Maternal pre-pregnancy weight and twins’ temperament

Elena C. Tore1,2, Evangelia E. Antoniou1, Keith Reed3, Taunton R. Southwood4, Luc Smits5, Joseph P. McCleery6 and Maurice P. Zeegers1,7

1Department of Complex Genetics, Care and Public Health Research Institute (School CAPHRI), Maastricht University, Maastricht, The Netherlands, 2Institute of Applied Health Research, College of Medical and Dental Sciences, University of Birmingham, Birmingham, UK, 3The Twins and Multiple Births Association (TAMBA), Aldershot, UK, 4Institute of Child Health, University of Birmingham, Birmingham, UK, 5Department of Epidemiology, Care and Public Health Research Institute (CAPHRI), Maastricht University, Maastricht, The Netherlands, 6Developmental and Behavioral Pediatrics, Children’s Hospital of Philadelphia, Philadelphia, PA, USA and 7Department of Complex Genetics, Nutrition and Translational Research in Metabolism (School NUTRIM), Maastricht University, Maastricht, The Netherlands

Abstract

Maternal pre-pregnancy weight has been related with young singletons’ cognitive and behavioral development, but it is not clear if it has an effect on temperament. We used a twin cohort to evaluate the association between maternal pre-pregnancy body mass index (BMI) and infants’ temperament. The mothers of 834 twins answered questions regarding their pre-pregnancy BMI and their 0- to 18-month-old children’s temperament using the Revised Infant Behavior Questionnaire. Three temperamental dimensions were examined: activity level, distress to limitation and duration of orienting. The relationship between maternal pre-pregnancy BMI and each temperamental component was investigated by means of multilevel mixed-effects linear regression analysis. We found no clear evidence of an association of maternal pre-pregnancy BMI with twins’ temperament. The development of temperament is influenced by a large number of factors, probably different from those influencing children’s emotional and behavioral development.

Introduction

Temperament refers to individual differences in emotional, motor and attentional reactivity measured by latency, intensity and recovery of response, and self-regulation processes such as effortful control. Rothbart and Derryberry suggested that infant temperament can be assessed by the degree to which infants react and regulate their responses. Since reactivity is the response to external stimuli and regulation is the manner in which the infant returns to homeostasis, differences in individual infant reactions can be assessed behaviorally and understood biologically.

An increasing body of literature has suggested a link between temperamental aspects and child psychopathology. Specifically, three dimensions of the broad temperamental components have been linked with the development of psychopathology later in life: activity level (gross motor activity, including squirming and locomotor activity), distress to limitations (fussing, crying or showing distress when confined in a place/position or when unable to perform a desired action) and duration of orienting (attention to and/or interaction with an object). Infants high in distress are at greater risk of being more aggressive. A meta-analysis on the relationship between problems in infancy and long-term behavioral outcomes suggests that high distress, usually manifested as excessive crying, in the first year of life is predictive of attention problems at school age. Persistent problems with behavioral control, such as the inability to regulate feeding and sleeping behavior in infancy, are precursors of behavior control difficulties such as hyperactivity or conduct problems in childhood. Finally, difficulties with anger regulation are associated with attention problems from preschool through adulthood.

Previous research has examined the genetic and environmental etiological factors of infant temperament development. Twin studies provide strong evidence of genetic influence on temperament including activity, distress and attention. Estimates of heritability suggest that genetic factors account for 20–60% of the variability of temperament within a population with no consistent pattern of differential heritability across dimensions.

The influence of prenatal environment on children’s temperament and behavior is probably less strong than the influence genetic factors have. In general, a genetically informative study design helps controlling for a large number of confounders that might affect the results. However, the prenatal environment experienced by twins may be different from the one...
singleton experience. This is mainly due to space and nutrients scarcity, which could lead to various growth complications.\textsuperscript{22} Moreover, it is possible that monozygotic (MZ) twins, as compared to singletons and dizygotic (DZ) twins, face a more challenging environment while in the uterus, as a very large proportion of them share one chorion.\textsuperscript{23} However, no study has analyzed the association of chorionicity on temperament,\textsuperscript{23} while an older study\textsuperscript{24} showed that there is no clear pattern of genetic influences in the neonatal period and no significant differences between the MZ and DZ twins correlations, suggesting the presence of shared prenatal environmental influence on temperament.

