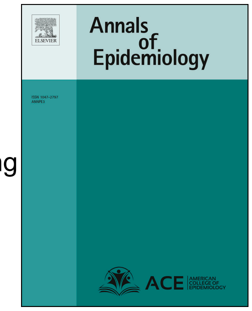
The association between family structure and children's BMI over time - the mediating role of income

Journal Item

Journal Pre-proof



The association between family structure and children's BMI over time - the mediating role of income

Sarah Burkill, Philippa Waterhouse, Laura Pazzagli

PII: S1047-2797(20)30397-5

DOI: https://doi.org/10.1016/j.annepidem.2020.10.007

Reference: AEP 8985

To appear in: *Annals of Epidemiology*

Received Date: 26 December 2019

Revised Date: 24 August 2020

Accepted Date: 15 October 2020

Please cite this article as: Burkill S, Waterhouse P, Pazzagli L, The association between family structure and children's BMI over time - the mediating role of income, *Annals of Epidemiology* (2020), doi: https://doi.org/10.1016/j.annepidem.2020.10.007.

Association between family structure and children's BMI over time - the potential mediating role of income

Sarah Burkill [a, c], Philippa Waterhouse[b], Laura Pazzagli[a] (corresponding author)

[a] Centre for Pharmacoepidemiology, Department of Medicine Solna, Karolinska Institutet, Stockholm, Sweden

[b] School of Health, Wellbeing and Social Care, The Open University, Milton Keynes, The United Kingdom

[c] Saw Swee Hock School of Public Health, National University of Singapore, Singapore

Declaration of interests

Sarah Burkill, Philippa Waterhouse, and Laura Pazzagli declare no conflict of interest and no funding was received for this study. Laura Pazzagli is an employee and Sarah Burkill is a former employee of the Centre of Pharmacoepidemiology at Karolinska Institute, which receives grants from several entities (pharmaceutical companies, regulatory authorities and contract research organizations) for the performance of drug safety and drug utilization studies, unrelated to this work.

The association between family structure and children's BMI over time - the mediating role of income

Sarah Burkill [a, c], Philippa Waterhouse[b], Laura Pazzagli[a] (corresponding author)

[a] Centre for Pharmacoepidemiology, Department of Medicine Solna, Karolinska Institutet, Stockholm, Sweden

[b] School of Health, Wellbeing and Social Care, The Open University, Milton Keynes, The United Kingdom

[c] Saw Swee Hock School of Public Health, National University of Singapore, Singapore

Abstract

Background: Whilst both family structure and income have previously been indicated as being associated with body mass index (BMI), the extent to which the effect of family structure on BMI is mediated through income is incompletely understood. Taking the case of the United Kingdom, this study aims to investigate the association between family structure, defined in this study as whether children live in a one or two adult household, and childhood BMI, and whether this varies by child sex and with increased age. Secondly, the study aims to examine whether family equivalised income as a proxy for socio-economic status, mediates the association between family structure and child's BMI.
Methods: This study uses data from the Millennium Cohort Study (MCS). Data from 7,478 children born between 2000 and 2001 in the UK at the ages of 3, 5, 7, 11, and 14 was used. Mediation analysis was used to consider, at each age, the extent to which the association between living in a one or two adult household and BMI was mediated through income overall, and stratified by sex. To assess the robustness of the mediation analysis estimates, we used both E-values, and multiple confounder adjustment.
Findings: At ages 3 and 5, there was no direct or indirect effect of family structure mediated by income on BMI. From the age of 7 to 11, the overall proportion of the association mediated vastly increased, from 19.70% at age 7 up to 42.70% at the age of 11. The E-values show that substantial unmeasured confounder associations would be needed to fully explain away the conclusions from the mediation analysis. Results remained significant when models were additionally adjusted for geographic region, main respondent's (usually mother's) highest educational attainment, and ethnicity.
Interpretation: An increasing proportion of the association between family structure and BMI is mediated by income as children grow older. The study focuses on the mediating role of income between family structure and BMI using the available data as an empirical application of the potential impact of income as mediator in the causal pathway.

Keywords family structure; children´s BMI; socioeconomic status; mediation.

Introduction

The prevalence of childhood overweight and obesity is increasing globally, and has become a major public health issue. Overweight and obesity during childhood increases the risk of immediate health complications, as well as having long-term consequences for health and wellbeing in adulthood[1-3], placing new and increased pressures on individuals, families and health and social care systems. Therefore, understanding factors that can have an important influence on childhood weight and possible preventative actions is needed.

The ecological system theory[4] highlights the importance of the environment for child outcomes. In this model the family has been identified as a core part of a child's microsystem which immediately influences their development and outcomes. Recent research has focused on the association between family structure, specifically whether a child lives in a single parent household, and childhood overweight and obesity, suggesting a significant relationship[5-10] or no effects[11,12]. Where significant associations have been found, frequently results indicate that living with a single adult increases the risk of childhood overweight and obesity.

Whilst there is an evidence base on whether living in a single adult household is associated with childhood overweight and obesity, there has been less consideration of the possible mechanisms that could explain this relationship. Family structure may affect the risk of childhood overweight and obesity through various economic and social processes. Two-adult families, for example, tend to have a more stable economic situation than single-adult families leading to better access to extracurricular activities and healthier food[13]. Indeed Scharte et al.'s (2012)[10] research among German children found that the the positive association between living with a single mother and poor health and overweight was attenuated when accounting for socio-economic factors, including income.

Taking the case of the United Kingdom, this study aims to investigate the association between family structure, defined here as whether children live in a one or two adult household, and childhood body mass index (BMI), and whether this varies by child sex and with increased age at the age of 3, 5, 7, 11 and 14 years. Secondly, the study aims to examine whether family equivalised income as a proxy for socio-economic status, mediates the association between family structure and child's BMI using a potential outcomes based mediation approach[14].

Methods

Study design and participants

The Millennium Cohort Study (MCS) data was used for this investigation. The MCS is an ongoing longitudinal study of children born between September 2000 and January 2002 in the United Kingdom. All births during this timeframe whose family could receive Child Benefit were eligible for inclusion in the MCS[15]. Child Benefit is a universal provision payable to parents or guardians from the child's date of birth. 19,244 children (defined as cohort members) and their families were recruited into the MCS at baseline. The main respondent was the household member who answered the questions from the health visitor, and was either a parent or guardian of the cohort member.

The sampling was a clustered, stratified design, which oversampled children living in areas of high poverty, or in areas with large ethnic minority populations. Details of the study design and sampling procedures have been published elsewhere[16]. Visits were conducted by trained interviewers employed by the National Centre for Social Research (NatCen), with an initial visit when the child was age 9 months, with follow-up visits at ages 3, 5, 7, 11, and 14. These visitors collected information on the weight and height of the child, equivalised income, and the relationships of each individual in the household to the cohort member.

