analyses. We also relied on fairly crude measures of dietary intake and activity level in the regression models. While they were significantly associated with overweight/obesity, they do not fully capture these behaviors and lack precision. Finally, while we adjusted for established confounding, it is possible that unmeasured confounding may have contributed to the observations made here. Despite these limitations, the large randomly selected population combined with the robust associations, observed independent of major confounding, builds on previous work and adds to the evidence that adverse childhood experiences are associated with obesity risk later in life.

## CONCLUSIONS

Exposure to adverse experiences in childhood is associated with an increased risk of overweight and obesity in early adolescence. This association is particularly evident among adolescents living in lower-income households.

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## AUTHOR CONTRIBUTIONS

J.M. devised the original proposal, secured funding for the analyses, and had overall responsibility for the study. R.G. helped develop the original proposal, was involved in the analysis of data, and drafted the manuscript. A.F. was responsible for data analysis, data interpretation, and drafted the manuscript. R.L. was involved in data collection, data management, data interpretation, and writing the manuscript. J.W. designed and had overall responsibility for the Growing Up in Ireland Cohort study, contributed to interpretation of findings. All authors contributed to data interpretation, reviewed and contributed to drafts of the manuscript, and approved the final report.

## ADDITIONAL INFORMATION

The online version of this article (<https://doi.org/10.1038/s41390-019-0414-8>) contains supplementary material, which is available to authorized users.

**Competing interests:** The authors declare no competing interests.

**Ethics:** All stages of the Growing Up in Ireland project were approved by the Health Research Board's standing Research Ethics Committee based in Dublin, Ireland and these analyses were approved by the Biomedical Research Ethics Board at the University of Manitoba.