Since both pregnancy and obesity are associated with massive metabolic alterations acting together, they might impact the environment experienced by the fetus. It has been hypothesized that maternal adiposity at the time of conception may be important for child mental health programming, since the prenatal development of the brain might depend on the level of maternal energy supply.\textsuperscript{25,26} However, the possible influence of maternal weight before pregnancy, as a proxy for the prenatal environment, on children psychological development has only recently been studied. Van Lieshout et al.\textsuperscript{27} analyzed the association of maternal pre-pregnancy body mass index (BMI) with offspring temperament and behavior in children aged 1 year and 2 years, respectively. In their analysis, maternal BMI was not found to be related with any temperamental component, measured using the Toddler Temperament Scale, nor with internalizing behavior. However, a higher maternal BMI was found to be positively associated with elevated externalizing problems at age 2.\textsuperscript{27} Higher maternal pre-pregnancy BMI was also predictive of a high degree of distress and inattention\textsuperscript{28–30} and a tendency for child aggressive behavior.\textsuperscript{31}

To the best of our knowledge, there are no studies on the relationship between maternal pre-pregnancy weight and twins’ temperament. In the present study, we used maternal pre-pregnancy BMI as a proxy of the shared prenatal environment to evaluate its influence on infants’ temperament in MZ and DZ twins. A deeper understanding of this association could help preventing the development of difficult temperament in children, as well as antisocial behavior later in life, by informing prospective mothers on the possible effects of overweight and obesity on children’s psychopathology.

**Method**

**Study population**

The Twins and Multiple Births Association Heritability Study (TAMBAHS) is a volunteer-based study focusing on the development of twins from birth until 5 years of age. For the present study, mothers of twins aged 0–18 months at the time of the survey were identified. Between July 2008 and May 2010, 417 mothers completed the study’s self-assessed questionnaire on their twins’ temperament. For the determination of the twins’ zygosity, the adapted version of Goldsmith’s zygosity questionnaire was used.\textsuperscript{32} This adapted questionnaire, as a 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 cases.\textsuperscript{33} In total, 834 twins were included in the analyses; 188 MZ male twins, 188 MZ female twins, 120 DZ male twins, 118 DZ female twins and 220 opposite-sex twins.

**Maternal and twins’ characteristics**

Pre-pregnancy BMI (expressed as kg/m\textsuperscript{2}) was based on maternal self-report of weight and height and introduced as a continuous variable in the linear regression analysis. Gestational age (measured in completed weeks of gestation), level of education (high school diploma or less, college/professional education and university degree), employment status (housekeeper or unemployed, working part-time, working full-time and others) and smoking (before, during, after pregnancy; yes/no) were noted for mothers; age (in months), sex and birthweight (in grams) were noted for all twins.

**Temperament**

Infant temperament was assessed using the revised Infant Behavior Questionnaire (IBQ-R).\textsuperscript{34} The parents were asked to report on a seven-point Likert-type scale the relative frequency of occurrence of specified infant reactions to concrete situations during the previous 7 days. The scale ranged from 1 to 7 (never, very rarely, less than half the times, about half the times, more than half the times, almost always, always and does not apply). The IBQ-R consists of 14 scales. For the purposes of this study, we used only three dimensions of temperament: (1) activity level, which consists of items examining the twins’ movement of arms and legs, squirming and locomotor activity; (2) distress to limitations, which consists of items looking into twins’ fussing, crying or showing distress while (a) in a confining place or position; (b) involved in caretaking activities; (c) unable to perform a desired action; (3) duration of orienting, which consists of items on the twins’ attention to and/or interaction with a single object for extended periods of time. Reliability, convergent validity and relative stability have been demonstrated for the IBQ-R.\textsuperscript{35,36} The internal consistency for the IBQ-R items was high with the Cronbach’s \( \alpha \), ranging from 0.81 to 0.90. Consistency between parent report on the IBQ-R and indicators of temperament based on home and laboratory observations has been demonstrated.\textsuperscript{37}

**Statistical analysis**

Mean and standard deviation (s.d.) or median and interquartile range for each continuous variable were calculated as appropriate, stratified by zygosity group. Intrapair twin correlations for each variable, subdivided into MZ and DZ twins, were calculated by using Pearson’s (\( r \)) and Spearman’s (\( \rho \)) coefficient statistics where appropriate.

The association between maternal pre-pregnancy BMI and each temperamental dimension was analyzed using a multilevel mixed-methods linear regression, in which a random-effect model was added to the default fixed-effects. The intercept of each twin pair was modeled as a function of the population intercept plus a unique contribution of the twin pair, as thoroughly explained by Carlin et al.\textsuperscript{38} and summarized by the following equation:

\[
Y_{ij} = \beta_0 + \beta_2 X_{ij} + \alpha_{ij} + \epsilon_{ij}
\]

in which \( Y_{ij} \) represents the outcome (i.e., the specific temperamental dimension’s score) of the \( j \)th twin in the \( i \)th pair. In addition to the linear regression model, a pair-specific error term (\( \alpha_{ij} \)) allows a random shift of the intercept. Regression coefficients (\( \beta \))s were used as a measure of change on the temperamental dimensions’ scores by a unit change in the mother’s BMI.
Twins’ age, gender, birthweight and gestational age, and maternal age, smoking (before, during and after pregnancy), level of education and employment status were adjusted for in the analysis.