In order to be included in our present analysis, all information for each of our included variables was required for wave 2 of the study, when the child was 3, up until wave 6, when the child was 14. In total, 17,146 of the original 19,244 children who were enrolled in the MCS were still partaking by the age of 3. In order to be included in our final analysis population, full data on the variables of interest was required for each child, for all time points. Overall, 7,859 were excluded because they did not participate in all five waves. A further 356 were excluded due to missing information on family structure for one or more waves. Additionally, 1,311 were excluded because information on BMI was not complete. Finally, of the remaining 7,620 children, 142 were excluded because they did not have complete data on equivalised income. This resulted in a final sample size of 7,478 children who had complete information, at all time points, ensuring the same individuals were being compared over time. We additionally undertook analysis which adjusted for geographic region, highest educational attainment of the main respondent (usually the cohort member's mother), and ethnicity. For this adjusted analysis, a further 20 children were excluded due to missing data for one or more of the adjustment variables.

Exposure and mediator

The exposure family structure in this study refers to whether the child lives in a one or two adult household. For each cohort member, family structure was determined through questions asked about the main respondent's relationship to the cohort member, and the relationship of other household members to the cohort member. The main respondent was asked how many household members lived in the same residence as the cohort member, and then questions on the relationship of each household member to the cohort member. From this, the number of adults in the household could be determined. A binary variable was created equal to one if there was one adult in the household, and zero if there were two or more adults in the household.

Information on equivalised income was also recorded by the MCS, derived through questions on household resources. Equivalised income is a measure which considers 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. Each household member is weighted according to age, with the assumption being the spending capacity of household members differs by age. This division 'equivalises' the available income, in order to allow for comparability across different households[17-19].

Complex survey weights which accounted for unequal selection probability, non-response and attrition were applied[20] to improve generalizability of the results. Standard errors took into consideration clustering within wards at the point of recruitment into the study.

Outcomes

The outcome for this analysis was childhood BMI. Information on child weight and height at ages 3, 5, 7, 11, and 14 was retrieved from the MCS. Children were weighed by MCS interviewers without shoes or outdoor clothing, and weight was recorded in kilograms to one decimal place. Height measurements were obtained by Leicester Height Measurement Stadiometer and recorded to the nearest millimetre[21]. The weight and height measurements were then used to calculate body mass index (BMI), which was used as a continuous measure in the outcome model. Overweight and obesity were reported for descriptive purposes and defined according to CDC growth chart percentiles. These cut points are sex specific, and so are reported separately for girls and boys, not overall[22]. Figure 1 shows via a directed acyclic graph (DAG) the hypothesized relationships between the exposure family structure, the mediator family income, the outcome child's BMI, and the confounder age of the main caregiver at baseline.

In addition to our overall analysis, we conducted an analysis which further adjusted for geographical region, main respondent's highest educational attainment, and ethnicity as covariates.

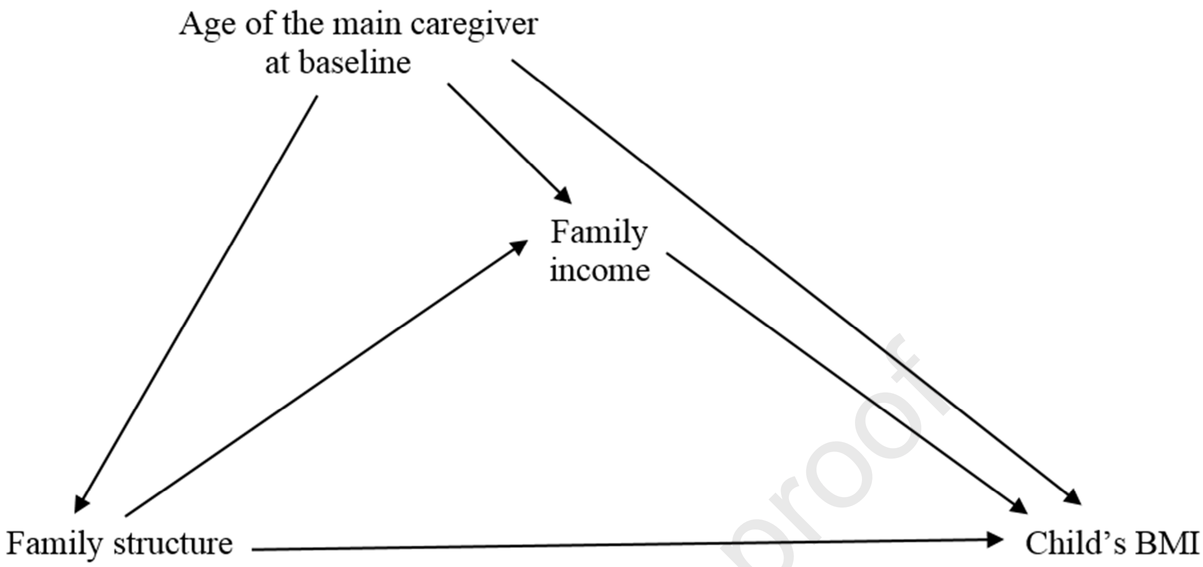


Figure 1- DAG of the relationship between family structure and child's BMI mediated by family income and considering the confounder age of the main caregiver at baseline

Potential outcomes based mediation analysis

To capture to what extent income mediates the association between family structure (living in a one or two adult household) and childhood BMI, we applied a mediation analysis approach built under the causal inference framework based on potential outcomes[14]. A series of mediation analyses were repeated cross-sectionally over time to show to what extend the mediating role of income changes as children grow older. For each child in the study population we denote with *Y* the outcome "child's BMI", with *A* the exposure "family structure", with *M* the mediator "equivalised income", and with *C* the set of baseline confounders including "age of the main caregiver at cohort member's birth" for the single confounder adjusted analysis and additionally "geographic region", "highest educational attainment of the main respondent", and "ethnicity" for the multiple confounders adjusted analysis, with *M(a)* the potential mediator income when the exposure family structure *A* is set to *a*, and finally with *Y(am)* the potential outcome child's BMI when the exposure family structure *A* and the mediator income *M* are set to *a* and *m*. We can define the natural direct effect (NDE) of family structure on child's BMI comparing the potential outcomes for the two exposure levels *A=a (one adult household)* and *A=ã (two adult household)* for a fixed level *M=M(ã)* of the mediator income, and the natural indirect effect (NIE) comparing the potential outcome child's BMI for differing income levels *M=M(a)* and *M=M(ã)* and a fixed family structure level of *A=a*. For the single confounder adjusted analysis when the age of the main caregiver at cohort member's birth C is set to c the conditional NDE, the NIE, and the TE can be identified as

$$E[NDE|c]=E[Y(a, M(\tilde{a}))|c]-E[Y(\tilde{a}, M(\tilde{a}))|c]$$
$$E[NIE|c]=E[Y(a, M(a))|c]-E[Y(a, M(\tilde{a}))|c] \text{ and}$$
$$E[TE|c]=E[Y(a)-Y(\tilde{a})|c]=NDE+NIE.$$

