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Maternal pre-pregnancy weight and externalising behaviour problems in preschool children: a UK-based twin study

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ABSTRACT

Objective: To estimate the heritability of child behaviour problems and investigate the association between maternal pre-pregnancy overweight and child behaviour problems in a genetically sensitive design.

Design: Observational cross-sectional study.

Setting: The Twins and Multiple Births Association Heritability Study (TAMBAHS) is an online UK-wide volunteer-based study investigating the development of twins from birth until 5 years of age.

Participants: A total of 443 (16% of the initial registered members) mothers answered questions on pre-pregnancy weight and their twins' internalising and externalising problems using the Child Behavior Checklist and correcting for important covariates including gestational age, twins' birth weight, age and sex, mother's educational level and smoking (before, during and after pregnancy).

Primary outcomes: The heritability of behaviour problems and their association with maternal pre-pregnancy weight.

Results: The genetic analysis suggested that genetic and common environmental factors account for most of the variation in externalising disorders (an ACE model was the most parsimonious with genetic factors (A) explaining 46% (95% CI 33% to 60%) of the variance, common environment (C) explaining 42% (95% CI 27% to 54%) and non-shared environmental factors (E) explaining 13% (95% CI 10% to 16%) of the variance. For internalising problems, a CE model was the most parsimonious model with the common environment explaining 51% (95% CI 44% to 58%) of the variance and non-shared environment explaining 49% (95% CI 42% to 56%) of the variance. Moreover, the regression analysis results suggested that children of overweight mothers showed a trend (OR=1.10, 95% CI 0.58% to 2.06) towards being more aggressive and exhibit externalising behaviours compared to children of normal weight mothers.

Conclusions: Maternal pre-pregnancy weight may play a role in children's aggressive behaviour.

Strengths and limitations of this study

- In the twin genetic design, maternal pre-pregnancy weight was included in the genetic model, in order to investigate the influence of the intrauterine environment on children's behaviour problems.
- Cut-off scores applied to the child behaviour scale enabled us to clinically assess the observed association.
- A number of covariates of post-natal influence were adjusted such as maternal educational level and smoking after pregnancy.
- Information on other parental characteristics such as maternal psychopathology and personality was not available.

INTRODUCTION

The preschool years of a child are generally considered important, since during this period many clinically significant problem behaviours may occur.[1 2] Externalising (eg, aggression, conduct problems, hyperactivity) and internalising problems (eg, emotional problems, anxiety, depression) can often be identified first in early childhood, which then shows considerable stability across older ages.[3–5] Toddlers with problem behaviours are at risk for a variety of adverse developmental outcomes including conflictual relationships with other peers or family, poor academic performance, delinquency and later maladjustment.[6–8] Given the life course implications of early onset symptomatology, it is essential to understand the underlying aetiology of problem behaviours in preschool children.

Twin studies investigating externalising and internalising problems have revealed substantial genetic influence, with heritabilities ranging from 40–70% in these age groups.[9–11]

The influence of the shared environment is, however, more modest, explaining up to 40% of the variance in behaviour problems.[9–12]

Since the 1990s, there has been an increased interest in the research of the effect of the intrauterine environmental and maternal well-being during pregnancy on later child development. Epidemiological studies suggest strong links between measures of the quality of the prenatal environment and the risk of cardiovascular and metabolic diseases,[13 14] and more research evidence suggests that low birth weight can be linked with impaired cognitive development and behavioural disorders, especially hyperactivity/inattention,[15 16] while several studies have examined the association between low birth weight and internalising and externalising behaviours.[17–19]

Research findings[20–23] suggest that another intrauterine factor, maternal pre-pregnancy obesity/weight, is associated with reduced cognitive abilities, symptoms of inattention and negative emotionality in school aged children. These findings are of clinical importance, especially in the light of the increasing prevalence of obese women entering pregnancy.[24] Pregnancy comes with main changes in the maternal body and a high pre-pregnancy weight is more likely to make these adaptations even more difficult, affecting child development. With the exception of one recent study[25] suggesting that fetal exposure to increased maternal body mass index (BMI) is associated with elevated levels of externalising problems in 2-year-old children, not much is known about the influence of maternal pre-pregnancy weight on externalising and internalising behaviour problems in young age groups after that age and before the age of 5. By implementing a twin research design including maternal pre-pregnancy weight in the genetic model, we set out to investigate the role of the intrauterine, common and genetic environment on children's behaviour problems.