All analyses were performed using STATA v.14.9

**Results**

Descriptive statistics as well as Pearson and Spearman correlations between each covariate and the three temperament dimensions stratified by zygosity are shown in Table 1. Mothers’ age was 33.47 years (4.22) for mothers of MZ and 34.65 years (4.05) for mothers of DZ twins. Mothers’ BMI mean score was 23.40 (4.56) for mothers of MZ and 23.46 (5.40) for mothers of DZ, respectively. For MZ and DZ twins, respectively, the median [interquartile range (IQR)] for gestational age was 36 weeks (2.93) and 37 weeks (3.71); for birthweight it was 2438.06 g (793.78) and 2590 g (708.74). MZ and DZ twins were significantly different with respect to gestational age (P = 0.0001), birthweight (P < 0.0001) and maternal age (P = 0.0001).

Means of temperamental dimensions and intrapair twin correlations for MZ and DZ twins are shown in Table 2. For activity level, MZ correlation was *r* = 0.75 and the DZ correlation was *r* = 0.45. For distress to limitations, MZ and DZ correlations were *r* = 0.83 and *r* = 0.56, respectively. For duration of orienting, MZ and DZ correlations were *r* = 0.94 and *r* = 0.85, respectively.

### Table 1. Means/frequencies, standard deviations/percentages and Pearson correlations with the three temperament scales for each covariate, stratified by zygosity

| Maternal characteristics | MZ twins | | | | | DZ twins | | | |
|--------------------------|----------|---|---|---|---|---|---|---|---|---|
|                          | Mean or median | SD or IQR | *r* | *r* | *r* | Mean or median | SD or IQR | *r* | *r* | *r* |
| Pre-pregnancy BMI §       | 23.40     | 4.56 | -0.04 | -0.01 | 0.04 | 23.46     | 5.40 | -0.03 | -0.13* | 0.00 |
| Age (years)              | 33.47     | 4.22 | -0.12* | -0.05 | -0.10 | 34.65     | 4.05 | -0.19** | -0.14*** | -0.09 |
| Gestational age (weeks) § | 36        | 2.93 | 0.04 | -0.06 | 0.06 | 37        | 3.71 | 0.03 | 0.03 | -0.04 |
| Smoking (yes)            | N         | %   | *r* | *r* | *r* | N         | %   | *r* | *r* | *r* |
| Before                   | 28        | 16  | -0.03 | -0.02 | 0.03 | 35        | 16  | -0.03 | 0.09 | 0.04 |
| During                   | 4         | 2   | 0.00 | 0.07 | 0.03 | 11        | 5   | 0.02 | 0.07 | -0.02 |
| After                    | 11        | 6   | -0.04 | 0.02  | 0.16*** | 17        | 8   | -0.03 | 0.09  | 0.9*** |
| Level of education       | N         | %   | *r* | *r* | *r* | N         | %   | *r* | *r* | *r* |
| High school diploma or less | 33       | 18.6 | 0.03 | -0.02 | 0.03 | 47       | 21.1 |
| College/professional education | 31     | 17.4 | -0.15 | -0.11 | -0.07 | 52       | 23.3 | -0.06 | -0.13 | -0.05 |
| University education     | 114       | 64.0 | 0.04 | -0.11 | -0.07 | 124      | 55.6 |
| Employment status        | N         | %   | *r* | *r* | *r* | N         | %   | *r* | *r* | *r* |
| Housekeeper or unemployed | 192       | 53.6 | 0.11 | 0.06  | 0.09  | 216      | 47.8 |
| Working part-time        | 80        | 22.3 | 0.01 | -0.19** | 0.02 | 136      | 30.1 | -0.04 | 0.04  | -0.04 |
| Working full-time        | 68        | 19.0 | 0.10* | 0.03  | 0.09  | 88       | 19.5 |
| Other                    | 18        | 5.1  | 0.00 | 0.07  | 0.04  | 12       | 2.6  |
| Twin characteristics     |           |     |     |     |     |           |     |     |     |     |
| Birthweight (in grams) § | 2438.06   | 793.78 | 0.08 | -0.03 | 0.05 | 2590     | 708.74 | -0.03 | -0.03 | -0.02 |
| Age (months) §           | 8         | 8    | 0.35** | 0.11* | 0.10* | 9        | 8    | 0.16** | 0.04  | 0.20** |
| Sex                      | N         | %   | *r* | *r* | *r* | N         | %   | *r* | *r* | *r* |
| Male                     | 188       | 50.00 | 0.00 | 0.07  | 0.04  | 110       | 26.20 |
| Female                   | 188       | 50.00 | -0.14** | -0.16** | -0.04 | 118      | 25.77 | -0.03 | -0.11* | 0.07 |
| Opposite sex             | –         | –    | –    | –    | –    | 220       | 48.03 |