The NDE and NIE of family structure on child's BMI can be identified under the assumptions that there are no unmeasured confounders of the relationships between family structure and child's BMI, income and child's BMI, and family structure and income, and there is no income and child's BMI confounder affected by family structure. We estimated the NDE and NIE via structural equation modeling[23] using *STATA version 13*. We also calculated the proportion mediated (PM) by income as

$$PM = \frac{NIE}{NDE + NIE}$$

which shows the extent to which the effect of family structure on child's BMI is due to the effect of the mediating role of income[24]. The analyses are stratified by children's sex and repeated cross-sectionally at ages 3, 5, 7, 11, and 14 and an interaction term between family status and income was considered[25]. When the interaction between exposure-mediator is present, the mediation approach based on the potential outcome framework leads to different NDE and NIE estimates showing that traditional mediation approaches[26], which rely on the key assumption for the identification of NDE and NIE in the model specification used, are not suitable for the identification of the effects[27]. For the single confounder adjusted analysis E-values were calculated to give the minimum strength of the unmeasured confounder associations necessary to totally nullify the NDE and the NIE of the family structure on child's BMI. Finally, we adjusted for additional confounders to assess whether results remained stable. Confounders included were geographic region (south of England or elsewhere), the main respondent's highest educational attainment (degree level or below), and ethnicity (white, or other as self-reported by the main respondent). Geographical region in particular we believed could influence both family structure, and childhood BMI in the UK context. The north-south divide in health inequalities known to exist in the UK means poorer health outcomes, including higher rates of obesity, persist to a greater extent in the north than the south[28]. Small numbers in subcategories led to the decision to use variables categorized as binary.

Results

Characteristics of the analytical sample

A total of 7,478 children with information available for all the variables used in the analysis were included in the study. In Table 1 the characteristics of the children at the ages of 3, 5, 7, 11, and 14 years are reported, separately by whether they lived in a one or two adult household. The distribution of the characteristics changes slightly over time within children but there are pronounced differences between family structure type, with the most likely change being children moving from being in a two adult to a one adult household. The predicted mean and 95% CIs for BMI according to age and family structure are plotted and displayed in Figure 3 together with the estimated probabilities of overweight and obesity by age and family structure (Figure 1A to Figure 2B). For the analysis adjusted for multiple confounders, an additional 20 children (total sample 7,458) were excluded due to missing data for one or more of the adjustment variables.

TABLE 1 & FIGURES 1-3 HERE

TABLE 2 HERE

Potential outcomes based mediation analysis

Table 2 reports the results from the potential outcomes-based mediation analysis approach with single confounder adjustment, under which income is not used as a covariate in the outcome regression model, but treated as a mediator. Additionally, an interaction between family structure and equivalised income is included in the outcome model. The model is run overall, and stratified by sex. The analysis is performed cross-sectionally over time at children's age of 3, 5, 7, 11, and 14 years. The results indicate that the NDE of family structure on child's BMI is insignificant (p-value >0.05, with the exception of overall analysis at age 14 and analysis performed in girls at age 11). However, the NIE of family structure is significant (p-value <0.05) overall at ages 7, 11 and 14, and for boys and girls separately at ages 11 and 14, confirming that a sizeable portion of the association between family structure and child's BMI is explained by the mediating role of income. The PM clearly shows the importance of income as a mediator, overall, and for boys and girls separately in later childhood and adolescence. The role of family structure mediated by income on child's BMI appears to be stronger in girls. The E-values show that overall and at age of 14, to explain away the NDE of family structure on child's BMI an unmeasured confounder association greater than or equal to 1.97 would be necessary. For boys the association should be greater than 1.93 and for girls greater than 2. To cancel away the NIE of family structure on child's BMI the confounder association needed is weaker but still over 1 (1.46 overall, 1.37 and 1.52 for boys and girls respectively). To fully explain away the TE, stronger unmeasured confounder associations would be needed (2.28 overall, and 2.16 and 2.39 for boys and girls respectively).

In addition to reporting E-values, we undertook an analysis in which we adjusted for additional potential confounders to assess whether this changed the conclusions. In this analysis, we adjusted for geographical region, highest educational attainment of the main respondent, and ethnicity (see table 3). Results showed that the proportion of the association between family structure and child's BMI mediated by income was considerable after the additional confounding adjustment.

Discussion

This study aimed to understand the mediating role of income in the association between family structure and childhood BMI. We used mediation analysis to avoid potentially inaccurate interpretations which could occur when standard regression models are used in isolation. Our results indicated that there is no significant direct or indirect effect of family structure, in this analysis defined as whether the child lived in a one or two adult household, on child's BMI before the age of 7. However, as children grow older, the association between family structure and child's BMI increases, and is mediated through income. The mediating effect of income increases up until children are 11 years old for both girls and boys. The high PM through income remains when children are 14, but does not appear to increase overall and for boys. It is possible that the PM remains stable after age 11, a finding which would require further research using future data collected for the MCS to confirm. In line with the significance of the estimates from the mediation analysis, the E-values increase approximately at each increase in age. Consistent with the mediation analysis results, the highest unmeasured confounder associations necessary to completely cancel the NDE, the NIE, and the TE estimates, correspond to older ages. The multiple confounders adjusted analysis, which included variables on geographic region, main respondent's highest educational attainment, and ethnicity in the model, demonstrated that the indirect effect of family structure mediated through income was significant at older ages, and represented a reasonable proportion of the total effect of family structure on childhood BMI.

It has been consistently found that there is an inverse association between income and BMI, in particular development of overweight and obesity, in the UK[29]. The mechanism behind why this is the case could relate to the availability of particular food types within a given geographical area[30], with lower income areas tending to have greater access to fast-food outlets and poorer access to healthier foods. For example, access to chain supermarkets in which fresh produce is available is statistically significantly associated with lower BMI amongst adolescents in the US[31], indicating that ease of access and convenience can play a role in how children consume food, and what they eat. Focusing poor quality food with low nutritious value and high calorie content in areas with higher levels of deprivation can result in some geographical regions creating a more obesogenic environment than other, usually more affluent areas. Additionally, past research has highlighted the larger proportion of lone adult families in areas with higher levels of deprivation and lower mean incomes[32]relative to areas with less deprivation and more financial resources. Living in areas of higher deprivation could link to obesity due to the availability and more widespread advertisement of food with high calorie content. Previous research has indicated that food cues such as advertising can affect childhood BMI two years later[33], indicating that the response to an obesogenic environment could be delayed. The effect on the younger children may therefore not manifest until they are older, and may explain why there is no indirect effect of family structure through income when the children in this study were 3 and 5 years old.

An interesting finding of this study is the seemingly differential effect of family structure and income on childhood BMI by sex. For girls, the effect of family structure before consideration of income as a mediating factor is much more evident than is the case for boys (see Figures 1A-2B). Additionally, for girls the increase in proportion of the total effect of family structure mediated by income followed a clearer pattern as the cohort member grew older relative to boys, with larger differentiation in BMI according to family structure in older ages. The reasons for this are incompletely understood, however there is evidence to suggest families tend to monitor the weight and healthy eating of girls to a greater extent than boys, who are often provided with more calorific foods[34,35]. Past studies have indicated parents recognise their child is overweight more frequently if the child is female relative to male[34], possibly due to body ideals of thinness that are applied to girls to a greater extent than boys[36]. If the family has the financial resources to access healthier food and lives in a more affluent, generally less obesogenic environment, the protective effect on BMI may therefore be stronger for girls than for boys due to greater familial intervention, and the resources to apply a less calorific diet to daughters. This could partially explain the greater differences between those families with and without such resources for girls, relative to boys.