METHODS

The Twins and Multiple Births Association Heritability Study (TAMBAHS) is a volunteer-based study, investigating the development of twins from birth until 5 years of age. An invitation letter to this study was sent to all present (n=2712), at the moment of the study, twin family registered members of the Twins and Multiple Births Association (TAMBA) beginning of July 2008. TAMBA is an association, which registers and provides support to multiple birth families across the UK. Mothers of twins aged between 18 months and 5 years at the time of the survey were identified. In the time period between July 2008 and May 2010, 443 (16%) mothers completed the study's online questionnaire on their twins' emotional and behavioural development. The participants show a similar and representative geographical spread of the twin families across the UK. All mothers consented before participating.

Zygosity determination

For the determination of the twins' zygosity, the previously adapted version of Goldsmith's zygosity questionnaire was used.[26] This questionnaire method of assigning zygosity has been validated against determination by identity of polymorphic DNA markers and has reached accuracy in verifying zygosity in 95% of the cases.[27]

Twin sample

In total, 443 twin pairs were included in the analyses; 186 monozygotic (MZ) male twins, 138 MZ female twins, 144 dizygotic (DZ) male twins, 158 DZ female twins and 260 opposite-sex twins.

MATERIALS

Maternal pre-pregnancy weight and covariates

The primary exposure variable was maternal pre-pregnancy BMI. Pre-pregnancy BMI was based on the maternal self-report of weight and height and was calculated by dividing their weight in kilograms by their self-report height in metres squared ((kg)/height (m^2)). Pre-pregnancy BMI was analysed both as a continuous and as a categorical variable and was classified according to the WHO standard guidelines as: underweight (<18.5 kg), normal weight (18.5–24.99 kg), overweight/obese (≥25 kg). Overweight and obese mothers were combined in one category due to the limited number of obese mothers.

Gestational age (measured in completed weeks of gestation), educational level and smoking (before, during and after pregnancy) were noted for mothers; age, sex and birth weight were noted for all twins.

The Child Behavior Checklist (CBCL/1½y-5y)

The Child Behavior Checklist for toddlers (CBCL/1½-5)[28] is used to obtain standardised parent reports of children's problem behaviours. It contains 99 problem items, split into 7 subcategories: emotionally reactive, anxious/depressed, somatic symptoms, withdrawn, sleep problems, attention problems and aggressive behaviour originally derived by factor analyses.[28] The broadband scale 'Internalizing' is the sum score of items in the first four syndrome scales, whereas 'Externalizing' is the sum score of attention problems and aggressive behaviour. 'Total problems' is the sum score of all ninety-nine problem items. Each item is scored 0=not true, 1=somewhat or sometimes true, and 2=very true or often true, based on the preceding 2 months. Good reliability and validity criteria have been reported for this checklist.[28] To identify children who may be above the normal range for the syndrome scales, children were categorised as being in the normal range when their T scores were below 65 (or the 93rd centile) and as being in the borderline/clinical range when their T scores ≥65 (or the 97th centile).[28] For internalising, externalising and total problem broadband scales, the cut-off point used for the normal range was a T score <60, and borderline/clinical ≥60. The selection of lower cut-off scores for the

broadband scales was based on the notion that these scales encompass more numerous and diverse problems than any of the syndrome scales, with the latter comprising smaller, more homogeneous sets of problems. Therefore, higher scores are needed for the syndrome scales in order to conclude that a behaviour is clinically deviant (ref. 28, p.1392).