§ Median (IQR) shown.
*r*<sub>a</sub>, Pearson/Spearman correlation with activity level.
*r*<sub>b</sub>, Pearson/Spearman correlation with distress to limitations.
*r*<sub>c</sub>, Pearson/Spearman correlation with duration of orienting.
*P* < 0.05; **P < 0.001; ***P < 0.0001.
Table 2. Descriptive statistics of temperament scales for monozygotic and dizygotic twin pairs

|                          | Monozygotic twin pairs (n = 188) | Dizygotic twin pairs (n = 229) |
|--------------------------|---------------------------------|--------------------------------|
| Temptament scales        |                                  |                                |
|                          | Twin 1                          | Twin 2                        | Twin 1                          | Twin 2                        |
| Activity level           | N: 185                          | M: 4.12                        | s.d.: 1.01                      | N: 215                        | M: 4.13                        | s.d.: 0.98                      |
|                          | r: 0.75**                       |                                |                                | r: 0.85**                      |                                |                                |
| Distress to limitations  | N: 185                          | M: 3.48                        | s.d.: 1.02                      | N: 215                        | M: 3.57                        | s.d.: 0.99                      |
|                          | r: 0.83**                       |                                |                                | r: 0.85**                      |                                |                                |
| Duration of orienting    | N: 171                          | M: 3.72                        | s.d.: 1.20                      | N: 202                        | M: 3.57                        | s.d.: 1.13                      |
|                          | r: 0.95**                       |                                |                                | r: 0.85**                      |                                |                                |

A: Number of twins; M: Mean; r: Within-twin correlations.
Twin 1 is the first born.
Twin 2 is the second born.
*P < 0.05; **P < 0.001.

Linear regressions

Table 3 presents the results of the linear regressions. In the unadjusted analyses, we found a small decrease in the DZ twins’ distress to limitations score for every unit increase of mother’s pre-pregnancy BMI (β = −0.03; [95% confidence intervals (CI): −0.050, −0.001]; P = 0.04). This association was not substantially affected after important confounders were adjusted for (β = −0.04; [95% CI: −0.065, −0.013]; P = 0.003). Similar results were obtained when analyzing the MZ and DZ twins combined (results not shown). No association remained statistically significant after controlling for multiple testing; the statistically significance cut-off was set at α = (0.05/18) = 0.0028. The normality of residuals was checked through normal quantile plots and confirmed for all regression analyses (results not shown).

Discussion

The aim of this study was to examine the relationship between maternal pre-pregnancy weight and infants’ temperament, measured through three dimensions of the revised version of the IBQ: activity level, distress to limitation and duration of orienting. A statistically significant, negative association between maternal pre-pregnancy weight and distress to limitation in DZ twins initially emerged from the present analysis. However, the relative P-value failed to reach the critical level of significance after controlling for multiple testing. Although the Bonferroni method for multiple testing adjustment has been criticized and could be considered excessively conservative in this case, the 95% CI clearly shows that the true value of β is close to null, falling between −0.065 and −0.013. This means that for a 1-unit increase in maternal pre-pregnancy BMI, scores in distress to limitation would decrease on average by 0.04 points, on a 1–7-point scale. Consequently, the beneficial effect of a high maternal BMI on children’s temperament we observed is certainly not enough to suggest that a higher maternal pre-pregnancy weight could be beneficial, especially in light of the many negative effects over-weight and obesity have on perinatal outcomes and maternal and offspring’s health.

