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Is earlier obesity associated with poorer executive functioning later in childhood? Findings from the Millennium Cohort Study

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Summary

Background: Children affected with overweight or obesity have been associated with having lower educational achievement compared to peers who are non-overweight/obese. One of the drivers of this association could be a link between obesity and poorer executive function. Evidence is limited to small, cross-sectional studies which lack adjustment for important common causes.

Objective: We investigate the association between weight status and executive function longitudinally in mid-childhood, accounting for potential common causes.

Methods: Linear regression analyses were conducted to examine associations between weight status between 5 and 7 years and executive functioning at 11 years in members of the Millennium Cohort Study (n = 7739), accounting for a wide range of potential common causes. Age- and sex-specific International Obesity Taskforce cut-points for body mass index (BMI) were used. Executive function, including decision-making, impulsivity and spatial working memory, was assessed using the Cambridge Neuropsychological Test Automated Battery.

Results: There were no unadjusted associations between weight status and decision-making or impulsivity. After adjustment for all potential common causes, there was a lack of consistent evidence to support an association between persistent obesity (including overweight) between 5 and 7 years and spatial working memory task at 11 years.

Conclusions: We found little evidence that poorer spatial working memory contributes to the association of children with obesity having lower educational achievement.

KEYWORDS

childhood, executive, function, obesity, overweight

1 | INTRODUCTION

Overweight (including obesity) has been linked to poorer school performance.[1,2] One proposed mechanism for this is that children affected with access weight develop poorer executive function.[3,4] Executive functions refer to related, but distinct, mental processes needed to store, hold and manipulate information, which are essential skills for educational achievement.[5-7] There are three core executive functions[5,8]: inhibition control (including impulsivity), working memory and cognitive flexibility. All three have been associated with academic achievement in mid-childhood.[9,10] Following its emergence during the first few years of life, executive function continues to develop during childhood and adolescence.[11]

There are several plausible biological mechanisms which may produce an association between overweight and impaired executive functioning.[3] For example, obesity-associated biomarkers, inflammatory processes and hormones have been shown to lead to poorer working memory and cognitive flexibility.[12,13] In addition, human and rodent studies have found chronic exposure to sugar- and/or fat-rich foods is associated with long-term alterations in brain reward regions, learning, memory and motivation.[14-16]

However, it is also likely that the perceived association between childhood overweight and lower executive functioning is due to the 'common cause' hypothesis, which postulates that associations are due to 'third variables' which affect multiple areas of development in childhood and adolescence.[17] Confounding is a bias due to the existence of a common cause of exposure and outcome which occurs temporally prior to both exposure and outcome.[18] Both obesity and poor educational achievement are socially patterned, with disadvantaged socioeconomic groups more likely to be at risk of overweight or obesity[19-21] and low performance in tests of executive function.[2,22,23] Important common causes to account for include socioeconomic measures such as family income[21] and maternal education,[24] and child and maternal characteristics[21] that are associated with both childhood overweight and cognitive development, such as breastfeeding duration,[25,26] maternal smoking during pregnancy[27,28] and birthweight.[29,30]

Studies which have tested associations between overweight and executive function have generally been limited to cross-sectional design, small sample size, lacked control for socioeconomic circumstances, an important confounder, socially patterned health-related behaviours and have not assessed repeat measures of weight status during childhood.[2,9,31,32] There is a need for longitudinal evidence to better understand the relationship between weight status and executive functioning.

The primary aim of this study was to test whether overweight or obesity was associated with subsequent impaired executive functioning during mid-childhood. We use nationally representative UK data, the Millennium Cohort Study (MCS), which has rich data in socio-demographic factors and executive function and longitudinal data on weight status. Executive function is commonly measured during childhood and adolescence[11]; there was a complete battery of executive function tests measured at 11 years in MCS, and we examined weight status in the earlier data collection sweep to investigate temporality. To investigate whether the common cause hypothesis is the underlying mechanism, we tested whether the association between obesity and executive functioning was due to confounding by common cause variables. To understand the relationship between longitudinal weight status and executive functioning, we also examine associations for longitudinal characterizations of weight status using the data collection sweeps at 5 and 7 years.