Strengths and limitations

There are a number of limitations to this study. Calculations of equivalised income rely on accurate reports of financial resources by the main respondents in the survey, in this instance usually the cohort members' mother. If income is not accurately reported, it will impact on the reliability of the measure of the mediator. Moreover, the mediation approach used strongly relies on the assumption that there are no unmeasured confounders of the exposure-outcome, mediator-outcome and exposure-mediator relationships, and there is no mediator-outcome confounder affected by the exposure. Additionally, with this work we aimed to show with an empirical application the potential role of income as mediator between family structure and child's BMI and consequent risk of overestimating the direct effect of family structure on children's health, attempting to answer the question "Does family structure cause obesity or is it income?". In our application the use of all potential confounders is complicated by several issues such as the fact that some confounders are not available for all the time points of interest, and the fact that over time, variables which are confounders for one point are potential mediators for a different time point. These complications would affect the causal DAG of interest in such a way that is difficult to have a suitable adjustment method. Consequently, we decided to focus our research question only on the mediating role of income between family structure and child's BMI using the available data as a mere empirical application of the potential effect on the results, and reporting the E-values to gain an understanding of the robustness of the estimates to potential unmeasured confounders. We added an additional analysis which includes as potential confounders geographical region, highest educational attainment of the main respondent, and ethnicity which showed that the proportion of association between family structure and child's BMI mediated by income was considerable even after the additional confounding adjustment.

Despite these limitations, there were several strengths of using the MCS. The MCS is a nationally representative probability sample intended, after weighting, to represent the general population of children born in 2000 and 2001 in the UK. The repeated measures nature of the sample allows for the same children to be followed for their entire childhood up until the age of 14, enabling us to study the effect of family structure and equivalised income at each age group and to show how this has an impact on health consequences. Self-reported measures of BMI are recognized as frequently being inaccurate and often underreported[37]. In this study, BMI measurements were taken by trained visitors, increasing the internal validity of the results. Moreover, in this study we used a potential outcomes mediation approach which, by avoiding the use of the mediator variable in the outcome model as done by other approaches, reduces the risk of introducing bias in the TE estimate. Namely, when the mediating role of a variable is not identified and the variable is used for adjustment in the outcome model, we encounter the risk of interpreting the association between the exposure and the outcome as the TE when it actually represents only the NDE.

Conclusion

Childhood overweight and obesity is becoming a growing public health concern in the UK. Whilst several studies have considered the association between family structure and childhood overweight and obesity[10], research on the mediating role of income in this relationship remains relatively under investigated. This study provided evidence that a higher proportion of the effect of family structure on child's BMI is mediated through income as the child grows older. Future perspectives could provide more nuance to our understanding of the association between family structure and childhood BMI by considering the precise nature of the relationships between adults and children within a given household. Understanding the links between childhood BMI, family structure and income will aid the design of public health interventions to tackle overweight and obesity in childhood.

Declaration of interests

Sarah Burkill, Philippa Waterhouse, and Laura Pazzagli declare no conflict of interest and no funding was received for this study. Laura Pazzagli is an employee and Sarah Burkill is a former employee of the Centre of Pharmacoepidemiology at Karolinska Institute, which receives grants from several entities (pharmaceutical companies, regulatory authorities and contract research organizations) for the performance of drug safety and drug utilization studies, unrelated to this work.

References

1. Ebbeling CB, Pawlak DB, Ludwig DS. Childhood obesity: public-health crisis, common sense cure. *Lancet* 2002; **360**(9331): 473-82.
2. Must A, Strauss RS. Risks and consequences of childhood and adolescent obesity. *Int J Obes Relat Metab Disord* 1999; **23 Suppl 2**: S2-11.
3. Reilly JJ, Kelly J. Long-term impact of overweight and obesity in childhood and adolescence on morbidity and premature mortality in adulthood: systematic review. *Int J Obes (Lond)* 2011; **35**(7): 891-8.
4. Bronfenbrenner. The ecology of human development: Harvard University Press; 1979.
5. Byrne LK, Cook KE, Skouteris H, Do M. Parental status and childhood obesity in Australia. *Int J Pediatr Obes* 2011; **6**(5-6): 415-8.
6. Chen AY, Escarce JJ. Family structure and childhood obesity, Early Childhood Longitudinal Study - Kindergarten Cohort. *Prev Chronic Dis* 2010; **7**(3): A50.
7. Formisano A, Hunsberger M, Bammann K, et al. Family structure and childhood obesity: results of the IDEFICS Project. *Public Health Nutr* 2014; **17**(10): 2307-15.
8. Huffman FG, Kanikireddy S, Patel M. Parenthood--a contributing factor to childhood obesity. *Int J Environ Res Public Health* 2010; **7**(7): 2800-10.
9. Schmeer KK. Family structure and obesity in early childhood. *Soc Sci Res* 2012; **41**(4): 820-32.
10. Scharte M, Bolte G, Group GMES. Increased health risks of children with single mothers: the impact of socio-economic and environmental factors. *Eur J Public Health* 2013; **23**(3): 469-75.
11. Hesketh K, Crawford D, Salmon J, Jackson M, Campbell K. Associations between family circumstance and weight status of Australian children. *Int J Pediatr Obes* 2007; **2**(2): 86-96.
12. Parikka S, Maki P, Levalahti E, Lehtinen-Jacks S, Martelin T, Laatikainen T. Associations between parental BMI, socioeconomic factors, family structure and overweight in Finnish children: a path model approach. *BMC Public Health* 2015; **15**: 271.
13. Drewnowski A, Specter SE. Poverty and obesity: the role of energy density and energy costs. *Am J Clin Nutr* 2004; **79**(1): 6-16.
14. Rubin DB. Estimating Causal Effects of Treatments in Randomized and Nonrandomized Studies. *J Educ Psychol* 1974; **66**(5): 688-701.
15. I P. The Millennium Cohort Study: Technical Report on Sampling 4th Edition, 2007.
16. K H. Millennium Cohort Study: A Guide to the Datasets (Eighth Edition), 2014.
17. Barton KL, Chambers S, Anderson AS, Wrieden WL. Time to address the double inequality of differences in dietary intake between Scotland and England. *Br J Nutr* 2018; **120**(2): 220-6.
18. Maguire ER, Monsivais P. Socio-economic dietary inequalities in UK adults: an updated picture of key food groups and nutrients from national surveillance data. *Br J Nutr* 2015; **113**(1): 181-9.
19. Ejebu OZ, Whybrow S, McKenzie L, et al. What can Secondary Data Tell Us about Household Food Insecurity in a High-Income Country Context? *Int J Environ Res Public Health* 2018; **16**(1).
20. S JEK. Millennium Cohort Study User Guide to Analysing MCS Data Using SPSS, 2010.
21. Hope S, Pearce A, Whitehead M, Law C. Parental employment during early childhood and overweight at 7-years: findings from the UK Millennium Cohort Study. *BMC Obes* 2015; **2**: 33.
22. Prevention CfDCa. Clinical Growth Charts. 2017.

