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Maternal Depression Symptoms, Unhealthy Diet and Child Emotional-Behavioral  
Dysregulation

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## Abstract

**Background:** Maternal depression and unhealthy diet are well-known risk factors for adverse child emotional-behavioral outcomes, but their developmental relationships during the prenatal and postnatal periods are largely uncharted. This study sought to examine the inter-relationships between maternal depression symptoms and unhealthy diet (assessed during pregnancy and postnatal periods) in relation to child emotional-behavioral dysregulation (assessed at ages 2, 4, and 7 years).

**Methods:** In a large prospective birth cohort of 7814 mother-child pairs, path analysis was used to examine the independent and inter-related associations of maternal depression symptoms and unhealthy diet with child dysregulation.

**Results:** Higher prenatal maternal depression symptoms were prospectively associated with higher unhealthy diet, both during pregnancy and postnatal period, which in turn, was associated with higher child dysregulation up to age 7 years. In addition, during pregnancy, higher maternal depression symptoms and unhealthy diet were each independently associated with higher child dysregulation up to age 7 years. These results were robust to other prenatal, perinatal and postnatal confounders (such as parity and birth complications, poverty, maternal education, etc.).

**Conclusions:** Maternal depression symptoms and unhealthy diet show important developmental associations, but are also independent risk factors for abnormal child development.

**Keywords:** ALSPAC; Pregnancy; Maternal Depression; Nutrition; Child emotional-behavioral dysregulation.

## Introduction

Maternal depression is a well-known risk factor for adverse child outcomes including internalizing and externalizing problems (Goodman *et al.*, 2011). This association has often been explained by maladaptive parenting and/or negative maternal cognitions (Silberg and Rutter, 2002), but also by child exposure to risk factors that associate with depression, such as low social support of the mother or poverty (Barker *et al.*, 2012, Goodman and Gotlib, 1999, Jensen *et al.*, 2013, Pachter *et al.*, 2006). Unhealthy dietary patterns have been associated with different forms of mental illness (Scott and Happell, 2011), including depression (Akbaraly *et al.*, 2013), and with co-occurring risk factors, such as poverty (Hiza *et al.*, 2013, Moshfegh, 2007). However, the association between the nutritional environment provided to a child and maternal depression has rarely been assessed.

Mental illness is associated with the type of food that is available in a household (Rao *et al.*, 2008), which may alter the quality of nutrients which are available to a child (Monk *et al.*, 2013). Research robustly shows the important influence of dietary patterns (at different developmental stages) on child cognitive, emotional and behavioral outcomes. More specifically, unhealthy diet in pregnancy and early childhood has been associated with child cognitive function, emotional-behavioral difficulties in adolescence, and criminality in adulthood (Liu *et al.*, 2004, Nyaradi *et al.*, 2013, Raine *et al.*, 2003). Moreover, a recent study showed that unhealthy prenatal diet was associated with poorer child emotional-behavioral development, independent of early postnatal maternal depression symptoms (Jacka *et al.*, 2013). However, this study did not assess the potential developmental inter-relationships between maternal depression symptoms and child nutrition. A recent epidemiological study showed that maternal depression in pregnancy was associated with unhealthy gestational diet, which, in turn, was associated with reduced child cognitive function at age 8 years (Barker *et al.*, 2013). This study also showed stability in the unhealthy nutritional

environment from prenatal periods (i.e. what the mother eats) to postnatal periods (i.e. what the mother feeds her child)

Intervention studies confirm the plausibility of a relationship between maternal depression and dietary patterns during prenatal and postnatal periods, as well as the relationship between poor nutrition and child wellbeing. For example, experimental studies have shown that dietary supplementation with micronutrients may curb depressive symptoms and improve birth outcomes in mothers with perinatal depression (Rechenberg and Humphries, 2013). Studies have also shown that interventions that focus on healthy eating in childhood reduce aggressive behaviors in adolescence and adulthood (Raine *et al.*, 2003).

The present study sought to assess the extent to which maternal depression and unhealthy dietary patterns might developmentally inter-relate during the prenatal and postnatal periods and be negatively associated with child emotional-behavioral development. Specifically, we examined if prenatal maternal depression symptoms would associate with child unhealthy dietary patterns, which, in turn, would increase emotional-behavioral dysregulation in childhood. We also examined potential independent associations of both prenatal maternal depression and prenatal unhealthy nutrition with subsequent child dysregulation. That is, the extent to which prenatal maternal depression symptoms and poor nutrition might prospectively associate with child dysregulation, above and beyond each other (and postnatal assessments).