A large part of the literature suggests that the risk of cognitive and behavioral problems is associated with adverse intrauterine factors. Maternal pre-pregnancy overweight or obesity was associated with symptoms of attention-deficit/hyperactivity disorder (ADHD) in school-aged children and in child with attention and behavioral problems. Furthermore, a UK-based, longitudinal study analyzed the influence of maternal pre-pregnancy BMI on children’s cognitive ability, reporting a statistically significant, negative association. However, the effect size was as limited as the one reported in the present study, with a 10-point increase in maternal BMI being associated with a 1/10 s.d. decrease in cognitive performance at age 7 years. To the best of our knowledge, only one study has analyzed the possible influence of maternal pre-pregnancy BMI on singletons’ temperament. In spite of important methodological differences, such as the specific questionnaire used and the population of interest (i.e., singletons vs. twins), there is consistency in the results between the present and Van Lieshout’s study. Specifically, they reported that temperament at 1 year of age was not associated with maternal pre-pregnancy BMI. Of note, however, is that measures of externalizing behavior on the same population were found to be significantly associated with maternal pre-pregnancy weight. Another study, which analyzed children’s behavior development and cognition in two separate, large cohorts in the United Kingdom and the Netherlands, found no consistent evidence of perinatal influence on these outcomes. The strong association was observed with children’s IQ at 8 years, while outcomes in younger children were not statistically significant after adjusting for critical confounders nor was repeated in both cohorts. Overall, most of the clinically significant results are reported in studies analyzing older children as opposed to infants and pre-school children, suggesting that the effect of maternal pre-pregnancy BMI may manifest later in children’s development.

The biggest strength of the present study is that the population analyzed is a cohort of young twins. Analyzing twins instead of singletons, automatically controls for genetic (in MZ twins) and common environmental factors (in both MZ and DZ twins). It has been shown previously that temperament, as well as cognitive and behavioral development, has substantial genetic and environmental influences; therefore not having a genetically informed study design could be an important limitation of all the studies cited above, limiting the confidence in their significant results. Furthermore, the pre-pregnancy environment experienced by singletons may not be comparable with that experienced by twins. In fact, multiple pregnancies are often characterized by nutrient and space scarcity, which may lead to discordant growth or more serious, pathological complications, such as the twin-to-twin transfusion syndrome. This implies that twins, and especially MZ twins, might be more susceptible to challenging intrauterine environment that might influence their future temperament. As far as we know, only one study explored the
association between maternal pre-pregnancy weight and twins’ behavior, finding a tendency for children of overweight and obese mothers toward clinically aggressive and externalizing behaviors. It is therefore essential to analyze further the influence of perinatal factors on twins’ psychopathological development.

A vast part of the literature focuses on children’s cognitive and behavioral development as opposed to infants’ temperament, limiting the comparability and understanding of the process. Various suggestions have been put forward for the explanation of the relation between temperament and psychopathology. Of the models suggested, one poses that temperament can be considered as a spectrum, or a common cause model, with normal and abnormal falling at different points on the same continuum. In essence, this model considers temperament to be a sub-clinical manifestation of psychopathology, with shared etiological determinants. The results of the present study suggest, however, that some of the etiological factors important in emotional/behavioral problems, including maternal pre-pregnancy BMI, may not be important for specific temperamental dimensions. This suggests that temperament is not simply a manifestation of psychopathology with a shared etiology. Shiner and Caspi have argued that it is implausible that complex behavior such as child psychopathology is the simple product of one or two temperamental factors. Instead, these temperamental factors likely interact with each other and with other variables such that the “true” impact of temperament is larger than the effect of the individual temperamental factors themselves. Evidence for this type of interaction of temperament with other etiological factors has been provided by Owens et al., who found that high levels of emotionality in children are linked to lower levels of responsiveness in mothers, which, in turn, may compromise the establishment of a secure attachment relationship. The lack of a secure attachment, then, could further enhance the risk of the development of internalizing/externalizing psychopathology.

The results of this study should be interpreted in light of some limitations. There was no data available to assess the psychopathology of mothers and their soothing practices toward their twins. Maternal psychopathology is considered a risk factor for obesity and internalizing/externalizing problem behaviors, and it may have an impact on maternal perception of offspring’s behavior and temperament. Furthermore, we could not control for parental practices, which might as well be related to infants’ temperament. We had no data regarding breastfeeding and maternal Type II diabetes mellitus, which have been found to be associated with children’s temperament and behavior. Full control for the familiar socioeconomic status (SES) was not possible, since we lacked the data regarding parental income. Nonetheless, maternal level of education and employment status are considered the other two core components of SES and can provide a reliable indication of the familiar situation. Additionally, we were not able to account for the presence of other children in the family, which might have affected maternal ratings. Although previous studies did not observe an association between chorionicity and children’s psychopathology, we cannot exclude an uncontrolled effect of chorion type on our results. Finally, although self-reported height and weight are considered accurate enough and widely used in epidemiological studies, it was suggested that overweight and obese women are more likely to under-report their pre-pregnancy weight. Consequently, we cannot rule out the effect of biased reports on results.

In sum, the results of this study provide evidence that maternal pre-pregnancy BMI, which has been suggested as an important factor in emotional/behavioral problems, is not related with infants’ temperament. These findings suggest that temperament is a complex constellation of characteristics with varying influences, as opposed to a unified, biologically driven system, as previously suggested. Additional studies are needed for elucidating the developmental paths of infant temperament and should consider not only maternal pre-pregnancy BMI but also maternal diet and physical health before and during pregnancy, as well as maternal temperament and psychopathology.