Statistical analysis

Correlations

Intrapair twin correlations were calculated by using Pearson's (r) and Spearman's rho coefficient statistics as appropriate to explore the genetic and environmental influences.

Heritability analysis

Univariate genetic models were fit to the data in order to estimate the heritability of the problem scales using a maximum likelihood approach implemented in Mx.[29] The classical twin study design relies on studying twins raised in the same family environments. MZ twins share all of their genes, while DZ twins share only about half of them. So if a researcher compares the similarity between sets of identical twins to the similarity between sets of fraternal twins for a particular trait, then any excess likeness between the identical twins should be due to genes (ie, the A component in a genetic model fitting) rather than environment. Researchers use this method, and variations on it, to estimate the heritability of traits: the proportion of variance in a population explained by genes. Modern twin studies also try to quantify the effect of a person's common environment (family, ie, the C component in a genetic model fitting) and non-shared environment (the individual events that shape a life, ie, the E component in a genetic model fitting) on a trait.

The estimates of the heritability are presented with 95% CIs and goodness of fit statistics for several models: a full ACE model, in which the phenotypic variance is explained by genetic (A) common environmental factors (C) and non-shared (E) environmental factors. Reduced models were estimated by removing one of the parameters at a time and rerunning the model. The goodness of fit of the reduced models was compared to the full model to assess whether they represented a better explanation of the data using the likelihood ratio χ^2 test and the Akaike Information Criterion (AIC). The models were assessed by examining the decrease in the fit of the model; if a parameter could be dropped without a significant decrease in fit, then on the grounds of parsimony the reduced model was accepted as the best fitting model. Models were fit both unadjusted and adjusted for pre-pregnancy maternal weight.

Regression analyses

Effects on a continuous scale

Standardised coefficients (βs) are presented, reflecting the change on the subcategories and the broadband problem scales by a change in the mother's weight, both expressed as SD change.

Effects on clinically important behaviour problems

In order to estimate the effect of the different categories of maternal weight on clinical problems, logistic regression models were fitted. In these models, the intercept of each twin pair was modelled as a function of the population intercept plus the individual contribution of the twin pair. Associations of maternal pre-pregnancy weight and the syndrome and broadband scales were explored unadjusted and adjusted for twins' sex, age, birth weight, gestational age, maternal smoking (before, during and after pregnancy) and maternal educational level. All analyses were performed in STATA V.11.[30]

RESULTS

Correlations

The means for the three broadband scales and the intrapair twin correlations for MZ and DZ twins were calculated (table 1). For externalising problems, the MZ correlation was r=0.89 and the DZ correlation was r=0.62. For internalising problems, the MZ and DZ correlations were r=0.81 and r=0.56, respectively. For Total problems, the MZ and DZ correlations were r=0.92 and r=0.75, respectively.

Heritability analyses

Variance estimates of ACE models and submodels with their 95% CI are presented in table 2, in which the most parsimonious model is highlighted. For externalising problems, an ACE model was the most parsimonious with genetic factors explaining 46% (95% CI 33% to 60%) of the variance, common environment explaining 42% (95% CI 27% to 54%) and non-shared environmental factors explaining 13% (95% CI 10% to 16%) of the variance. For internalising problems, a CE model was the most parsimonious with common environment explaining 51% (95% CI 44% to 58%) of the variance and non-shared environment explaining 49% (95% CI 42% to 56%) of the variance. For total problems, an ACE model was the most parsimonious with genetic factors explaining 26% (95% CI 13% to 39%) of the variance, common environment explaining 61% (95% CI 49% to 70%) of the variance and non-shared environment explaining 13% (95% CI 10% to 17%) of the variance.