## Methods

### *Design and Recruitment Procedure.*

The Avon Longitudinal Study of Parents and Children (ALSPAC) is a prospective study where all pregnant women residing in the former Avon Health Authority in the South West of England and having an expected date of delivery between 1<sup>st</sup> April 1991 and 31<sup>st</sup> December 1992 were invited to participate. 14 541 was the initial number of pregnancies for which the mothers were enrolled in the study and had either returned at least one questionnaire or attended a “Children

in Focus” clinic by 19<sup>th</sup> July 1999. Of these initial pregnancies, there was a total of 14 676 fetuses, resulting in 14 062 live births and 13 988 children who were alive at 1 year of age (Fraser *et al.*, 2013). This sample was found to be similar to the United Kingdom population as a whole when compared to 1991 National Census Data (Boyd *et al.*, 2013). Ethical approval for the study was obtained from the ALSPAC Ethics and Law Committee and the Local Research Ethics Committees. All participants provided informed consent.

#### *Measures & Assessments*

During the study, mothers have completed questionnaires about themselves, their children and their demographic characteristics. A comprehensive guide to all measurements in all participants can be found on the ALSPAC website: <http://www.bris.ac.uk/alspac/researchers/data-access/data-dictionary/>. The present study variables and assessment time points are available in Supplementary Table 1

*Demographics, Pregnancy and Birth Information.* Mother age at the time of child birth was recorded. Education level, marital status/presence of partner, socio-economic status and ethnicity were recorded at 18 weeks gestation from self-reported questionnaires. Ethnicity was recorded using the format asked in the 1991 United Kingdom Census. This categorized the person as White or non-white (Black/Caribbean, Black/African, Black/other, Indian, Pakistani, Bangladeshi, Chinese and Other (Specified)). Mother parity (primiparity vs. multiparity) was also recorded. Obstetric complications were dichotomized to contrast mothers with one or more complications (1) vs. without any complication (0).

*Maternal depression symptoms.* Maternal depression symptoms were measured by the Edinburgh Postnatal Depression Scale (EPDS), a 10-item self-report questionnaire that has been validated for its use in the prenatal and postnatal period (Cox *et al.*, 1987, Murray and Carothers, 1990), with higher scores reflecting higher levels of depressive symptoms. The EPDS was collected twice prenatally (at 18 and 32 weeks of gestation), and four times after birth (at 8 weeks, 8 months,

2 years and 3 years). For the current analysis, two latent depression scores were created: one for the prenatal period and one for the postnatal period.

*Unhealthy Diet.* The Food Frequency Questionnaire (FFQ) (Rogers and Emmett, 1998) was used to assess (i) maternal dietary patterns at 32 weeks gestation, and (ii) what the mother reported feeding to the child at 3 and 4.5 years of age. The FFQ contains a set of questions about the frequency of consumption of a wide variety of foods and drinks, with higher scores indicating higher frequency of intake (i.e., never or rarely, once in 2 weeks, 1–3 times/ week, 4–7 times/week, more than once daily). An unhealthy diet score had been previously created through the use of confirmatory factor analysis (Barker *et al.*, 2013). Specifically, a second order latent factor, which indicated level of general unhealthy diet (higher = worse), was defined by two first order latent factors: processed food (i.e., fried food, meat pies or pasties, chips) and confectionery (i.e., crisps, chocolate bars, cakes or buns, biscuits). At each age, these models showed acceptable fit to the data: CFI = 0.927 through 0.940; TLI = 0.900 through 0.902; RMSEA = 0.041 through 0.048.

*Child emotional-behavioral dysregulation.* As done previously (Barker, 2013), at child age 2 years, four subscales of the Carey Infant Temperament Scale (Carey and McDevitt, 1978) – activity, adaptability, intensity and mood – were used for the operationalization of a latent construct of child emotional-behavioral dysregulation (hereafter referred as child dysregulation). At child age 4 and 7 years, three subscales of the Strengths and Difficulties Questionnaire (SDQ) (Goodman, 2001) – hyperactivity, conduct problems and emotional difficulties – were used for the operationalization of a latent construct of child dysregulation.

Although the Carey Infant Temperament Scales the SDQ provide different measures, their subscales are based on maternal reports assessing levels of child internalizing and externalizing symptoms. Moreover, as shown previously (Barker, 2013), a coefficient of prediction from latent Carey Temperament Infant Scales (at age 2) to the latent SDQ (at age 4) was of a magnitude ( $b = 0.597$ , S.E. 0.013,  $p < 0.0001$ ) suggestive of homotypic stability of the construct.

*Control variables* were summated into an index and regressed on all study variables, including the child dysregulation outcomes, in the results presented below. Perinatal control variables consisted of parity and birth complications (described above). Prenatal control variables included (1) mother's involvement with police, (2) substance use, and (3) mother experiencing cruelty from partner. We also controlled for repeated measures of contextual risk factors, via maternal reports, which are known to be prospectively associated with child dysregulation (Barker, 2013, Barker *et al.*, 2012). These assessments spanned pregnancy, child age 0 to 2 years, and child age 2 to 4 years. At each time point, seven total risks (scored 1 with indication, 0 without indication) were assessed: (1) inadequate basic living conditions; (2) inadequate housing; (3) housing defects; (4) poverty; (5) being a single caregiver; (6) early parenthood; and (7) low educational attainment. Further details on the prenatal, perinatal and contextual risk factors and the assessment time points are shown in Supplementary Table 1.