Acknowledgments. The authors wish to thank all participating families.

Financial support. The study was supported by the University of Birmingham (grant number: GAS1168).

Conflicts of interest. None.

Ethical standards. The authors assert that all procedures contributing to this work comply with the ethical standards of the relevant national guidelines on human experimentation and with the Helsinki Declaration of 1975, as revised in 2008, and has been approved by the University of Birmingham Ethics Committee.

Informed consent. Informed consent was obtained from all individual participants included in the study by the University of Birmingham Ethics Committee.

### Table 3. Linear regressions for the temperamental scales stratified by zygosity based on maternal BMI

| Outcomes by BMI | Monozygotic twins | Dizygotic twins |
|-----------------|-------------------|----------------|
|                 | β coefficient     | CI             | P   | β coefficient^ | CI^ | P^ |
| Activity Level  | -0.01             | -0.04, 0.02    | 0.57 | -0.01         | -0.04, 0.03    | 0.71 | -0.01 | -0.03, 0.02     | 0.61 | -0.01 | -0.04, 0.01     | 0.33 |
| Distress to limitations | -0.00          | -0.04, 0.03    | 0.94 | 0.00          | -0.03, 0.04    | 0.88 | -0.03 | -0.05, -0.00   | 0.04  | -0.04 | -0.07, -0.01   | 0.003  |
| Duration of orienting | 0.01           | -0.03, 0.06    | 0.61 | 0.02          | -0.03, 0.07    | 0.37 | 0.00 | -0.03, 0.04   | 0.98  | 0.02 | -0.01, 0.06     | 0.25  |

SE: standard error of β.

^Adjusted for twins’ age, sex, mother’s age, level of education, employment status and smoking (before, during and after pregnancy).