2 | SUBJECTS AND METHODS

2.1 | Data

We used the MCS, a longitudinal study of children born in the UK between September 2000 and January 2002. Survey interviews were carried out in the home with the main respondent (almost always the mother). We used data from sweeps when children were 9 months, 5, 7 and 11 years old.

2.2 | Inclusion and exclusion criteria

There were 18 296 single born children who participated in the first MCS data collection sweep at age 9 months. Attrition is a problem common to all cohort studies, and by age of 11 years, the number of families who had participated in all waves required for this analysis (9 months, 5 and 7 years) up to age 11 had declined to 11 064. We excluded 504 children based on potential differences in BMI and/or executive function due to medical conditions (children with: autism spectrum disorders; attention-deficit hyperactivity disorder; a Statement of Educational Needs or a visual or hearing impairment). After excluding those with missing data on executive functioning measures and weight status, resulting in samples of 9059 children for analysis between 7 and 11 years, and 8828 children for analysis between 5, 7 and 11 years. In multivariable analyses, full data were required on covariates, reducing analytic samples to 7739 for analysis between 7 and 11 years and 7325 for analysis between 5, 7 and 11 years.

2.3 | Exposure, outcomes and covariates

2.3.1 | Weight status at ages 5 and 7 years

To calculate body mass index (BMI), children's heights and weights without shoes using Tanita scales were measured during home visits. Sex- and age-specific cut points as defined by the International Obesity Taskforce[33] categorized children's BMI as non-overweight/obese, overweight or obesity. Due to small cell sizes, overweight and obesity were combined for longitudinal weight status between 5 and 7 years, resulting in a four category variables: stable non-overweight/obese (not overweight/obese at 5 or 7); grew out of overweight or obesity (has overweight or obesity at 5 but non-overweight/obese at 7); developed obesity (non-obese at 5 but has obesity at 7) and stable overweight or obesity (has overweight or obesity at 5 and 7).

2.3.2 | Executive functioning at age 11 years

At 11 years, children's decision-making, impulsivity and spatial-working memory were measured using the Cambridge Neuropsychological Test Automated Battery (CANTAB).[34] The CANTAB battery has been compared against more traditional psychological assessment in order to assess validity and suitability in various populations and across age ranges in childhood (4–15 years).[35-37]

Spatial working memory

The Cambridge Spatial Working Memory Task (SWM) is a searching task which tests children's ability to retain spatial information and to manipulate remembered items in working memory, with scores for search strategy, the time taken and the number of errors the child makes.[38] Higher search strategy scores, time taken and greater errors indicate poorer searching efficiency.

Decision-making and impulsivity

The Cambridge Gambling Task (CGT) assesses (1) decision-making, with scores for the quality of decision-making and overall proportional bet, and (2) impulsivity, with scores for deliberation time, and delay aversion. Higher decision-making scores equate to a higher proportion of correct answers. Children who bet high proportions are 'high risk takers' and those who only bet a little are 'low risk takers.' Deliberation time indicates the child's latencies in making a choice, in this instance, shorter deliberation time is indicative of greater impulsivity. If participants are unwilling or unable to wait to make a decision, then they will be more likely to bet larger amounts when the possible bets are displayed in descending rather than ascending order. The delay aversion outcome measures this behaviour, with higher scores indicative of greater impulsivity.

2.4 | Explanatory variables

Potential common causes of both low executive function score and obesity identified from relevant literature included: breastfeeding status (<3 months vs. >3 months)[25,39]; birthweight; maternal pre-pregnancy BMI[40] and maternal smoking status[27,28] during pregnancy all collected at 9 months; at 7 years cohort member age (within sweep), sex, behavioural problems measured using total socio-emotional difficulties score from the Strengths and Difficulties Questionnaire[41-43] and socioeconomic position measured by family income quintile and maternal education[19,20,22] and at 11 years whether the child had a long-term health condition and whether English was the primary language spoken in the home.[44,45] More information on these variables can be found in Table 1.