*Selected sample of ALSPAC mothers and children.* Of the original 14 541 mother-offspring pairs, a **total of 7814 singleton mothers** who completed the SDQ assessment at child age 7 years were included in this study. Mother-offspring pairs who had **no** data on the SDQ at child age 7 years were excluded. Of the 7814 who were included, 99.3% ( $n=7758$ ) had complete data for prenatal depression symptoms; 98.8% ( $n=7721$ ) for postnatal depression symptoms; 94.9% ( $n=7413$ ) for prenatal unhealthy diet; 92.9% ( $n=7260$ ) for postnatal unhealthy diet at 3 years; 91.9% ( $n=7184$ ) for postnatal unhealthy diet at 4.5 years; 93.2% ( $n=7276$ ) for child dysregulation at age 2 years; and 90.1% ( $n=7044$ ) for child dysregulation at age 4 years.

In a multivariate model, we tested the extent to which the study variables were associated with exclusion. Prenatal depression symptoms (OR = 1.19; 95% CI = 1.15–1.25), postnatal depression symptoms (OR = 1.17; 95% CI = 1.12–1.23), unhealthy diet in pregnancy (OR = 1.12; 95% CI = 1.06–1.19) – and at child age 3 years (OR = 1.34; 95% CI = 1.26–1.42) and 4.5 years (OR = 0.79; 95% CI = 0.73–0.85) – as well as child dysregulation at age 4 years (OR = 1.17; 95%



CI = 1.10 – 1.24) were all significantly associated with exclusion in the present analysis. We note that inclusion of these variables in the analysis – in conjunction with missing data replacement by full-information maximum likelihood – can help to minimize bias and maximize recoverability of ‘true’ scores (Little & Rubin, 2002).

### *Analysis*

The analysis proceeded in two main steps. In the first step, we performed a path analysis examining inter-relations between maternal depression symptoms and unhealthy diet, and their independent associations with child dysregulation. In the second step, four indirect pathways that could lead to child dysregulation at age 7 years were examined. *Pathway 1* examined the degree to which **prenatal maternal depression** associated with increased child dysregulation at age 7 indirectly via an unhealthy postnatal diet. *Pathway 2* examined the degree to which unhealthy prenatal diet associated with increased child dysregulation at age 7 indirectly via postnatal maternal depression symptoms. *Pathway 3* examined the degree to which prenatal maternal depression symptoms associated with child dysregulation at age 7 years via levels of child dysregulation at ages 2 and 4 years. *Pathway 4* examined the degree to which prenatal unhealthy diet associated with child dysregulation at age 7 years via levels of child dysregulation at ages 2 and 4 years.

Indirect pathways were programmed in model constraint statements in Mplus (Muthén and Muthén, 1998-2013). For example, for *Pathway 1*, the indirect associations were defined by the product term of the two pathways of interest (i.e., maternal depression *to* unhealthy diet *BY* unhealthy diet *to* child dysregulation, and so forth). Because standard errors underlying indirect effects (i.e., product terms) are known to be skewed, we bootstrapped all indirect effects 10,000 times with bias corrected 95% confidence intervals. The indirect pathways reported below are based on the bootstrapped variability around the product of non-standardized

path coefficient estimates. **An example of the Mplus code used in this analysis with the indirect effect of prenatal maternal depression to child dysregulation at age 7, via child dysregulation at age 2 and age 4:**

```
!auto regression child dysregulation
dysage4 on dysage2 (a2);
dysage7 on dysage4 (a3);
!cross-lag child dysregulation on prenatal maternal depression symptoms
dysage2 on pre_dep (a1);
model constraint: new(indirectdep);
indirectdep = a1*a2*a3;
```

Model fit was established using root mean square error of approximation (RMSEA; acceptable fit  $\leq 0.08$ ), as well as the Comparative Fit Index and Tucker-Lewis Index (CFI & TLI; acceptable fit  $\geq 0.90$ ) (Bentler, 1990, Browne and Cudeck, 1993). Maximum likelihood estimation with robust standard errors was used to estimate the model parameters, and missing data was handled through Full Information Maximum Likelihood. All analyses were conducted using Mplus version 7.0 (Muthén and Muthén, 1998-2013).

## Results

### *Descriptive statistics and correlations amongst study variables*

Prior to presenting the overall results, we first show the descriptive statistics. Table 1 contains the demographic, pregnancy and birth characteristics of the mother-child pairs included in this study. Table 2 shows the pair-wise correlation coefficients amongst the study variables – as well as the means and standard deviations. Higher levels of prenatal maternal depression symptoms

were associated with higher levels of prenatal and postnatal unhealthy diet, as well as with higher levels of postnatal maternal depression symptoms. Prenatal unhealthy diet scores were not associated with postnatal maternal depression symptoms. Higher levels of child dysregulation (age 2, 4, and 7 years) were associated with higher levels of (prenatal and postnatal) maternal depression symptoms and unhealthy diet. The control variables were associated with all study variables, particularly prenatal and postnatal maternal depression symptoms. Of note, there was strong temporal stability within construct (i.e., maternal depression symptoms, unhealthy diet and child dysregulation, respectively).