^P < 0.05; *P < 0.0028.
References

1. Rothbart MK, Derryberry D. Development of individual differences in temperament. In Advances in Developmental Psychology (eds. Lamb ME, Brown AL). 1982; pp. 37–86; Lawrence Erlbaum: Hillsdale.
2. Eisenberg N, Sadosky A, Spinzar TL, et al. The relations of problem behavior status to children’s negative emotionality, effortful control, and impulsivity: concurrent relations and prediction of change. Dev Psychol. 2005; 41, 193–211.
3. Kagan J, Snidman N. Early childhood predictors of adult anxiety disorders. Biol Psychiatry. 1999; 46, 1536–1541.
4. Nigg JT, Goldsmith HH, Sachek J. Temperament and attention deficit hyperactivity disorder: the development of a multiple pathway model. J Clin Child Adolesc Psychol: The Official Journal for the Society of Clinical Child and Adolescent Psychology. American Psychological Association, Division 53. 2004; 33, 42–53.
5. Olson SL, Sameroff AJ, Kerr DC, Lopez NL, Wellman HM. Developmental foundations of externalizing problems in young children: the role of effortful control. Dev Psychopathol. 2005; 17, 25–45.
6. Rettew DC, Copeland W, Stanger C, Hudziak JJ. Associations between temperament and DSM-IV externalizing disorders in children and adolescents. J Dev Behav Pediatr: JDBP. 2004; 24, 383–391.
7. Eisenberg N, Cumberland A, Spinzar TL, et al. The relations of regulation and emotionality to children’s externalizing and internalizing problem behavior. Child Dev. 2001; 72, 1112–1134.
8. Hemmi MH, Wolke D, Schneider S. Associations between problems with crying, sleeping and/or feeding in infancy and long-term behavioural outcomes in childhood: a meta-analysis. Arch Dis Child. 2011; 96, 622–629.
9. Degangi GA, Dipietro JA, Greenspan SI, Porges SW. Psychophysiological characteristics of the regulatory disordered infant. Infant Behav Dev. 1991; 14, 37–50.
10. Moffitt TE, Caspi A, Dickson N, Silva P, Stanton W. Childhood-onset versus adolescent-onset antisocial conduct problems in males: Natural history from ages 3 to 18 years. Dev Psychopathol. 1996; 8, 399–424.
11. Wolke D, Rizzo P, Woods S. Persistent infant crying and hyperactivity problems in middle childhood. Pediatrics. 2002; 109, 1054–1060.
12. Douglas VI, Parry PA. Effects of reward and nonreward on frustration and attention in children with ADHD. J Abnorm Child Psychol. 1994; 22, 281–302.
13. Ramirez CA, Rosén LA, Dellenbacher JL, et al. Anger and anger expression in adults with high ADHD symptoms. J Atten Disord. 1997; 2, 115–128.
14. Emde RNE, Hewitt JKE. Infancy to Early Childhood: Genetic and Environmental Influences on Developmental Change. 2001. Oxford University Press: New York, NY, US.
15. Matheny AP. Children’s behavioral inhibition over age and across situations: genetic similarity for a trait during change. J Pers. 1989; 57, 215–35.
16. Cherry SS, Fulker DW, Corley RP, Plomin R, DeFries JC. Continuity and change in infant shyness from 14 to 20 months. Behav. Genet. 1994; 24, 365–379.
17. Wood AC, Saudino KJ, Rogers H, Asherson P, Kuntsi J. Genetic influences on mechanically-assessed activity level in children. J Child Psychol. 2007; 48, 695–702.
18. Cyphers LH, Phillips KY, Fulker DW, Mrazek DA. Twin temperament during the transition from infancy to early childhood. J Am Acad Child Adolesc Psychiatry. 1990; 29, 392–397.
19. Goldsmith HH, Buss KA, Lemery KS. Toddler and childhood temperament: expanded content, stronger genetic evidence, new evidence for the importance of environment. Dev Psychol. 1997; 33, 891–905.
20. Saudino KJ. Behavioral genetics and child temperament. J Dev Behav Pediatrics: JDBP. 2005; 26, 214–223.
21. Knopik VS, Neiderhiser JM, de Geus E, Boomsma D. The importance of the prenatal environment in behavioral genetics: introduction to special issue. Behav Genet. 2016; 46, 281–285.
22. Long E, Ferriman E. Twin pregnancy, Obstet Gynaecol Reprod Med. 2016; 26, 38–45.
23. Marceau K, McMaster MTB, Smith TF, et al. The prenatal environment in twin studies: a review on chorionicity. Behav Genet. 2016; 46, 286–303.
24. Riese ML. Neonatal temperament in monozygotic and dizygotic twin pairs. Child Dev. 1990; 61, 1230–1237.
25. Luke B, Dickinson C, Petrie RH. Intrauterine growth: correlations of maternal nutritional status and rate of gestational weight gain. Eur J Obstet Gynecol. 1981; 12, 113–121.
26. Salvati S, Attorri L, Avellino C, Di Biase A, Sanchez M. Diet, lipids and brain development. Dev Neurosci. 2000; 22, 481–487.
27. Van Liershout RJ, Schmidt LA, Robinson M, Niccols A, Boyle MH. Maternal pre-pregnancy body mass index and offspring temperament and behavior at 1 and 2 years of age. Child Psychiatry Hum Dev. 2013; 44, 382–389.
28. Dallman MF, Pecoraro N, Akana SF, et al. Chronic stress and obesity: a new view of “comfort food”. Proc Natl Acad Sci USA. 2003; 100, 11696–11701.
29. Rodriguez A. Maternal pre-pregnancy obesity and risk for inattention and negative emotionality in children. J Child Psychol. 2010; 51, 134–143.
30. Rodriguez A, Miettunen J, Henrksen TB, et al. Maternal adiposity prior to pregnancy is associated with ADHD symptoms in offspring: evidence from three prospective pregnancy cohorts. Int J Obes. 2008; 32, 550–557.
31. Antoniou EE, Fowler T, Reed K, et al. Maternal pre-pregnancy weight and externalising behaviour problems in preschool children: a UK-based twin study. BMJ Open. 2014; 4; e005974.
32. Goldsmith HH. A zygosity questionnaire for young twins: a research note. Behav Genet. 1991; 21, 257–269.
33. Price TS, Freeman B, Craig I, et al. Infant zygosity can be assigned by parental report questionnaire data. Twin Res Hum Genet. 2000; 3, 129–133.
34. Gartstein MA, Rothbart MK. Studying infant temperament via the Revised Infant Behavior Questionnaire. Infant Behavior Dev. 2003; 26, 64–86.
35. Bridges LJ, Palmer SA, Morales M, Hurtado M, Tsai D. Agreement between affectively based observational and parent-report measures of temperament at infant age 6 months. Infant Behavior Dev. 1993; 16, 501–506.
36. Worobey J. Convergence among assessments of temperament in the first month. Child Dev. 1986; 57, 47–55.
37. Schaughency EA, Fagot BI. The prediction of adjustment at age 7 from activity level at age 5. J Abnorm Child Psychol. 1993; 21, 29–50.
38. Carlin JB, Gurin LC, Sterne JA, Morley R, Dwyer T. Regression models for twin studies: a critical review. Int J Epidemiol. 2005; 34, 1089–1099.
39. StataCorp. (2015). Stata Statistical Software: Release 14.
40. Streiner DL, Norman GR. Correction for multiple testing. Chest. 2011; 140, 16–18.
41. Papachatzis E, Dimitriou G, Dimitropoulos K, Vantarakis A. Pre-pregnancy obesity: maternal, neonatal and childhood outcomes. J Neonatal Perinatal Med. 2013; 6, 203–216.
42. Deardo rf J, Smith LH, Pettit L, Kim H, Abrams BF. Maternal prepregnancy weight and children’s behavioral and emotional outcomes. Am J Prev Med. 2017; 53(4), 432–440.
43. Negers YH, Goldenberg RL, Ramey SL, Cliver SP. Maternal prepregnancy body mass index and psychomotor development in children. Acta Obstet Gynecol Scand. 2003; 82, 235–240.
44. Tanda R, Salsberry PJ, Reagan PB, Fang MZ. The impact of prepregnancy obesity on children’s cognitive test scores. Matern Child Health J. 2013; 17, 222–229.
45. Thapar A, Fowler T, Rice F, et al. Maternal smoking during pregnancy and attention deficit hyperactivity disorder symptoms in offspring. Am J Psychiatry. 2003; 160, 1985–1989.
46. Basatemur E, Gardiner J, Williams C, et al. Maternal prepregnancy BMI and child cognition: a longitudinal cohort study. Pediatrics. 2013; 131, 56–63.
47. Oberklaid F, Prior M, Golvan D, Clements A, Williamson A. Temperament in Australian infants. Aust Paediatr J. 1984; 20, 181–184.
48. Carey WB, McDevitt SC. Revision of the Infant Temperament Questionnaire. Pediatrics. 1978; 61, 735–739.
49. Brion MJ, Zeegers M, Jaddoe V, et al. Intrauterine effects of maternal prepregnancy overweight on child cognition and behavior in 2 cohorts. Pediatrics. 2011; 127, e202–211.
50. Shiner R, Caspi A. Personality differences in childhood and adolescence: measurement, development, and consequences. *J Child Psychol*. 2003; 44, 2–32.