After adjusting for maternal pre-pregnancy weight, the most parsimonious model for externalising problems was the ACE model with genetic factors explaining 50% (95% CI 36% to 68%), common environment explaining 38% (95% CI 20% to 52%) and non-shared environment explaining 12% (95% CI 0.09% to 16%) of the variance. For Internalising problems, the most parsimonious model was the AE model with genetic factors explaining 59% (95%: 50% to 67%) and non-shared environment explaining 41% (95% CI 33% to 50%) of

Table 1 Descriptive statistics of problem broadband scales for monozygotic and dizygotic twin pairs

	Monozygotic twin pairs							Dizygotic twin pairs						
	Twin 1			Twin 2				Twin 1			Twin 2			
Problem scales	N	M	SD	N	M	SD	r	N	M	SD	N	M	SD	r
Externalising (range 0–48)	167	12.88	7.72	167	12.83	7.51	0.89	269	12.79	6.61	269	12.66	6.95	0.62
Internalising (range 0–96)	167	5.94	4.55	167	9.13	6.98	0.81	269	5.49	4.11	269	8.24	5.89	0.56
Total problems (range 0–78)	167	31.58	16.24	167	34.66	18.90	0.92	269	30.45	14.18	269	33.06	16.10	0.75

M, mean; N, number of twins; r, within-twin correlations.

the variance. For Total problems, the most parsimonious model was the ACE model with genetic factors explaining 25% (95% CI 14% to 38%), common environment explaining 62% (95% CI 49% to 72%) and non-shared environment explaining 13% (95% CI 0.10% to 17%) of the variance.

The mean maternal BMI, gestational age, age and sex of the twins stratified by zygosity are presented in table 3. There were no differences in maternal weight between MZ and DZ twins. However, differences were observed between MZ and DZ twins with regard to their age and gestational age. Mothers of DZ twins had a higher gestational age (36.22, 95% CI 36.00% to 36.43, p<0.001) compared to mothers of MZ twins (35.24, 95% CI 35.12% to 36.43); the MZ twins were older (3.13 years old, 95% CI 3.03% to 3.23, p<0.001) compared to the DZ twins (2.91 years old, 95% CI 2.83% to 2.98). Correlations of maternal and twin covariates and problem broadband scales are also presented in the same table.

Regression analyses

In the adjusted model (table 4), there was a significant increase of 0.08 SDs in aggressive behaviour with every SD increase in maternal weight (p=0.02). The logistic regression analysis partly confirmed these findings. Overweight mothers were 1.10 times more likely to have a child with clinically aggressive behaviour when compared to normal weight mothers and 0.78 times more likely when compared to underweight mothers. The individual OR did not reach statistical significance; a trend, however, (OR=1.10, 95% CI 0.58% to 2.06%) is observed for children of overweight mothers to show clinically aggressive behaviour.

Similarly, there was an increase of 0.09 SDs (p=0.02) in externalising problems with every SD increase in maternal weight. An increase in the likelihood of externalising (OR=1.32, 95% CI 0.84% to 2.05) for children with overweight mothers compared to children of normal weight mothers was also apparent. No other statistically significant associations between maternal pre-pregnancy weight and behaviour problems were observed.

DISCUSSION

In this study, the effect of maternal pre-pregnancy weight on problem behaviours and the influence of genetic and environmental factors on these problems were investigated. The heritability analysis suggested that genetic and common environmental factors account for most of the variation in externalising disorders, while common and non-shared environment explain most of the variation in internalising disorders. After adjusting for mothers' weight, there was a non-significant decrease (of 2%) of variation in externalising problems that

Table 2 Univariate genetic model-fitting for the problem scales presenting full and nested models