*Step 1: Autoregressive cross-lagged model (ARCL)*

Figure 1 depicts the ARCL model, which showed acceptable fit to the data ( $\chi^2 [133] = 3275.632$ ;  $p < .0001$ ; CFI = 0.910; TLI = 0.884; RMSEA = 0.055, 90% CIs = 0.053, 0.057). Four results are highlighted. First, higher levels of prenatal maternal depression symptoms were prospectively associated with higher levels of postnatal unhealthy diet. Second, higher levels of both prenatal and postnatal maternal depression symptoms and prenatal and postnatal unhealthy diet were associated with higher levels of child dysregulation, with the exception that unhealthy diet at 4.5 years was not significantly associated with child dysregulation at age 7 years. Third, higher levels of child dysregulation (age 2 and 4 years) were prospectively associated with higher levels of postnatal unhealthy diet (age 3 and 4.5 years), respectively. Fourth, each construct showed high stability over time.

*Step 2: Indirect Pathways*

In the second step of the analysis, four indirect pathways that could lead to child dysregulation at age 7 years were examined (Table 3). Three results are highlighted. First, as seen in *Pathway 1*, prenatal maternal depression symptoms were associated with unhealthy diet at child age 3 years, which, in turn, was associated with higher levels of child dysregulation at age 7 years, via higher levels of child dysregulation at age 4 years. Of note, the counterpart indirect pathway

(*Pathway 2*) – from prenatal unhealthy diet to postnatal maternal depression symptoms – did not differ from zero (i.e., the 95% CIs crossed zero). Second, with regard to *Pathway 3*, prenatal maternal depression symptoms were associated with higher levels of child dysregulation at age 7 years, via higher levels of child dysregulation at ages 2 and 4 years. Third, as seen in *Pathway 4*, prenatal unhealthy diet was associated with higher levels of child dysregulation at age 7 years, via higher levels of child dysregulation at ages 2 and 4 years.

### Discussion

Using a large epidemiological birth cohort study, we tested 4 indirect pathways – beginning in pregnancy – that could lead to child dysregulation. Study results indicated that higher levels of maternal depression symptoms during pregnancy were associated with higher unhealthy diet of the child provided by the caregiver(s) – in the case of the present study, mothers – during the postnatal period, which, in turn, led to higher levels of child emotional-behavioral dysregulation at age 7 years (*Pathway 1*). We did not find evidence that unhealthy diet in pregnancy associated with postnatal maternal depression, which, in turn, increased child emotional-behavioral dysregulation (*Pathway 2*). The results did indicate that both maternal depression symptoms and unhealthy diet during pregnancy were independently associated with higher levels of child emotional-behavioral dysregulation at age 7 years (*Pathways 3 and 4*), via stability of child dysregulation at ages 2 and 4 years.

The current study adds to a small but growing body of evidence suggesting that maternal depression and unhealthy dietary patterns are inter-related risk factors that can be synergistically associated with adverse child outcomes (Monk *et al.*, 2013). It is worth noting that one of the key diagnostic features of depressive disorders is presenting with changes in appetite (American Psychiatric Association, 1994), and that maternal anxiety and/or depressed mood during pregnancy associates with unhealthy eating patterns (Barker *et al.*, 2013, Hurley *et al.*, 2005), especially in low-income mothers (Braveman *et al.*, 2010). The current results extend these studies to show that

higher symptoms of maternal depression during pregnancy can be prospectively associated with what a mother feeds her child during the postnatal period.

Prenatal maternal depression symptoms and prenatal unhealthy diet were also independently associated with child dysregulation at age 7 years via stability of dysregulation through childhood. Of note, both of these risk factors can affect fetal development by different biological mechanisms. For example, abnormal hormonal and physiological profiles of depressed mothers – such as reduced blood flow and increased levels of cortisol – can have a negative impact on fetal development (Glover *et al.*, 2010, Weinstock, 2008). Unhealthy (e.g., high-fat) diet has been associated with reduction of neural plasticity and disturbances of fetal serotonergic and dopaminergic systems, independent of nutrient deficiencies (Sullivan *et al.*, 2010, Vucetic *et al.*, 2010, Wu *et al.*, 2003). Hence, both maternal depression and unhealthy diet can impair neural fetal developmental and thereby increase risk and susceptibility for abnormal child dysregulation and cognitive function (Barker *et al.*, 2013, Jacka *et al.*, 2013, Liu *et al.*, 2004).