51. Owens EB, Shaw DS, Vondra JL. Relations between infant irritability and maternal responsiveness in low-income families. *Infant Behav Dev*. 1998; 21, 761–777.

52. Fearon RP, Bakermans-Kranenburg MJ, van IJzendoorn MH, Lapsley AM, Roisman GI. The significance of insecure attachment and disorganization in the development of children’s externalizing behavior: a meta-analytic study. *Child Dev*. 2010; 81, 435–456.

53. Durbin CE, Wilson S. Convergent validity of and bias in maternal reports of child emotion. *Psychol Assess*. 2012; 24, 647–660.

54. Avila C, Holloway AC, Hahn MK, et al. An overview of links between obesity and mental health. *Curr Obesity Rep*. 2015; 4, 303–310.

55. Kroes G, Veerman JW, De Bruyn EEJ. Bias in parental reports? *Eur J Psychol Assess*. 2003; 19, 195–203.

56. Lahti M, Savolainen K, Tuovinen S, et al. Maternal depressive symptoms during and after pregnancy and psychiatric problems in children. *J Am Acad Child Adolesc Psychiatry*. 2017; 56, 30–39.

57. Madigan S, Oatley H, Racine N, et al. A meta-analysis of maternal prenatal depression and anxiety on child socioemotional development. *J Am Acad Child Adolesc Psychiatry*. 2018; 57, 645–657.

58. Prady SL, Kiernan K, Fairley L, Wilson S, Wright J. Self-reported maternal parenting style and confidence and infant temperament in a multi-ethnic community: results from the Born in Bradford cohort. *J Child Health Care: For Professionals Working with Children in the Hospital and Community*. 2014; 18, 31–46.

59. Ornoy A. Growth and neurodevelopmental outcome of children born to mothers with pregestational and gestational diabetes. *Pediatr Endocrinol Rev: PER*. 2005; 3, 104–113.

60. Shelton KH, Collishaw S, Rice FJ, Harold GT, Thapar A. Using a genetically informative design to examine the relationship between breastfeeding and childhood conduct problems. *Eur Child Adolesc Psychiatry*. 2011; 20, 571–580.

61. National Center for Education Statistics. Improving the Measurement of Socioeconomic Status for the National Assessment of Educational Progress: A Theoretical Foundation–Recommendations to the National Center for Education Statistics. 2012.

62. Russell A, Gillespie S, Satya S, Gaudet LM. Assessing the accuracy of pregnant women in recalling pre-pregnancy weight and gestational weight gain. *J Obstet Gynaecol*. 2013; 35, 802–809.