2.5 | Statistical analyses

Linear regression analyses were used to test if weight status at 7 years (overweight or obesity compared to non-overweight/obese) was associated with scores for executive function at 11 years. Then, whether longitudinal weight status between 5 and 7 years was associated with executive function at 11 years.

As differences in associations between weight status and cognitive ability have been found by sex in a previous analysis using the MCS,[46] the potential interaction between sex and weight status for different executive function outcomes was formally tested using a likelihood ratio test. There was no evidence for interaction effects; therefore, analysis was combined for males and females.

Stata 15 was employed for all analyses, with all models weighted for clustered sampling and non-response.[47] To account for multiple testing of difference executive function scores, we used a Bonferroni Correction and considered significance at the 0.001 level.[48]

2.6 | Sensitivity analyses

In addition to standard anthropometry using heights and weights, we assessed total body fat at age 11 using a Tanita scale which measured four-limb bioimpedance and estimated body fat using proprietary equations. For analysis, body fat percentage was categorized at the 85th percentile and the 95th percentile of the sample for overweight and obesity, respectively. As the eligible sample was reduced due to item missing data (n = 3053) and exclusions on medical conditions (n = 504), analysis was conducted to examine if the distribution of characteristics in the omitted samples compared to the analysis sample (n = 7739 for analysis between 7 and 11 years; 70% of those eligible).

3 | RESULTS

Around 80% of the sample were non-overweight/obese at 7 years, with 15% overweight and 5% having obesity. Table 1 provides the sample characteristics by weight status at 7 years.

3.1 | Associations of weight status at 7 years with executive functioning at 11

Based on the stringent criteria applied for significance following the Bonferroni correction for multiple testing (p < 0.001), the analysis showed that overweight and obesity were not associated with any of the scores for decision-making or impulsivity (see Supplementary Material).

For scores in the spatial working memory task, children affected by overweight or obesity at age 7 years had higher search strategy scores and errors, indicating a less optimal use of search strategy at 11 years compared to children who were non-overweight/obese (see Table 2). With adjustment for potential common causes, the associations were fully attenuated.

3.2 | Weight status between 5 and 7 years and executive functioning at 11 years

When looking at weight status longitudinally, 78% of children were classified as being stable non-overweight/obese at both 5–7 years (reference category); 7% grew out of overweight or obesity; 2% developed obesity from non-overweight/obese or overweight and 13% were stably affected by overweight or obesity overtime (see Table 3).

Compared to children who were always non-overweight/obese, there were no associations with spatial working memory at 11 years for those who grew out of having overweight/obesity or developed obesity between 5 and 7 years. Children who were persistently affected with overweight or obesity between 5 and 7 years reported more errors and higher search strategy scores in the spatial memory task at age 11 years than those who remained non-overweight/obese

TABLE 1 Characteristics of participants categorized by weight status at 7 years old (n = 7739)

Sample Characteristics	Non-overweight/obese (n = 6187) Mean (SD)	Overweight (n = 1125) Mean (SD)	Obese (n = 427) Mean (SD)
Age in years	7.22 (0.24)	7.24 (0.25)	7.24 (0.23)
Birth weight (in kilograms)	3.39 (0.55)	3.48 (0.54)	3.44 (0.55)
SDQ score	7.08 (4.89)	6.96 (5.08)	7.73 (5.35)
Maternal pre-pregnancy bodymass index	24.24 (4.37)	26.45 (5.06)	28.05 (5.83)
Cantab Memory task scores			
Strategy	34.16 (5.10)	34.65 (4.79)	35.12 (4.67)
Search time	28 618.99 (6118.34)	28 780.70 (5901.86)	28 922.83 (5503.82)
Errors	34.05 (17.96)	35.80 (17.51)	36.44 (17.42)
Cantab decision-making and impulsivity task scores			
Decision making	0.81 (0.17)	0.80 (0.16)	0.80 (0.16)
Proportional bet	0.48 (0.15)	0.48 (0.16)	0.48 (0.16)
Deliberation time	3301.28 (1235.01)	3365.06 (1376.65)	3283.82 (1186.08)
Delay aversion	0.28 (0.24)	0.28 (0.26)	0.29 (0.25)
Proportion of sample	**Percentage**	**Percentage**	**Percentage**
Male	52.4	44.2	43.2
Female	47.6	55.8	56.8
Breastfeeding status			
<3 months	72.5	77.3	81.5
≥3 months	27.5	22.7	18.5
Maternal smoking status			
Non-smoker	66.1	64.0	58.2
Smoker	34.0	36.0	41.8
Puberty status			
Not begun	93.1	87.3	80.8
Has begun	6.9	12.7	19.3
Long-term condition			
No	88.4	87.8	86.3
Yes	11.6	12.2	13.7
Language spoken in the household			
English	99.0	99.1	97.9
Other	1.0	0.9	2.1
Income quintile			
Top	16.1	14.0	19.3
Fourth	17.2	19.0	24.0
Third	21.0	24.0	21.5
Second	22.4	24.0	18.9
Bottom	23.4	19.2	16.4
Maternal education			
NVQ Level 5	13.3	10.8	8.1
NVQ Level 4	38.2	36.6	32.0
NVQ Level 3	16.2	18.1	16.8
NVQ Level 2	22.6	23.8	27.5
NVQ Level 1	5.0	5.3	6.3
None of these	5.2	5.4	9.3