Other relevant findings from this study include the strong stability in maternal depression symptoms from prenatal to postnatal periods, which is congruent with findings from previous studies (Barker, 2013, Barker *et al.*, 2013, Campbell *et al.*, 2007). Moreover, there was a strong stability in the unhealthy nutrition factor. That said, the type of analysis employed here does not shed light on the degree to which certain children might be (a) temporarily, (b) intermittently or (c) continuously exposed to unhealthy diet and/or maternal depression during the prenatal and/or postnatal periods.

In addition, family processes may explain some of the effects identified here. For example, child dysregulation may be associated with subsequent parental depression, which could further relate to the nutritional environment, but parental depression might also be at least partially related to the association between early unhealthy diet and subsequent child dysregulation (e.g., (Jacka *et al.*, 2013)). An interesting (but not hypothesized) result of the present study was that child

dysregulation was prospectively associated with higher levels of unhealthy diet of the child (as reported by the mothers). Future research might focus on the degree to which children can demand (from caregivers) unhealthy diets once the pattern is established early in the life course. Indeed, recent studies have identified 'evocative' child effects on parenting (Elam *et al.*, 2013).

Five main limitations should be considered when interpreting the present results. First, this research is correlational in nature; hence no causative relationship can be derived. Moreover, the magnitude of the prospective association between maternal depression, unhealthy nutrition and child dysregulation was not large, so the associations should not be interpreted as deterministic. That said, measurement error might be impacting the magnitude of the reported associations. For example, dietary pattern analysis using factor analysis usually only detects a small percentage of the variance in dietary intakes. Also, the assessment of diet is prone to extensive measurement error. Thus, it is quite likely that the 'true' association between exposure to unhealthy diet and child outcome are **weaker or stronger** than those detected in the current study. Second, the key measures were based on maternal self-reports rather than on more thorough clinical observations. Indeed, reliance on a single reporter may artificially inflate the magnitude of associations between constructs considered in the current study. Future studies should incorporate diagnostic interviews, multiple informants and biological indicators (e.g. metabolomics) of the nutritional intake of the mother and/or child (Gow *et al.*, 2013). Third, although the ALSPAC mother-offspring pairs represent a broad spectrum of ethnic and socio-economic backgrounds, the sample includes relatively low rates of ethnic minorities that can limit generalizability of the findings (Goodman *et al.*, 2011). Fourth, although this study controlled for many potential confounding prenatal and postnatal factors, we did not assess other relevant potential confounders (e.g., environmental factors such as quality of parenting). Neither did we control for genetic factors. Indeed, in the present study, mothers were biologically related to their children. In such a design it is not possible to account for common genetic influences, such as passive genotype-environment correlations, which

may underlie mother-to-child effects. Fifth, this study focused on unhealthy dietary intake of the mother and child. Previous research strongly suggests that that people with depression not only preferentially choose high fat, sugary foods, but also eat fewer vegetables and fruits. Hence there is a higher intake of unhealthy and an insufficient intake of nutrition-dense foods (i.e., healthy diets). This is important as high fat and sugar foods can be directly noxious to the brain and body, while nutrient and fibre insufficiency impose their own detrimental outcomes, potentially via different pathways (Akbaraly et al., 2009; Barker *et al.*, 2013, Jacka *et al.*, 2013).

In summary, maternal depression and unhealthy nutrition in pregnancy and early life periods are inter-related and independent risk factors for child dysregulation. As recently proposed by Monk and colleagues, the understanding of the early origins of child and adolescent health and disease needs a developmental framework in which the independent and synergistic influence of early exposures to different environmental risk factors can be assessed at different time points of child development (Monk *et al.*, 2013). Results from the present study have the potential to yield important developmental information to inform public policy, and to be used for preventive interventions.

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#### Conflict of interest

None.

#### Ethical standards

The authors assert that all procedures contributing to this work comply with the ethical standards of the relevant national and institutional committees on human experimentation and with the Helsinki Declaration of 1975, as revised in 2008.



## References

- Akbaraly TN, Sabia S, Shipley MJ, Batty GD & Kivimaki M (2013). Adherence to healthy dietary guidelines and future depressive symptoms: evidence for sex differentials in the Whitehall II study. *American Journal of Clinical Nutrition* 97, 419-27.
- Akbaraly, Tasnime N., Brunner, Eric J., Ferrie, Jane E., Marmot, Michael G., Kivimaki, Mika, & Singh-Manoux, Archana. (2009). Dietary pattern and depressive symptoms in middle age. *The British Journal of Psychiatry*, 195, 408-413.
- American Psychiatric Association (1994). *Diagnostic and statistical manual of mental disorders* (4<sup>th</sup> ed.). American Psychiatric Association: Washington, DC.
- Barker ED (2013). The duration and timing of maternal depression as a moderator of the relationship between dependent interpersonal stress, contextual risk and early child dysregulation. *Psychological Medicine* 43, 1587-96.
- Barker ED, Copeland W, Maughan B, Jaffee SR & Uher R (2012). Relative impact of maternal depression and associated risk factors on offspring psychopathology. *British Journal of Psychiatry* 200, 124-9.
- Barker ED, Kirkham N, Ng J & Jensen SK (2013). Prenatal maternal depression symptoms and nutrition, and child cognitive function. *British Journal of Psychiatry* 203, 417-21.
- Bentler PM (1990). Comparative fit indexes in structural models. *Psychological Bulletin* 107, 238-46.
- Boyd A, Golding J, Macleod J, Lawlor DA, Fraser A, Henderson J, Molloy L, Ness A, Ring S & Davey Smith G (2013). Cohort Profile: the 'children of the 90s'--the index offspring of the Avon Longitudinal Study of Parents and Children. *International Journal of Epidemiology* 42, 111-27.
- Braveman P, Marchi K, Egerter S, Kim S, Metzler M, Stancil T & Libet M (2010). Poverty, near-poverty, and hardship around the time of pregnancy. *Maternal and Child Health Journal* 14, 20-35.