	A (95% CI)	C (95% CI)	E (95% CI)	Δx^2	p Value	AIC
Externalising						
ACE*	0.46 (0.33 to 0.60)	0.42 (0.27 to 0.54)	0.13 (0.10 to 0.016)	–	–	–
AE	0.87 (0.84 to 0.90)	(0)	0.13 (0.10 to 0.16)	23.44	0.00	21.44
CE	(0)	0.74 (0.69 to 0.78)	0.26 (0.22 to 0.31)	49.69	0.00	47.69
Internalising						
ACE	0.23 (0.00 to 0.48)	0.35 (0.12 to 0.54)	0.43 (0.35 to 0.53)	–	–	–
AE	0.60 (0.52–0.67)	(0)	0.40 (0.33 to 0.48)	8.84	0.00	6.84
CE*	(0)	0.51 (0.44 to 0.58)	0.49 (0.42 to 0.56)	3.15	0.07	1.15
Total problems						
ACE*	0.26 (0.16 to 0.39)	0.61 (0.49 to 0.70)	0.13 (0.10 to 0.17)	–	–	–
AE	0.87 (0.84 to 0.90)	(0)	0.13 (0.10 to 0.16)	53.64	0.00	51.64
CE	(0)	0.79 (0.76 to 0.83)	0.21 (0.17 to 0.24)	22.17	0.00	20.17

*Best fitting model.
A, additive genetic; AIC, Akaike's Information Criterion; C, shared environment; E, non-shared environment; P, statistical significance <0.05; $\Delta\chi^2$, difference χ^2.

Table 3 Means, SDs and Pearson/Spearman correlations with three syndrome scales for each covariate by zygosity

Maternal Characteristics	MZ twins					DZ twins				
	Mean	SD	r_a	r_b	r_c	Mean	SD	r_a	r_b	r_c
BMI	24.51	4.32	0.07	−0.03	0.02	24.76	5.10	0.10*	−0.04	0.10*
Gestational age (weeks)	35.38	2.49	−0.04	−0.12*	−0.06	36.22	2.71	−0.04	−0.15***	−0.11**
Smoking (no/yes)†	n	%	ra	rb	rc	n	%	ra	rb	rc
Before	133/40	76.9/23.1	0.03	−0.02	0.05	255/54	82.5/17.5	0.07	0.04	0.06
During	156/5	96.9/3.1	0.07	0.00	0.06	280/10	96.6/3.4	0.10	−0.03	0.05
After	143/18	88.2/11.2	0.04	0.04	0.10	272/29	90.4/9.6	0.09	0.00	0.06
Educational level										
High school diploma or less	42	25.3				53	18.1			
College/professional education	23	13.9	−0.02	0.04	0.00	51	17.3	−0.00	0.03	−0.03
University	101	60.8				191	64.6			
Twin characteristics										
Age (years)	3.13	0.96	−0.23***	0.02	−0.15**	2.91	0.95	−0.07	0.11	−0.01
Sex	n	%	−0.05	0.18***	0.07	n	%	−0.08	−0.05	−0.09*
Male	206	57.22				164	26.28			
Female	154	42.78				174	27.88			
Opposite sex	–	–				286	45.84			

r_a Pearson/Spearman correlation with externalising scale; r_b Pearson/Spearman correlation with Internalising scale; r_c Pearson/Spearman correlation with Total Problems scale.
*<0.05; **<0.01; ***<0.001.
†Smoking refers to smoking before, during and after pregnancy.

could be explained by the common environment, suggesting that mothers' weight may play an important role in explaining externalising problems. In order to further explore the role of overweight in externalising problems, we repeated the analysis by comparing the twins of overweight mothers to the twins of normal weight mothers. The results suggested that 50% (CI's 29% to 67%) of the variation in externalising problem behaviour in twins of overweight mothers could be explained by common environment compared to 35% (CI's 10% to 53%) in twins of normal weight mothers.

In general, the results showed that children of overweight mothers showed a trend towards being more aggressive and exhibit externalising behaviours compared to children of normal weight mothers. Aggressive behaviour is considered an important aspect of externalising behaviour and has developmentally been linked to antisocial behaviour.[31 32] Studies with children focusing on aggression have shown that observed aggression and parental reports of externalising behaviours are relatively stable from toddlerhood to 5 years and beyond,[1 33] which may highlight the role of genetic influences. Consistent with this are the results of this study, which suggest that genetic factors can explain a large part of the variation in externalising and internalising behaviour problems.

The results from the logistic regression, however, do not suggest a strong association between maternal overweight and behaviour problems. Moreover, the significantly observed change in the standardised coefficients could not explain the distinction between normal range and borderline/clinical range. Therefore, children appeared to be more aggressive, but it is not clear whether this is of clinical significance.