23. De Stavola BL, Daniel RM, Ploubidis GB, Micali N. Mediation analysis with intermediate confounding: structural equation modeling viewed through the causal inference lens. *Am J Epidemiol* 2015; **181**(1): 64-80.
24. VanderWeele TJ. Policy-relevant proportions for direct effects. *Epidemiology* 2013; **24**(1): 175-6.
25. Valeri L, Vanderweele TJ. Mediation analysis allowing for exposure-mediator interactions and causal interpretation: theoretical assumptions and implementation with SAS and SPSS macros. *Psychol Methods* 2013; **18**(2): 137-50.
26. Baron RM, Kenny DA. The moderator-mediator variable distinction in social psychological research: conceptual, strategic, and statistical considerations. *J Pers Soc Psychol* 1986; **51**(6): 1173-82.
27. Imai K, Keele L, Tingley D. A general approach to causal mediation analysis. *Psychol Methods* 2010; **15**(4): 309-34.
28. Scarborough P, Allender S. The North-South gap in overweight and obesity in England. *Br J Nutr* 2008; **100**(3): 677-84.
29. Kim TJ, von dem Knesebeck O. Income and obesity: what is the direction of the relationship? A systematic review and meta-analysis. *Bmj Open* 2018; **8**(1).
30. Pearce J, Blakely T, Witten K, Bartie P. Neighborhood deprivation and access to fast-food retailing - A national study. *Am J Prev Med* 2007; **32**(5): 375-82.
31. Powell LM, Auld MC, Chaloupka FJ, O'Malley PM, Johnston LD. Associations between access to food stores and adolescent body mass index. *Am J Prev Med* 2007; **33**(4): S301-S7.
32. Stack RJ, Meredith A. The Impact of Financial Hardship on Single Parents: An Exploration of the Journey From Social Distress to Seeking Help. *J Fam Econ Iss* 2018; **39**(2): 233-42.
33. Folkvord F, Anschutz DJ, Buijzen M. The association between BMI development among young children and (un) healthy food choices in response to food advertisements: a longitudinal study. *Int J Behav Nutr Phy* 2016; **13**.
34. Vanhala ML, Keinanen-Kiukaanniemi SM, Kaikkonen KM, Laitinen JH, Korpelainen RI. Factors associated with parental recognition of a child's overweight status--a cross sectional study. *BMC Public Health* 2011; **11**: 665.
35. Scaglioni S, De Cosmi V, Ciappolino V, Parazzini F, Brambilla P, Agostoni C. Factors Influencing Children's Eating Behaviours. *Nutrients* 2018; **10**(6).
36. Grossbard JR, Neighbors C, Larimer ME. Perceived norms for thinness and muscularity among college students: what do men and women really want? *Eat Behav* 2011; **12**(3): 192-9.
37. Magnusson K, Haugen IK, Osteras N, Nordsletten L, Natvig B, Hagen KB. The validity of self-reported body mass index in a population-based osteoarthritis study. *BMC Musculoskelet Disord* 2014; **15**: 442.

Appendix

Table 1A

	Included (n(%))	Excluded (n(%))
Age 3		
One adult household	926 (10.6)	211 (12.4)
Two adult household	6552 (89.4)	1242 (87.6)
Mean BMI (SE)	16.4 (0.0)	16.7 (0.1)
Mean equivalised income (SE)	392.2 (8.5)	377.2 (13.3)
Mean age of caregiver when CM born (SE)	29.9 (0.1)	30.2 (0.2)
Age 5		
One adult household	1103 (13.1)	256 (15.7)
Two adult household	6375 (86.9)	1223 (84.3)
Mean BMI (SE)	16.2 (0.0)	16.6 (0.1)
Mean equivalised income (SE)	412.0 (8.1)	416.7 (12.7)
Mean age of caregiver when CM born (SE)	29.9 (0.1)	30.2 (0.2)
Age 7		
One adult household	1239 (14.9)	275 (16.5)
Two adult household	6239 (85.1)	1205 (83.5)
Mean BMI (SE)	16.4 (0.0)	17.0 (0.1)
Mean equivalised income (SE)	452.6 (8.3)	380.9 (10.1)
Mean age of caregiver when CM born (SE)	29.9 (0.1)	30.2 (0.2)
Age 11		
One adult household	1483 (18.7)	308 (18.5)
Two adult household	5995 (81.3)	1172 (81.5)
Mean BMI (SE)	18.9 (0.0)	19.6 (0.1)
Mean equivalised income (SE)	479.5 (6.4)	486.5 (11.3)
Mean age of caregiver when CM born (SE)	29.9 (0.1)	30.2 (0.2)
Age 14		
One adult household	1609 (20.5)	349 (22.2)
Two adult household	5869 (79.5)	1131 (77.8)
Mean BMI (SE)	21.2 (0.1)	21.3 (0.2)
Mean equivalised income (SE)	475.9 (6.6)	477.3 (11.1)
Mean age of caregiver when CM born (SE)	29.9 (0.1)	30.2 (0.2)

*1809 children are excluded and shown in this table in the excluded column due to missing information for one or more variables included in the model. Data missing by definition for at least one variable, for at least one time point so numbers do not add up to 1809 at all waves.

Table 1- Demographic characteristics of study population

	One adult household	Two adult household	Total
Age 3			
Total	926 (10.6)	6552 (89.4)	7478
Least deprived income quintile	20 (2.8)	1527 (27.8)	1547 (25.1)
Second least deprived income quintile	43 (6.2)	1578 (26.5)	1621 (24.4)
Mid quintile	92 (11.4)	1463 (22.5)	1555 (21.3)
Second most deprived income quintile	233 (26.3)	1267 (15.4)	1500 (16.5)
Most deprived income quintile	538 (53.2)	717 (8.9)	1255 (12.7)
Mean BMI	16.3 (16.2-16.5)	16.4 (16.4-16.5)	16.4 (16.4-16.5)
Mean equivalised income	181.6 (171.1-192.0)	417.2 (410.6-432.7)	392.2 (386.0-398.5)
Mean age of main carer when cohort member born	26.6 (26.2-27.1)	30.3 (30.2-30.5)	29.9 (29.8-30.1)
Overweight (girls)	772 (22.7)	107 (21.7)	879 (22.6)
Overweight (boys)	752 (22.9)	89 (19.4)	841 (22.5)
Obese (girls)	293 (8.7)	41 (8.0)	334 (8.7)
Obese (boys)	383 (11.0)	42 (8.4)	425 (10.7)
Age 5			
Total	1103 (13.1)	6375 (86.9)	7478
Least deprived income quintile	37 (4.4)	1535 (29.1)	1572 (25.9)
Second least deprived income quintile	63 (7.6)	1585 (26.6)	1648 (24.1)
Mid quintile	158 (16.9)	1396 (21.6)	1554 (21.0)
Second most deprived income quintile	306 (28.2)	1196 (15.5)	1502 (17.2)
Most deprived income quintile	539 (43.0)	663 (7.2)	1202 (12.0)
Mean BMI	16.2 (16.1-16.4)	16.2 (16.2-16.3)	16.2 (16.2-16.3)
Mean equivalised income	224.8 (215.0-234.6)	440.2 (433.7-446.7)	412.0 (405.8-418.1)
Mean age of main carer when cohort member born	27.4 (26.9-27.8)	30.3 (30.2-30.5)	29.9 (29.8-30.1)
Overweight (girls)	850 (25.9)	157 (24.5)	1,007 (25.7)
Overweight (boys)	911 (28.4)	148 (26.0)	1,059 (28.1)
Obese (girls)	320 (9.3)	62 (10.1)	382 (9.4)
Obese (boys)	382 (11.2)	53 (9.5)	435 (11.0)