TABLE 2 Associations between weight status at 7 and spatial working memory at 11 years (n = 7739)

	Unadjusted				Fully adjusted[a]			
	B (s.e.)	95% CI	β	p-value	B (s.e.)	95% CI	β	p-value
Strategy								
Overweight	0.49 (0.18)	0.13 to 0.84	0.033	0.007	0.34 (0.17)	0.01 to 0.68	0.022	0.047
Obese	0.95 (0.27)	0.42 to 1.49	0.038	0.001	0.50 (0.29)	−0.06 to 1.06	0.018	0.106
R2 change	0.003				0.055			
Search time								
Overweight	161.7 (206.9)	−245.2 to 568.6	0.004	0.435	109.5 (205.4)	−294.3 to 513.4	0.001	0.594
Obese	303.8 (371.2)	−426.1 to 1033.8	0.004	0.414	21.5 (376.8)	−719.4 to 762.4	−0.007	0.955
R2 change	0.000				0.024			
Errors								
Overweight	0.09 (0.02)	0.04 to 0.14	0.034	<0.001	0.07 (0.02)	0.02 to 0.12	0.023	0.003
Obese	0.13 (0.03)	0.06 to 0.20	0.037	<0.001	0.06 (0.03)	−0.01 to 0.13	0.014	0.102
R2 change	0.003				0.070			

[a]Fully adjusted models include breastfeeding; birthweight; child socioemotional difficulties, age, sex and longstanding condition; language spoken; income quintile and maternal smoking during pregnancy, pre-pregnancy BMI and education.

TABLE 3 Longitudinal weight status between 5 and 7 years

	Percentage
Stable non-overweight/obese	78.3
Grew out of overweight or obesity	7.4
Became obese	1.8
Stable overweight or obese	12.5

throughout. The association between making errors and having stable overweight/obesity overtime remained after adjusting for potential common causes. However, the association for higher search strategy scores was fully attenuated by potential common causes (Table 4).

3.3 | Sensitivity analysis: Associations for body fat at 7 years and executive function at 11 years

Results for body fat as a marker of adiposity replicated those for BMI. Higher body fat at 7 years was associated with poorer search strategy and higher errors on the spatial working memory task at 11 years. After adjustment for potential common causes, both associations were fully attenuated. Higher body fat was not associated with any of the scores for decision-making or impulsivity.

The analysis showed that those with missing items were more likely to be from low socioeconomic circumstances or to have obesity (7.7% of those omitted had obesity at 11 years vs. 5.9% in the analytical sample, Table A2). Those who were excluded due to medical conditions were more likely to have socioemotional difficulties, poorer spatial working memory and decision-making and greater impulsivity. Those who were excluded due to medical conditions were also more likely to be from low socioeconomic circumstances, to have obesity (excluded 8.7% vs. analytical sample 5.9% at 11 years) and much more likely to be boys (excluded 72.5% vs. analytical sample 50.6%, Table A3).