Two studies by Rodriguez and colleagues[20 21] suggested a link between pre-pregnancy overweight and obesity and symptoms of ADHD in children. In both studies, teacher ratings of the offspring of obese mothers had increased levels of ADHD. However, in the latter study, parent reports of childhood ADHD symptoms and negative emotionality failed to support a link. While this could mean that the effect may be small, in the light of the low to moderate associations seen between parent and teacher ratings of children's ADHD, one cannot rule out a link. A recent study by Van Lieshout *et al*[34] showed that increased maternal pre-pregnancy BMI was associated with higher levels of externalising problems at age 2. However, in that study, authors did not correct for maternal or paternal psychopathology, or maternal personality traits. Similarly, in our study, we may not be able to strongly establish a causal link between pre-pregnancy weight and aggressive/externalising problems, but by applying clinically relevant cut-off points in the measurement tool of child behaviour, we suggest that there may be a trend for more aggressive behaviours from children of obese mothers. As has been previously suggested,[23] future studies could benefit from the utilisation of genetically

Table 4 Logistic and linear regression for children's behavioural problems based on maternal BMI†

	Behavioural problems‡	No behavioural problems‡	OR	95% CI	β	p Value	OR†	95% CI	β	p Value
Emotional reactivity	N	N			0.03	0.42			0.02	0.58
Underweight	6	82	1.10	0.44 to 2.77			1.12	0.42 to 2.96		
Normal weight	25	376	1.00	Reference			1.00	Reference		
Overweight/obese	20	283	1.06	0.58 to 1.95			1.05	0.54 to 2.06		
Anxiety/depression	N	N			−0.03	0.40			−0.02	0.62
Underweight	5	83	0.77	0.29 to 2.06			0.86	0.31 to 2.41		
Normal weight	29	372	1.00	Reference			1.00	Reference		
Overweight/Obese	14	289	0.62	0.32 to 1.20			.65	0.32 to 1.30		
Somatic symptoms	N	N			−0.01	0.11			−0.07	0.07
Underweight	11	77	1.33	0.65 to 2.70			0.99	0.43 to 2.26		
Normal weight	39	362	1.00	Reference			1.00	Reference		
Overweight/obese	30	273	1.02	0.62 to 1.68			0.99	0.56 to 1.75		
Withdrawn behaviour	N	N			−0.06	0.09			−0.02	0.58
Underweight	3	85	1.14	0.32 to 4.14			1.53	0.36 to 6.61		
Normal weight	12	389	1.00	Reference			1.00	Reference		
Overweight/obese	14	289	1.57	0.72 to 3.45			2.66	0.99 to 7.09		
Attention	N	N			0.06	0.08			0.03	0.39
Underweight	5	83	0.74	0.28 to 1.98			1.17	0.42 to 3.29		
Normal weight	30	371	1.00	Reference			1.00	Reference		
Overweight/Obese	29	274	1.31	0.77 to 2.23			1.13	0.60 to 2.13		
Aggressive behaviour	N	N			0.08	0.02*			0.07	0.07
Underweight	4	84	0.78	0.26 to 2.32			.87	0.28 to 2.69		
Normal weight	23	378	1.00	Reference			1.00	Reference		
Overweight/obese	19	284	1.10	0.58 to 2.06			1.04	0.52 to 2.10		
Sleeping problems	N	N			0.06	0.11			0.03	0.48
Normal weight	14	387	1.00	Reference			1.00	Reference		
Underweight	3	85	0.98	0.27 to 3.47			0.97	0.20 to 4.66		
Overweight/obese	11	292	1.04	0.47 to 2.33			0.92	0.37 to 2.29		
Externalising	N	N			0.09	0.02*			0.07	0.08
Underweight	6	81	0.56	0.23 to 1.36			.66	0.26 to 1.66		
Normal weight	46	348	1.00	Reference			1.00	Reference		
Overweight/obese	44	253	1.32	0.84 to 2.05			1.17	.69 to 1.99		
Internalising	N	N			−0.04	0.29			−0.03	0.44
Underweight	16	72	1.85	0.99 to 3.46			1.86	0.93 to 3.73		
Normal weight	43	358	1.00	Reference			1.00	Reference		
Overweight/obese	34	269	1.05	0.65 to 1.70			1.01	0.59 to 1.74		
Total problems	N	N			0.07	0.05			0.06	0.14
Underweight	6	82	0.59	0.24 to 1.43			0.59	0.23 to 1.50		
Normal weight	44	355	1.00	Reference			1.00	Reference		
Overweight/obese	41	260	1.27	0.81 to 2.00			1.18	0.70 to 2.00		