Browne MW & Cudeck R (1993). Alternative ways of assessing model fit. In *Testing Structural Equation Models* (ed. K. A. Bollen and J. S. Long), pp. 230–258. Sage: Newbury Park, CA.

Campbell SB, Matestic P, von Stauffenberg C, Mohan R & Kirchner T (2007). Trajectories of maternal depressive symptoms, maternal sensitivity, and children's functioning at school entry. *Developmental Psychology* 43, 1202-15.

Carey WB & McDevitt SC (1978). Revision of the Infant Temperament Questionnaire. *Pediatrics* 61, 735-739.

Cox JL, Holden JM & Sagovsky R (1987). Detection of postnatal depression: The development of the Edinburgh 10-item Postnatal Depression Scale. *British Journal of Psychiatry* 150, 782-786.

Elam KK, Harold GT, Neiderhiser JM, Reiss D, Shaw DS, Natsuaki MN, Gaysina D, Barrett D & Leve LD (2014). Adoptive Parent Hostility and Children's Peer Behavior Problems: Examining the Role of Genetically Informed Child Attributes on Adoptive Parent Behavior. *Developmental Psychology* 50, 1543-52.

Fraser A, Macdonald-Wallis C, Tilling K, Boyd A, Golding J, Davey Smith G, Henderson J, Macleod J, Molloy L, Ness A, Ring S, Nelson SM & Lawlor DA (2013). Cohort Profile: the Avon Longitudinal Study of Parents and Children: ALSPAC mothers cohort. *International Journal of Epidemiology* 42, 97-110.

Glover V, O'Connor TG & O'Donnell K (2010). Prenatal stress and the programming of the HPA axis. *Neuroscience & Biobehavioral Reviews* 35, 17-22.

Moshfegh AJ (2001). Psychometric properties of the strengths and difficulties questionnaire. *Journal of the American Academy of Child & Adolescent Psychiatry* 40, 1337-45.

Goodman SH & Gotlib IH (1999). Risk for psychopathology in the children of depressed mothers: a developmental model for understanding mechanisms of transmission. *Psychological Review* 106, 458-90.

Goodman SH, Rouse MH, Connell AM, Broth MR, Hall CM & Heyward D (2011). Maternal depression and child psychopathology: a meta-analytic review. *Clinical Child and Family Psychology Review* 14, 1-27.

Gow RV, Vallee-Tourangeau F, Crawford MA, Taylor E, Ghebremeskel K, Bueno AA, Hibbeln JR, Sumich A & Rubia K (2013). Omega-3 fatty acids are inversely related to callous and unemotional traits in adolescent boys with attention deficit hyperactivity disorder. *Prostaglandins, Leukotrienes & Essential Fatty Acids* 88, 411-8.

Hiza HA, Casavale KO, Guenther PM & Davis CA (2013). Diet quality of Americans differs by age, sex, race/ethnicity, income, and education level. *Journal of the Academy of Nutrition and Dietetics* 113, 297-306.

Hurley KM, Caulfield LE, Sacco LM, Costigan KA & Dipietro JA (2005). Psychosocial influences in dietary patterns during pregnancy. *Journal of the American Dietetic Association* 105, 963-6.

Jacka FN, Ystrom E, Brantsaeter AL, Karevold E, Roth C, Haugen M, Meltzer HM, Schjolberg S & Berk M (2013). Maternal and early postnatal nutrition and mental health of offspring by age 5 years: a prospective cohort study. *Journal of the American Academy of Child & Adolescent Psychiatry* 52, 1038-47.

**Jensen SK, Dumontheil I & Barker ED (2014). Developmental Inter-Relations between Early Maternal Depression, Contextual Risks, and Interpersonal Stress, and Their Effect on Later Child Cognitive Functioning. *Depression and Anxiety* 31, 599-607.**

Little RJA & Rubin DB (2002). *Statistical Analysis with Missing Data*, 2nd ed. New York: Wiley.

Liu J, Raine A, Venables PH & Mednick SA (2004). Malnutrition at age 3 years and externalizing behavior problems at ages 8, 11, and 17 years. *American Journal of Psychiatry* 161, 2005-13.