4 | DISCUSSION

4.1 | Main findings and study implications

Using longitudinal data from a large and representative UK cohort, we demonstrated no associations between weight status and measures of decision-making or impulsivity and a weak association between having overweight or obesity at 7 years and spatial working memory at 11 years. This was attenuated after accounting for a range of potential common causes, including child and maternal characteristics and family socioeconomic position. Results indicate that 'common cause' factors do offer an explanation for the association between weight status and executive function. The only longitudinal weight status group associated with poorer spatial working memory was children who had overweight or obesity persistently overtime. However, of those associations, there were discrepancies across the different measures of spatial working memory, which suggests an unconvincing association between longitudinal weight status and spatial working memory.

4.2 | Comparison with existing literature

The evidence for childhood obesity impairing executive function is inconsistent, with some studies finding an association with markers of executive function and others findings no associations.[49-52] However, there are limitations to these studies, including small samples, lack of adjustment for confounding variables and cross-sectional design. Very few studies have examined how weight status measured at multiple

TABLE 4 Associations between change in weight status between 5 and 7 years and spatial working memory at 11 years (*n* = 7325)

	Unadjusted				Fully adjusted[a]			
	B (s.e.)	95% CI	*β*	*p*-value	B (s.e.)	95% CI	*β*	*p*-value
Strategy								
Grew out of overweight/ obesity	0.30 (0.25)	−0.20 to 0.80	0.018	0.235	0.28 (0.25)	−0.22 to 0.77	0.015	0.273
Developed obesity	0.76 (0.47)	−0.17 to 1.69	0.020	0.107	0.54 (0.50)	−0.44 to 1.53	0.011	0.279
Persistently overweight/ obesity	0.52 (0.18)	0.16 to 0.89	0.027	0.005	0.28 (0.19)	−0.09 to 0.66	0.012	0.133
R2 change	0.002				0.056			
Search time								
Grew out of overweight/ obesity	111.4 (298.4)	−475.3 to 699.0	0.012	0.709	164.3 (298.2)	−422.0 to 750.6	−0.026	0.582
Developed obesity	320.1 (507.0)	−676.6 to 1316.8	0.002	0.528	205.5 (518.2)	−813.2 to 1224.4	−0.002	0.692
Persistently overweight/ obesity	309.2 (252.0)	−186.2 to 804.6	0.005	0.221	216.6 (255.5)	−285.8 to 719.0	−0.000	0.397
R2 change	0.000				0.024			
Errors								
Grew out of overweight/ obesity	0.03 (0.04)	−0.04 to 0.10	0.009	0.454	0.03 (0.04)	−0.05 to 0.10	0.007	0.432
Developed obesity	0.10 (0.06)	−0.02 to 0.21	0.019	0.097	0.06 (0.06)	−0.06 to 0.18	0.008	0.281
Persistently overweight/ obesity	0.12 (0.02)	0.07 to 0.17	0.038	<0.001	0.09 (0.02)	0.04 to 0.14	0.024	<0.001
R2 change	0.003				0.071			

[a]Fully adjusted models include breastfeeding; birthweight; child socioemotional difficulties, age, sex and longstanding condition; language spoken; income quintile and maternal smoking during pregnancy, pre-pregnancy BMI and education.

time-points is linked to subsequent executive functioning or educational achievement. One study showed that adolescent girls who had overweight or obesity persistently from 11 to 16 years had lower educational achievement at 16 years than girls who were consistently non-overweight/obese, after adjustment for confounding factors.[1] The limited set of confounders used did not account for other potential common causes that we did adjust for, such as breastfeeding; whether mother had a long-term illness; maternal BMI; language in the home and income.