*<0.05.
†Adjusted for gestational age, twins' birth weight, age and sex, mother's educational level, smoking (before, during and after pregnancy).
‡Categorised based on children within normal range and borderline/clinical range.

sensitive designs; in this study, we included pre-pregnancy weight in the genetic model and showed that there could be some intrauterine influence. Indeed, when we added pre-pregnancy weight in the genetic model, we observed a non-significant decrease in the variation of externalising problems explained by the common environment. This suggests that pre-pregnancy weight as an intrauterine factor may play an important role in the development of externalising problems.

A number of mechanisms could be responsible for the links between maternal obesity and neurodevelopmental problems in young children. The potential role of nutrition on the development of the brain has been investigated in the past. Although there is no clear pathway that links externalising problems to maternal overweight, several pathways have been proposed to explain this association and parallels between overweight and other developmental disorders can be drawn. Leptin, which is the protein produced by adipose cells, has been found to play multiple functions in reproduction,[35 36] glucose homoeostasis[37 38] as well as in brain[39 40] and neurocognitive development.[41] Another possible causal pathway suggests that pre-pregnancy overweight women may not be able to synthesise vitamin D, due to the excessive adipose tissue, which results in deficiency in both the mother and the neonate; in turn, vitamin D is associated with neurocognitive function.[42] In addition, high glucose levels pose a risk for neurobehavioural impairments.[43] Moreover, epigenetic mechanisms affecting the central nervous system dopamine signalling could be a mechanism by which exposure to elevated maternal BMI during pregnancy might increase levels of externalising behaviour in children.[44]

However, others have emphasised the importance of the dynamics within the family environment, such as the parent-child interaction and the individual differences in parenting[45 46] and their impact on the course of the developmental pathways of problem behaviours. Previous research has mainly linked externalising problems with family adversity, maternal depression and low socioeconomic status.[37 45 47]

In addition, there may be other environmental factors, which it was not possible to examine in this study, that could accentuate these symptoms. For instance, parents with children displaying symptoms of aggressive behaviours normally report higher levels of stress and frequent use of negative parenting strategies,[48] while it has been found that stress levels could be associated with weight gain.[49] Thus, parental behaviour may fuel non-compliance, aggression and poor regulation of emotion, rather than providing toddlers adaptive models of regulated and pro-social functioning.[50]

The current study has a number of strengths including the use of a validated measure of childhood behaviour problems for children older in age than was previously used in the literature, and utilised a genetically sensitive design to assess the influence of maternal pre-pregnancy weight.

Moreover, compared to previous studies,[20 44] we applied cut-off scores to the child behaviour scale, which enabled us to clinically assess the observed association. In addition, we were able to adjust for a number of covariates, which could indicate a post-natal influence on externalising behaviour, such as maternal educational level and smoking after pregnancy. However, we did not have information on other parental characteristics such as maternal psychopathology and personality.

To sum up, these results suggest a possible association between aggressive/externalising problems and maternal overweight. It is important, however, to keep in mind when conducting research with preschoolers that the investigation of children, who may be at risk for externalising problems, may pose the challenge of differentiating between age-related and normative levels of this behaviour from more serious early-emerging problems.[51]

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