Age 7			
Total	1239 (14.9)	6239 (85.1)	7478
Least deprived income quintile	46 (5.2)	1545 (30.3)	1591 (26.5)
Second least deprived income quintile	113 (11.1)	1578 (28.1)	1691 (26.0)
Mid quintile	181 (17.1)	1361 (20.6)	1542 (20.1)
Second most deprived income quintile	350 (27.6)	1064 (13.5)	1414 (15.6)
Most deprived income quintile	549 (39.1)	691 (7.5)	1240 (12.2)
Mean BMI	16.6 (16.5-16.8)	16.4 (16.3-16.4)	16.4 (16.3-16.5)
Mean equivalised income	269.0 (257.1-280.1)	484.9 (477.0-492.0)	452.6 (446.1-459.2)
Mean age of main carer when cohort member born	28.1 (27.6-28.5)	30.3 (30.1-30.4)	29.9 (29.8-30.1)
Overweight (girls)	724 (22.0)	169 (25.7)	893 (22.5)
Overweight (boys)	680 (20.8)	145 (23.9)	825 (21.2)
Obese (girls)	256 (7.4)	69 (10.9)	325 (8.0)
Obese (boys)	281 (8.0)	57 (9.0)	338 (8.1)
Age 11			
Total	1483 (18.7)	5995 (81.3)	7478
Least deprived income quintile	3 (0.3)	1768 (39.9)	1771 (32.5)
Second least deprived income quintile	57 (4.9)	1752 (31.0)	1809 (26.1)
Mid quintile	441 (34.5)	1177 (15.5)	1618 (19.1)
Second most deprived income quintile	548 (36.0)	708 (7.1)	1256 (13.3)
Most deprived income quintile	434 (24.3)	590 (5.5)	1024 (9.0)
Mean BMI	19.4 (19.2-19.7)	18.8 (18.7-18.9)	18.9 (18.8-19.0)
Mean equivalised income	300.9 (295-4306.5)	520.5 (515.8 -525.2)	479.5 (474.9-484.1)
Mean age of main carer when cohort member born	28.9 (28.5-29.2)	30.2 (30.0-30.3)	29.9 (29.8-30.1)
Overweight (girls)	779 (24.3)	251 (31.9)	1,030 (25.7)
Overweight (boys)	822 (25.8)	233 (30.9)	1,055 (26.8)
Obese (girls)	285 (8.6)	102 (12.5)	387 (9.4)
Obese (boys)	335 (10.1)	106 (14.3)	441 (10.9)
Age 14			
Total	1609 (20.5)	5869 (79.5)	7478

Least deprived income quintile	17 (1.6)	1962 (43.2)	1979 (34.7)
Second least deprived income quintile	122 (10.5)	1784 (30.8)	1906 (26.6)
Mid quintile	484 (34.8)	1059 (14.4)	1542 (18.6)
Second most deprived income quintile	545 (31.8)	552 (6.9)	1097 (12.0)
Most deprived income quintile	441 (21.3)	512 (4.7)	953 (8.1)
Mean BMI	21.8 (21.5-22.1)	21.1 (21.1-21.2)	21.2 (21.1-21.3)
Mean equivalised income	307.6 (301.9-313.3)	519.2 (514.4-524.0)	475.9 (471.2-480.5)
Mean age of main carer when cohort member born	29.2 (28.9-29.5)	30.1 (29.9-30.3)	29.9 (29.8-30.1)
Overweight (girls)	753 (24.6)	280 (31.6)	1,033 (26.1)
Overweight (boys)	736 (23.8)	225 (26.6)	961 (24.4)
Obese (girls)	348 (11.0)	144 (16.2)	492 (12.1)
Obese (boys)	285 (8.9)	120 (14.7)	405 (10.1)

Table 2- Mediation analysis for the effect of family structure on children's BMI with family income as mediator adjusted for a single confounder

	NDE	P-value	E-value*** for point estimate	NIE	P-value	E-value for point estimate	Total effect	P-value	E-value for point estimate	Proportion Mediated
All										
Age 3	-0.13	0.38	1.31	0	0.88	1.04	-0.13	0.35	1.32	-
Age 5	-0.04	0.77	1.16	0.04	0.06	1.16	0	1.00	1.01	-
Age 7	0.23	0.13	1.44	0.06	0.02	1.18	0.29	0.05	1.51	19.70%
Age 11	0.58	0.15	1.60	0.43	0.00	1.48	1.02	0.01	1.93	42.70%
Age 14	1.23	0.01	1.97	0.46	0.00	1.46	1.68	0.00	2.28	27.10%
Boys										
Age 3	-0.07	0.74	1.2	0	0.91	1.05	-0.07	0.74	1.20	
Age 5	-0.02	0.92	1.11	0.04	0.19	1.16	0.02	0.92	1.11	
Age 7	0.11	0.59	1.28	0.06	0.09	1.19	0.17	0.39	1.37	33.80%
Age 11	-0.12	0.84	1.22	0.40	0.00	1.46	0.27	0.65	1.36	-
Age 14	1.14	0.08	1.93	0.33	0.00	1.37	1.46	0.02	2.16	22.30%
Girls										
Age 3	-0.2	0.33	1.44	-0.01	0.80	1.06	-0.21	0.30	1.45	-
Age 5	-0.05	0.79	1.18	0.04	0.14	1.17	-0.01	0.97	1.07	-
Age 7	0.35	0.11	1.58	0.06	0.16	1.18	0.41	0.05	1.64	13.65%
Age 11	1.24	0.02	2.09	0.46	0.00	1.5	1.70	0.00	2.47	27.26%
Age 14	1.29	0.06	2	0.56	0.00	1.52	1.85	0.00	2.39	30.15%

*Outcome model adjusted for age of main caregiver when cohort member was born including the interaction between family structure and income. In the causal mediation approach income is treated as mediator and not as covariate in the outcome model.
**BMI was used as a continuous measure in the outcome model.
***E-values give the minimum strength of confounder associations needed to explain away the effect of the exposure family structure on the outcome children's BMI.