Monk C, Georgieff MK & Osterholm EA (2013). Research review: maternal prenatal distress and poor nutrition - mutually influencing risk factors affecting infant neurocognitive development. *Journal of Child Psychology and Psychiatry* 54, 115-30.

Moshfegh AJ (2007). Research to advance understanding of the interrelationship of poverty and nutrition. *Journal of the American Dietetic Association* 107, 1882-5.

Murray L & Carothers A (1990). The validation of the Edinburgh Post-natal Depression Scale on a community sample. *British Journal of Psychiatry* 157, 288-290.

Muthén LK & Muthén BO (1998-2013). *Mplus. Statistical analyses with latent variables. User's guide*. Muthén & Muthén: Los Angeles, CA.

Nyaradi A, Li J, Hickling S, Foster J & Oddy WH (2013). The role of nutrition in children's neurocognitive development, from pregnancy through childhood. *Frontiers in Human Neuroscience* 7, 97.

Pachter LM, Auinger P, Palmer R & Weitzman M (2006). Do parenting and the home environment, maternal depression, neighborhood, and chronic poverty affect child behavioral problems differently in different racial-ethnic groups? *Pediatrics* 117, 1329-38.

Raine A, Mellinger K, Liu J, Venables P & Mednick SA (2003). Effects of environmental enrichment at ages 3-5 years on schizotypal personality and antisocial behavior at ages 17 and 23 years. *American Journal of Psychiatry* 160, 1627-35.

Rao TS, Asha MR, Ramesh BN & Rao KS (2008). Understanding nutrition, depression and mental illnesses. *Indian Journal of Psychiatry* 50, 77-82.

Rechenberg K & Humphries D (2013). Nutritional interventions in depression and perinatal depression. *Yale Journal of Biology and Medicine* 86, 127-37.

Rogers I & Emmett P (1998). Diet during pregnancy in a population of pregnant women in South West England. ALSPAC Study Team. Avon Longitudinal Study of Pregnancy and Childhood. *European Journal of Clinical Nutrition* 52, 246-50.

Scott D & Happell B (2011). The high prevalence of poor physical health and unhealthy lifestyle behaviours in individuals with severe mental illness. *Issues in Mental Health Nursing* 32, 589-97.

Silberg J & Rutter M (2002). Nature-nurture interplay in the risks associated with parental depression. In *Children of depressed parents: Mechanisms of risk and implications for treatment* (ed. S. H. Goodman and I. H. Gotlib), pp. 13-36. American Psychological Association: Washington, DC.

Sullivan EL, Grayson B, Takahashi D, Robertson N, Maier A, Bethea CL, Smith MS, Coleman K & Grove KL (2010). Chronic consumption of a high-fat diet during pregnancy

causes perturbations in the serotonergic system and increased anxiety-like behavior in nonhuman primate offspring. *Journal of Neuroscience* 30, 3826-30.

Surveys OoPCa (1991). *Standard Occupational Classification Volume 3*. HMSO: London.

Vucetic Z, Kimmel J, Totoki K, Hollenbeck E & Reyes TM (2010). Maternal high-fat diet alters methylation and gene expression of dopamine and opioid-related genes.

*Endocrinology* 151, 4756-64.

Weinstock M (2008). The long-term behavioural consequences of prenatal stress.

*Neuroscience & Biobehavioral Reviews* 32, 1073-86.

Wu A, Molteni R, Ying Z & Gomez-Pinilla F (2003). A saturated-fat diet aggravates the outcome of traumatic brain injury on hippocampal plasticity and cognitive function by reducing brain-derived neurotrophic factor. *Neuroscience* 119, 365-75.

Table 1. *Sample characteristics*

	Descriptive	N <sup>a</sup>
Demographics, pregnancy and birth information		
Mother age at the time of child birth, mean (SD)	25.39 (4.86)	7673
Mother ethnicity, No. (%) caucasian/white	7423 (95.0%)	7814
Mother education level, No. (%) achieved A-levels or above	3142 (41.5%)	7578
Marital status, No. (%) married	6204 (81.1%)	7653
Social class, No. (%) low socio-economic status*	622 (9.6%)	6475
Offspring sex, No. (%) male	3992 (51.1%)	7814
Birth weight (in grams), mean (SD)	3430.0 (536.0)	7717
Primiparity No. (%) Yes	2672 (34.9%)	7653
Birth complications, No. (%) with at least 1 complication	1414 (19.9%)	7111
Mother involvement with police - pregnancy, No. (%) Yes	133 (1.9%)	7089
Substance use - pregnancy, No. (%) Yes	1495 (19.2%)	7760
Mother experiencing cruelty from partner - pregnancy, No. (%) Yes	343 (4.8%)	7104
Inadequate basic living conditions - pregnancy, No. (%) Yes	184 (2.4%)	7623
Inadequate housing - pregnancy, No. (%) Yes	360 (4.7%)	7693
Housing defects - pregnancy, No. (%) Yes	831 (10.8%)	7693
Poverty - pregnancy, No. (%) Yes*	601 (8.1%)	7382
Being a single caregiver - pregnancy, No. (%) Yes	121 (1.6%)	7671
Early parenthood, No. (%) Yes	373 (4.8%)	7814
Low educational attainment - pregnancy, No. (%)	844 (11.1%)	7604

<sup>a</sup> N = number of mothers with available information from the selected sample of 7814.