4.3 | Strengths and limitations

This study is novel in providing longitudinal evidence from a large, UK cohort on the relationship between weight status and executive function. However, like with any longitudinal study, MCS is subject to attrition and missing data, which may lead to bias due to non-participation and missing data. The analysis showed that those with item missingness were more likely to suffer with obesity which may mean that the association between weight status and executive function is underestimated. We used response weights to account for attrition up to the 11-year survey.[47] While we used weights to account for attrition, item missingness that resulted from our inclusion of a large number of potential common causes reduced our sample size. However, our study is substantially larger than those existing in the literature.[49-52]

A particular strength of our study is the rich data which allowed us to adjust for a wide range of potential confounding common causes. We used objective measures of weight status and executive function, with a range of scores for decision-making, impulsivity and spatial working memory. However, as tests were conducted in the participant homes, it is possible interview conditions may have impacted data quality or test performance introducing potential measurement error. We were able to examine the impact of stability and change in weight status recorded at two times points. Weight status was assessed using age- and sex-specific BMI cut points. While BMI is considered to be an acceptable but imperfect measure of obesity, we repeated analysis using body fat and results replicated the pattern of associations reported in the main analyses.

5 | CONCLUSION

We found that weight status was unrelated to decision-making or impulsivity, and while weight status was associated with spatial working memory, this relationship was attenuated after accounting for 'common causes.' We show that it is unlikely that poorer executive function contributes to the association between obesity and lower educational achievement found by previous studies[31]; previous findings are likely to be due to limitations in study design and confounding. Our findings suggest that the use of interventions focussing on childhood overweight and obesity may not tackle poor educational achievement. Future research should explore how longitudinal weight status is associated with trajectories of educational achievement from childhood to adolescence.

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CONFLICT OF INTEREST

The authors declare that they have no conflict of interest.

AUTHOR CONTRIBUTIONS

Prof. Russell Viner conceived the project. Dr Hanna-Marie Creese conducted the data analysis and wrote the manuscript with support from Dr Steven Hope, Prof. Deborah Christie, Dr Anne-Lise Goddings and Prof. Russell Viner. Prof. Russell Viner and Dr Steven Hope supervised the project.

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SUPPORTING INFORMATION

Additional supporting information may be found online in the Supporting Information section at the end of this article.

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APPENDIX

TABLE A1 Associations between body fat at 7 years and spatial working memory at 11 years (n=7 633)

	Unadjusted				Fully adjusted[a]			
	B (s.e.)	95% CI	β	*p*-value	B (s.e.)	95% CI	β	*p*-value
Strategy								
Overweight	0.19 (0.23)	−0.27 to 0.65	0.018	0.417	−0.02 (0.23)	−0.48 to 0.43	0.004	0.919
Obese	0.92 (0.28)	0.36 to 1.48	0.039	0.001	0.33 (0.31)	−0.28 to 0.95	0.015	0.289
R_2 change	0.002				0.055			
Search time								
Overweight	173.0 (242.6)	−304.0 to 649.9	0.002	0.476	85.1 (243.0)	−392.7 to 562.9	−0.004	0.726
Obese	132.5 (390.6)	−635.5 to 900.5	−0.001	0.735	−260.1 (398.9)	−1044.6 to 524.3	−0.014	0.515
R_2 change	0.000				0.023			
Errors								
Overweight	0.05 (0.03)	−0.01 to 0.10	0.013	0.100	0.03 (0.03)	−0.02 to 0.09	0.005	0.270
Obese	0.13 (0.04)	0.05 to 0.20	0.037	0.001	0.05 (0.04)	−0.03 to 0.13	0.013	0.206
R_2 change	0.002				0.071			

[a]Fully adjusted models include breastfeeding; birthweight; child socioemotional difficulties, age, sex and longstanding condition; language spoken; income quintile and maternal smoking during pregnancy, pre-pregnancy BMI and education.