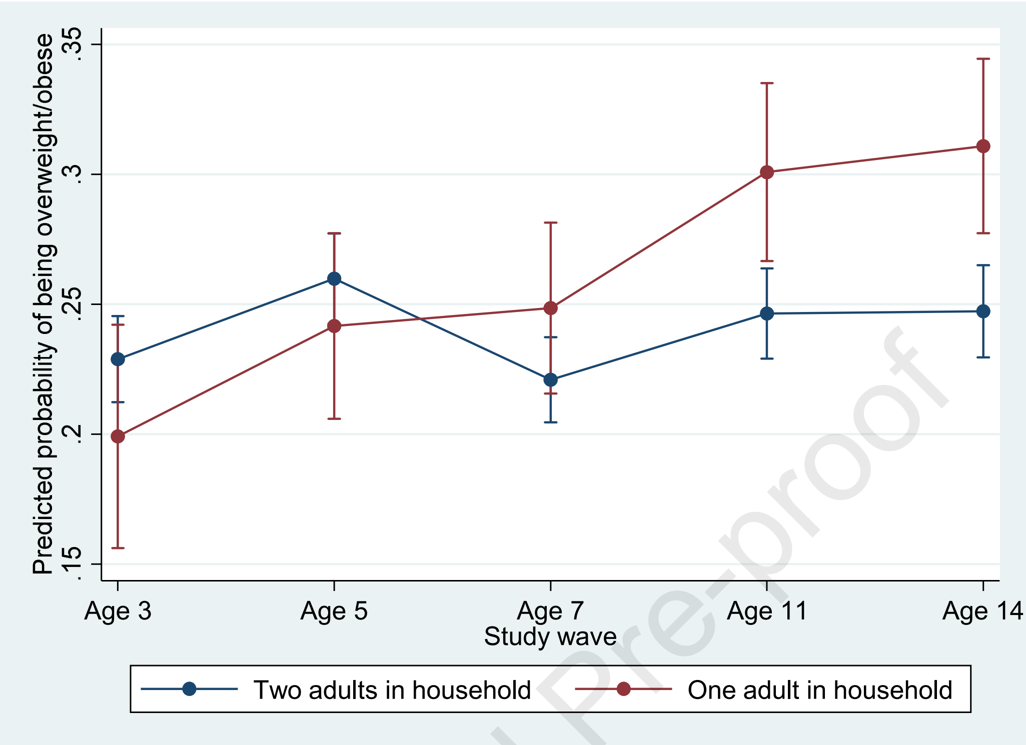
Table 3- Mediation analysis for the effect of family structure on children's BMI with family income as mediator adjusted for multiple confounders

	NDE	P-value	NIE	P-value	Total effect	P-value	Proportion mediated
All							
Age 3	-0.15	0.33	0.01	0.68	-0.14	0.34	-
Age 5	-0.04	0.75	0.02	0.36	-0.03	0.84	-
Age 7	0.23	0.14	0.02	0.51	0.24	0.10	6.2%
Age 11	0.60	0.14	0.23	0.00	0.83	0.04	27.6%
Age 14	1.25	0.01	0.31	<0.001	1.56	0.00	19.8%
Boys							
Age 3	-0.09	0.66	0.01	0.80	-0.09	0.68	-
Age 5	-0.03	0.90	0.02	0.43	0.00	0.99	-
Age 7	0.09	0.68	0.01	0.68	0.10	0.62	13.5%
Age 11	-0.17	0.79	0.18	0.11	0.01	0.98	-
Age 14	1.22	0.07	0.14	0.19	1.36	0.04	10.6%
Girls							
Age 3	-0.20	0.33	0.01	0.61	-0.19	0.35	-
Age 5	-0.04	0.81	0.01	0.54	-0.03	0.87	-
Age 7	0.37	0.10	0.02	0.66	0.38	0.07	4.4%
Age 11	1.29	0.02	0.27	0.01	1.56	0.00	17.3%
Age 14	1.24	0.07	0.45	<0.001	1.70	0.01	26.7%

*Outcome model adjusted for age of main caregiver when cohort member was born, income and family structure interaction, geographic region, ethnicity, and main respondent's highest educational attainment. In the causal mediation approach income is treated as mediator and not as covariate in the outcome model.

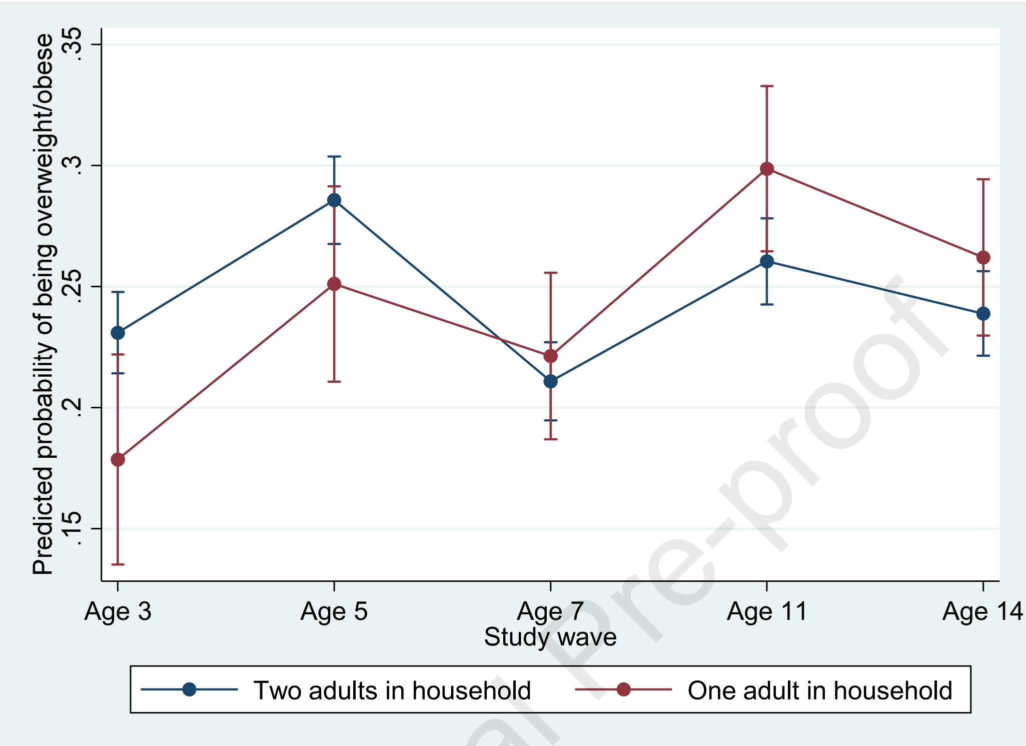
**BMI was used as a continuous measure in the outcome model.