\*via the Registrar General's social class scale (Surveys, 1991).

Table 2. Correlations and descriptive statistics of the study variables (in N=7814)

	1.	2.	3.	4.	5.	6.	7.	8.	9.
1. Child Dys Age 2y <sup>a</sup>	—								
2. Child Dys Age 4y <sup>b</sup>	0.568***	—							
3. Child Dys Age 7y <sup>b</sup>	0.459***	0.810***	—						
4. Mat dep Prenatal <sup>c</sup>	0.241***	0.336***	0.278***	—					
5. Mat dep Postnatal (0-3y) <sup>c</sup>	0.303***	0.394***	0.325***	0.848***	—				
6. Unhealthy Diet Prenatal <sup>d</sup>	0.104***	0.081***	0.064***	0.024*	0.012	—			
7. Unhealthy Diet 3y <sup>d</sup>	0.118***	0.127***	0.094***	0.077***	0.037**	0.401***	—		
8. Unhealthy Diet 4.5y <sup>d</sup>	0.092***	0.113***	0.075***	0.059***	0.036**	0.250***	0.621***	—	
9. Control Risk Factors <sup>e</sup>	0.092***	0.197***	0.188***	0.276***	0.238***	0.086***	0.121***	0.080***	—
<i>Mean (SD)</i>	75.17 (14.13) <sup>a</sup>	7.26 (3.82) <sup>b</sup>	5.71 (4.08) <sup>b</sup>	12.61 (8.44) <sup>c</sup>	16.25 (11.53) <sup>c</sup>	16.33 (3.51) <sup>d</sup>	21.16 (4.03) <sup>d</sup>	22.47 (3.82) <sup>d</sup>	1.62 (2.14) <sup>e</sup>

Abbreviations: Child Dys: child emotional-behavioral dysregulation; Mat dep: maternal depression; y: years; SD: standard deviation.

\*  $p \leq .05$ ; \*\* $p \leq .01$ ; \*\*\* $p \leq .001$ .

<sup>a</sup> By **raw** means of the activity, adaptability, intensity and mood subscales of the Carey Infant Temperament Scale.



<sup>b</sup> By **raw** means of the hyperactivity, conduct problem and emotional difficulty subscales of the Strengths and Difficulties Questionnaire (SDQ).

<sup>c</sup> By **raw** means of the Edinburgh Postnatal Depression Scale. A latent depression score was created for the prenatal and postnatal periods, with higher scores meaning higher levels of depressive symptoms.

<sup>d</sup> By **raw** means of the food frequency questionnaire (FFQ). An unhealthy diet factor was created at each time point through the use of confirmatory factor analysis, with higher scores meaning higher levels of unhealthy diet.

<sup>e</sup> Control risk factors included in the overall model are displayed in Supplementary Table 1.

Table 3. Indirect associations of prenatal and postnatal maternal depression symptoms and unhealthy diet with child emotional-behavioral dysregulation

	Prenatal risk factors	Postnatal risk factors	Child dysregulation			Estimate (95% CI)
			Age 2y	Age 4y	Age 7y	
Pathway 1	Maternal depression (+)	Unhealthy diet 3y (+)	---	(+)	(+)	0.01 (0.01-0.02)**
Pathway 2	Unhealthy diet (+)	Maternal depression (+)	---	(+)	(+)	-0.01 (-0.02-0.00)
Pathway 3	Maternal depression (+)	Maternal depression (+)	(+)	(+)	(+)	0.15 (0.12-0.18)***
Pathway 4	Unhealthy diet (+)	Unhealthy diet (+)	(+)	(+)	(+)	0.11 (0.08-0.15)***

Abbreviations: y: years; CI: bias corrected confidence intervals; [+] = higher; -- = not included in pathway; y = year; CI = confidence interval

\*  $p \leq .05$ ; \*\* $p \leq .01$ ; \*\*\* $p \leq .001$ .

Fig. 1.

Title: Path Model for Maternal Depression Symptoms, Unhealthy Diet, and Child Emotional-Behavioral Dysregulation

Legend: Path coefficients: Using Cohen's population effect size statistics, 0.10=small effect , 0.24=medium effect , 0.37=large effect. Solid arrow =  $p < .05$  (\*  $p \leq .05$ ; \*\* $p \leq .01$ ; \*\*\* $p \leq .001$ ); dashed arrow =  $p > .05$ . Abbreviations: Dep: depression; Child dys: child dysregulation; wks: weeks; y: years.