TABLE A2 Characteristics in missing and analytical samples

	Missing sample[a] Mean (SD)	Analytical sample Mean (SD)
Age in years	7.24 (0.25)	7.22 (0.24)
Birth weight (in kilograms)	3.28 (0.63)	3.42 (0.55)
SDQ score	7.79 (5.43)	7.04 (4.92)
Maternal pre-pregnancy body mass index	24.13 (4.80)	24.75 (4.68)
Cantab memory task scores		
Strategy	34.65 (5.14)	34.25 (5.05)
Search time	29035.12 (6520.17)	28637.68 (6051.22)
Errors	35.47 (20.41)	34.35 (17.88)
Cantab decision-making and impulsivity task scores		
Decision-making	0.80 (0.18)	0.81 (0.17)
Proportional bet	0.50 (0.16)	0.48 (0.16)
Deliberation time	3334.56 (1491.87)	3304.93 (1258.59)
Delay aversion	0.29 (0.25)	0.28 (0.24)
Proportion of sample	**Percentage**	**Percentage**
Male	47.8	50.6
Female	52.2	49.4
Breastfeeding status		
<3 months	76.2	73.5
≥ 3 months	23.8	26.5
Maternal smoking status		
Non-smoker	65.5	65.6
Smoker	34.5	34.4
Puberty status		
Not begun	90.5	91.7
Has begun	9.5	8.3
Long-term condition		
No	88.0	88.3
Yes	12.0	11.7
Language spoken in the household		
English	92.1	99.1
Other	7.9	0.9
Income quintile		
Top	15.3	22.5
Fourth	16.6	22.8
Third	17.6	21.3
Second	22.7	17.8
Bottom	27.9	15.6
Maternal education		
NVQ Level 5	10.3	12.8
NVQ Level 4	31.4	38.1
NVQ Level 3	14.5	16.4
NVQ Level 2	24.2	22.9
NVQ Level 1	6.1	4.6

TABLE A2 (Continued)

Proportion of sample	Percentage	Percentage
None of these	13.5	5.1
Weight status at 7 years		
Healthy weight	77.3	80.2
Overweight	15.6	14.6
Obese	7.2	5.2
Weight status at 11 years		
Non-overweight/obese	70.7	72.1
Overweight	21.6	22.1
Obese	7.7	5.9

[a]Omitted samples were those with item missingness (n = 3 053).

TABLE A3 Characteristics those excluded versus analytical sample

	Excluded on medical conditions[a] Mean (SD)	Analytical sample Mean (SD)
Age in years	7.22 (0.25)	7.22 (0.24)
Birth weight (in kilograms)	3.23 (0.71)	3.42 (0.55)
SDQ score	13.58 (7.50)	7.04 (4.92)
Maternal pre-pregnancy body mass index	25.03 (5.72)	24.75 (4.68)
Cantab Memory task scores		
Strategy	35.74 (4.99)	34.25 (5.05)
Search time	29826.92 (7495.40)	28637.68 (6051.22)
Errors	41.52 (19.21)	34.35 (17.88)
Cantab decision-making and impulsivity task scores		
Decision-making	0.77 (0.19)	0.81 (0.17)
Proportional bet	0.53 (0.17)	0.48 (0.16)
Deliberation time	3441.47 (1475.04)	3304.93 (1258.59)
Delay aversion	0.32 (0.28)	0.28 (0.24)
Proportion of sample	**Percentage**	**Percentage**
Male	72.5	50.6
Female	27.5	49.4
Breastfeeding status		
<3 months	80.1	73.5
≥3 months	20.0	26.5
Maternal smoking status		
Non-smoker	50.9	65.6
Smoker	49.1	34.4
Puberty status		
Not begun	87.7	91.7
Has begun	12.3	8.3
Long-term condition		
No	45.4	88.3
Yes	54.6	11.7
Language spoken in the household		
English	98.6	99.1
Other	1.4	0.9
Income quintile		
Top	14.7	22.5
Fourth	15.1	22.8
Third	18.5	21.3
Second	28.9	17.8
Bottom	22.9	15.6
Maternal education		
NVQ Level 5	7.8	12.8
NVQ Level 4	28.5	38.1
NVQ Level 3	17.0	16.4
NVQ Level 2	28.0	22.9
NVQ Level 1	7.6	4.6
None of these	11.1	5.1
Weight status at 7 years		
Healthy weight	80.4	80.2
Overweight	14.9	14.6
Obese	4.7	5.2
Weight status at 11 years		
Non-overweight/obese	70.7	72.1
Overweight	20.6	22.1
Obese	8.7	5.9

[a]Omitted samples were those with item missingness (n = 504).