Figure 1A – Probability of overweight or obese by age and family structure - Girls



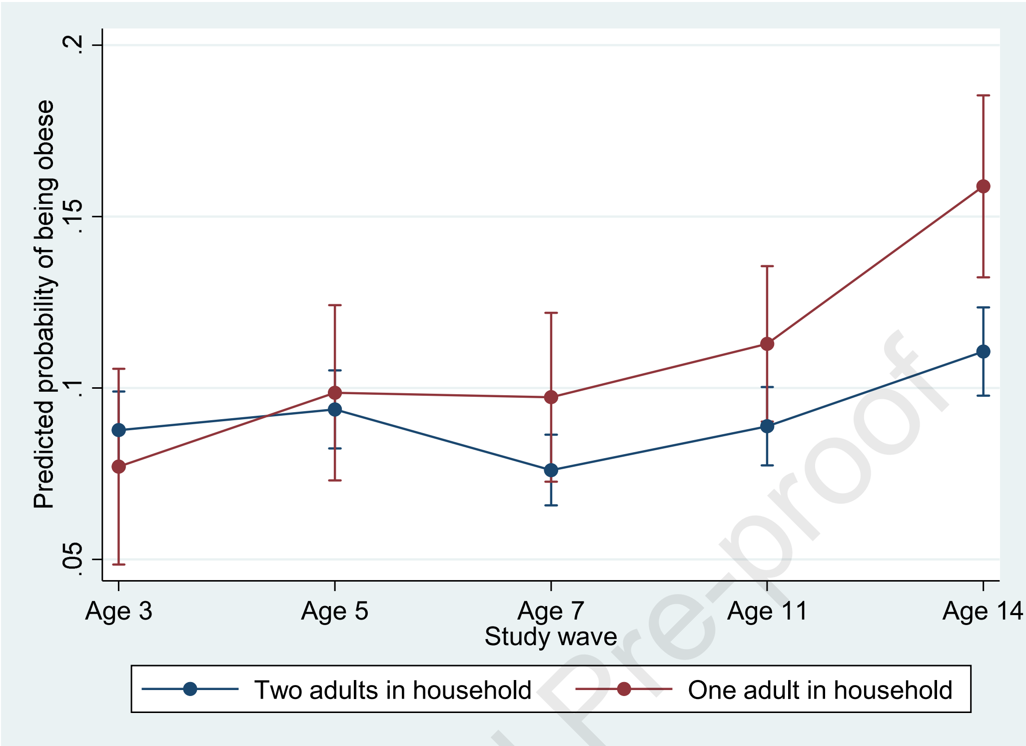
*Overweight or obese is defined as 85th percentile for BMI according to sex specific CDC growth charts

Figure 1B – Probability of overweight or obese by age and family structure - Boys



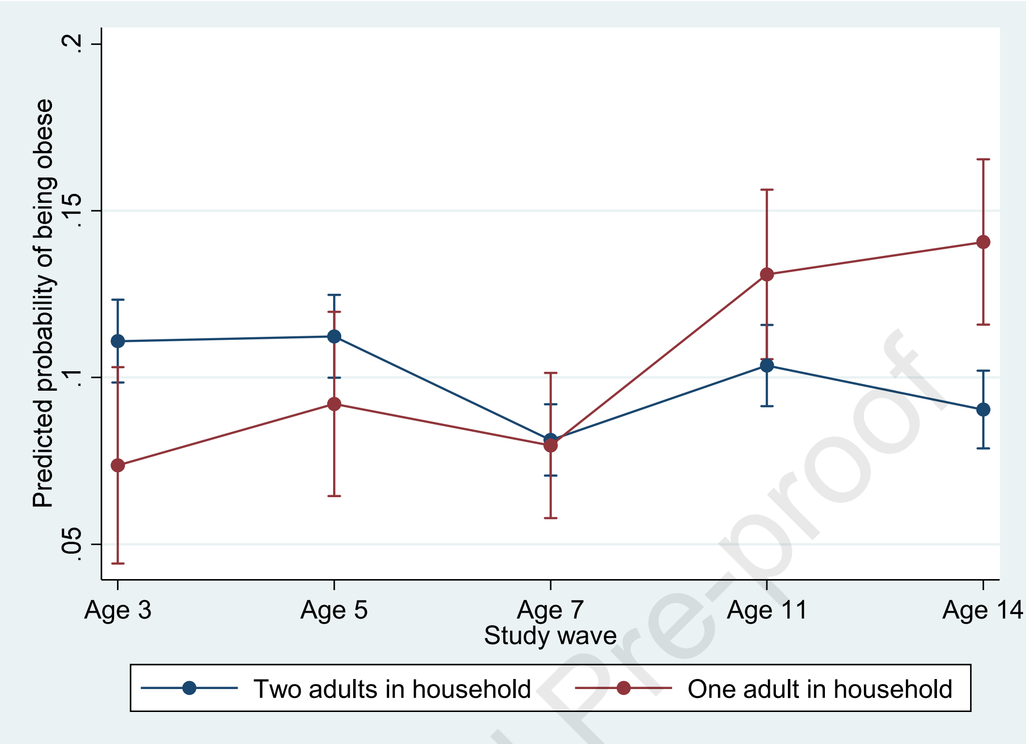
*Overweight or obese is defined as 85th percentile for BMI according to sex specific CDC growth charts

Figure 2A – Probability of obesity by age and family structure - Girls



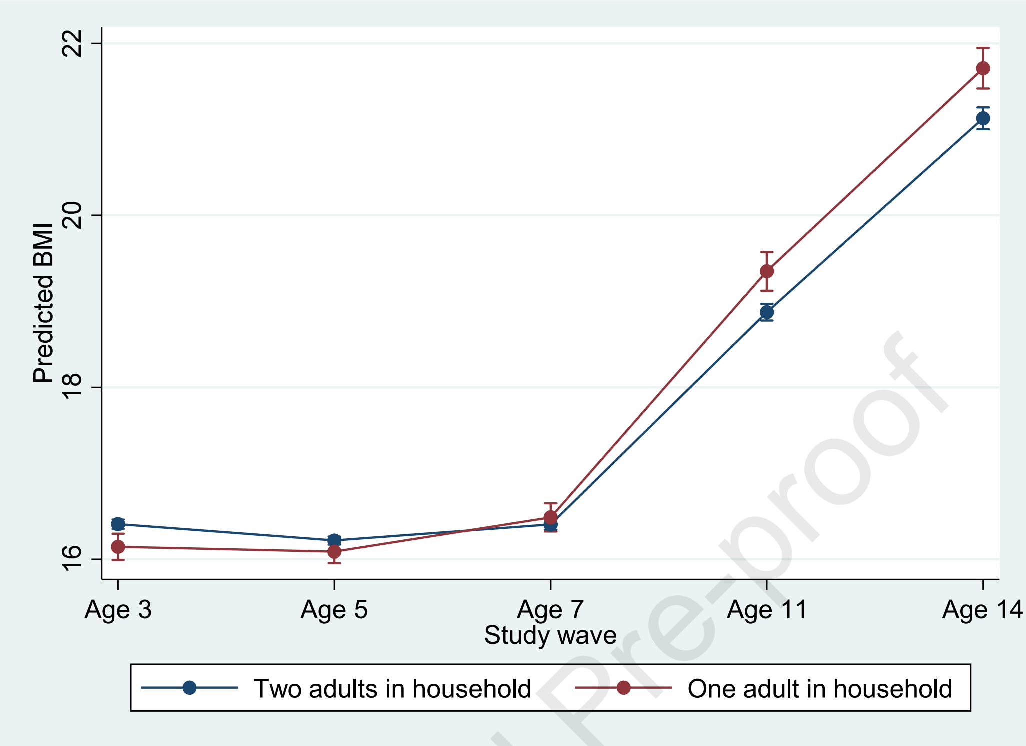
*Obesity is defined as 95th percentile for BMI according to sex specific CDC growth charts

Figure 2B – Probability of obesity by age and family structure - Boys



*Obesity is defined as 95th percentile for BMI according to sex specific CDC growth charts

Figure 3 – Predicted mean BMI by age and family structure



*BMI is defined as a continuous measure.