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## REFERENCES

- Ogden, C. L. et al. Trends in obesity prevalence among children and adolescents in the United States, 1988-1994 Through 2013-2014. *JAMA* **315**, 2292-2299 (2016).
- Lobstein, T. et al. Child and adolescent obesity: part of a bigger picture. *Lancet* **385**, 2510-2520 (2015).
- Wang, Y. et al. What childhood obesity prevention programmes work? A systematic review and meta-analysis. *Obes. Rev.* **16**, 547-565 (2015).
- McGavock, J., Dart, A. & Wicklow, B. Lifestyle therapy for the treatment of youth with type 2 diabetes. *Curr. Diab Rep.* **15**, 568 (2015).
- Watts, A. W. et al. Socioeconomic differences in overweight and weight-related behaviors across adolescence and young adulthood: 10-year longitudinal findings from Project EAT. *Prev. Med.* **87**, 194-199 (2016).
- Flaherty, E. G. et al. Adverse childhood experiences and child health in early adolescence. *JAMA Pediatr.* **167**, 622-629 (2013).
- Howe, L. D., Tilling, K. & Lawlor, D. A. Studying the life course health consequences of childhood adversity: challenges and opportunities. *Circulation* **131**, 1645-1647 (2015).
- Elsenburg, L. K., van Wijk, K. J. E., Liefbroer, A. C. & Smidt, N. Accumulation of adverse childhood events and overweight in children: a systematic review and meta-analysis. *Obesity (Silver Spring)* **25**, 820-832 (2017).
- Danese, A. & Tan, M. Childhood maltreatment and obesity: systematic review and meta-analysis. *Mol. Psychiatry* **19**, 544-554 (2014).
- Elsenburg, L. K., Smidt, N., Hoek, H. W. & Liefbroer, A. C. Body mass index trajectories from adolescence to early young adulthood: do adverse life events play a role? *Obesity (Silver Spring)* **25**, 2142-2148 (2017).
- Suglia, S. F., Duarte, C. S., Chambers, E. C. & Boynton-Jarrett, R. Cumulative social risk and obesity in early childhood. *Pediatrics* **129**, e1173-e1179 (2012).
- Evans, G. W., Fuller-Rowell, T. E. & Doan, S. N. Childhood cumulative risk and obesity: the mediating role of self-regulatory ability. *Pediatrics* **129**, e68-e73 (2012).
- Michels, N. et al. Cross-lagged associations between children's stress and adiposity: the Children's Body Composition and Stress study. *Psychosom. Med.* **77**, 50-58 (2015).
- Slopen, N., Goodman, E., Koenen, K. C. & Kubzansky, L. D. Socioeconomic and other social stressors and biomarkers of cardiometabolic risk in youth: a systematic review of less studied risk factors. *PLoS ONE* **8**, e64418 (2013).
- Lumeng, J. C. et al. Overweight adolescents and life events in childhood. *Pediatrics* **132**, e1506-e1512 (2013).
- Gooding, H. C. et al. Exposure to violence in childhood is associated with higher body mass index in adolescence. *Child Abuse. Negl.* **50**, 151-158 (2015).
- Murray, A. et al. *The Growing Up in Ireland Cohort: Design, Instrumentation and Procedures for the Child Cohort* (Economic Social Research Institute, Dublin, 2010).
- McCrorry, C. & Layte, R. Breastfeeding and risk of overweight and obesity at nine-years of age. *Soc. Sci. Med.* **75**, 323-330 (2012).
- Dube, S. R. et al. Childhood abuse, household dysfunction, and the risk of attempted suicide throughout the life span: findings from the Adverse Childhood Experiences Study. *JAMA* **286**, 3089-3096 (2001).
- NLSY Project Team - *What works for Children. National Longitudinal Survey of Children, Overview of Survey Instruments for 1994-95 Data Collection Cycle 1* (Government of Canada, Ottawa, 1995).
- Williams, J. G. et al. *Growing Up in Ireland National Longitudinal Study of Children. The Lives of 9 Year Olds* (Economic and Social Research Institute, Dublin, 2011).
- Rodd, C., Metzger, D. L. & Sharma, A., Canadian Pediatric Endocrine Group Working Committee for National Growth C. Extending World Health Organization weight-for-age reference curves to older children. *BMC Pediatr.* **14**, 32 (2014).
- de Onis, M. et al. Development of a WHO growth reference for school-aged children and adolescents. *Bull. World Health Organ.* **85**, 660-667 (2007).
- Rodd, C. & Sharma, A. K. Recent trends in the prevalence of overweight and obesity among Canadian children. *CMAJ* **188**, E313-E320 (2016).
- OECD Project on Income Distribution and Poverty What are Equivalency Scales. <http://www.oecd.org/els/soc/OECD-Note-EquivalencyScales.pdf>
- Queally, M. et al. Do mothers accurately identify their child's overweight/obesity status during early childhood? Evidence from a nationally representative cohort study. *Int. J. Behav. Nutr. Phys. Act.* **15**, 56 (2018).
- Hughes, K. et al. The effect of multiple adverse childhood experiences on health: a systematic review and meta-analysis. *Lancet Public Health* **2**, e356-e366 (2017).
- Brown, N. M. et al. Associations between adverse childhood experiences and ADHD diagnosis and severity. *Acad. Pediatr.* **17**, 349-355 (2017).
- Bellis, M. A. et al. Adverse childhood experiences and associations with health-harming behaviours in young adults: surveys in eight eastern European countries. *Bull. World Health Organ.* **92**, 641-655 (2014).
- Lee, H., Andrew, M., Gebremariam, A., Lumeng, J. C. & Lee, J. M. Longitudinal associations between poverty and obesity from birth through adolescence. *Am. J. Public Health* **104**, e70-e76 (2014).
- Wells, N. M., Evans, G. W., Beavis, A. & Ong, A. D. Early childhood poverty, cumulative risk exposure, and body mass index trajectories through young adulthood. *Am. J. Public Health* **100**, 2507-2512 (2010).
- Babey, S. H., Hastert, T. A., Wolstein, J. & Diamant, A. L. Income disparities in obesity trends among California adolescents. *Am. J. Public Health* **100**, 2149-2155 (2010).

33. Casey, P. H. et al. The association of child and household food insecurity with childhood overweight status. *Pediatrics* **118**, e1406–e1413 (2006).
34. Giovanelli, A., Reynolds, A. J., Mondri, C. F. & Ou, S. R. Adverse childhood experiences and adult well-being in a low-income, urban cohort. *Pediatrics* **137**, e20154016 (2016).
35. Braveman, P. & Barclay, C. Health disparities beginning in childhood: a life-course perspective. *Pediatrics* **124**(Suppl 3), S163–S175 (2009).
36. Garner, A. S. & Shonkoff, J. P. Early childhood adversity, toxic stress, and the role of the pediatrician: translating developmental science into lifelong health. *Pediatrics* **129**, e224–e231 (2012).
37. Danese, A. & McEwen, B. S. Adverse childhood experiences, allostasis, allostatic load, and age-related disease. *Physiol. Behav.* **106**, 29–39 (2012).
38. Mason, S. M. et al. Child maltreatment's heavy toll: the need for trauma-informed obesity prevention. *Am. J. Prev. Med.* **50**, 646–649 (2016).