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Trajectories of maternal gestational weight gain and child cognition assessed at 5 years of age in a prospective cohort study

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Abstract

Background—There has been concern that low gestational weight gain may cause poor fetal neurodevelopment.

Methods—The association between maternal weight gain and child IQ was examined using serial antenatal weight measurements (median 12) from a prospective cohort of non-obese Scandinavian women (1986–1988). Linear mixed models with piecewise regression were used to estimate participants' (n=552) trimester-specific average rate of weight gain. Linear regression was used to assess the association between weight gain and children's (n=344) full-scale, performance, and verbal IQ measured at age 5 using the Wechsler Preschool and Primary Scales of Intelligence-Revised.

Results—Children born to mothers who gained below vs. within the 2nd trimester 2009 recommendations tended to have lower IQ scores [Full-scale: 106.6 (standard deviation 15.1) vs. 110.2 (15.2), p=0.04; verbal: 102.5 (14.3) vs. 105.0 (14.9), p=0.10; performance: 109.5 (15.4) vs. 113.4 (14.5), p=0.03]. After adjustment there were no differences in child IQ by weight gain

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adequacy [full-scale: $\beta_{\text{below}}=-1.1$ (95% confidence interval (CI) -5.1, 2.9), $\beta_{\text{above}}=1.5$ (-3.8, 6.8); verbal: $\beta_{\text{below}}=-0.2$ (-3.1, 2.6), $\beta_{\text{above}}=1.8$ (-3.6, 7.3); performance $\beta_{\text{below}}=-1.2$ (-4.6, 2.2), $\beta_{\text{above}}=1.0$ (-4.6, 6.7)]. No differences were observed based on 3rd trimester adequacy. No differences were observed in IQ scores by quintile of weight gain for any trimester, particularly after adjustment for maternal IQ.

Conclusions—Our findings are reassuring that among normal weight women, pregnancy weight gain is not associated with child cognitive development. Further investigation should be conducted in contemporary cohorts that also include obese mothers, who are at the greatest risk for low weight gain.

Keywords

Pregnancy; weight gain; weight loss; neurodevelopment; cognition

INTRODUCTION

Gestational weight gain is an important predictor of maternal and child outcomes.[1] In 2009 the Institute of Medicine (IOM) recommend total and weekly rates of weight gain for pregnant women to optimize outcomes and balance risks with both low and high weight gain.[2] Because of the potential to reduce the risk of child obesity and improve long-term maternal health, [3,4] weight gain below recommendations may be desirable, especially for obese mothers.[5,6] Yet lower maternal weight gain may hinder fetal neurodevelopment.

The outcome of child neurodevelopment in relation to maternal weight gain remains understudied.[2] Of equal note, the findings of the few prior studies are inconsistent. A study of term deliveries observed an inverted U-shaped relation with weight gain; however, this was attenuated with adjustment for familial factors.[7] Another study of term deliveries reported a small positive association between increasing weight gain and better child IQ scores.[8] Albeit not directly comparable with child cognitive outcomes, another study reported an increased risk of autism spectrum disorders with increasing weight gain.[9] Two of these studies were limited in that only total weight gain across pregnancy was available. [7, 9] Using total weight gain limits the ability to assess the impact within particular windows of fetal susceptibility across gestation.[10] In addition, not all studies explored non-linear associations, which may be important given the developing brain's resilience to moderate nutritional insults.[11]

This analysis used serial measures of antenatal weight to comprehensively examine the association between gestational weight gain and children's cognitive abilities, using IQ assessed at 5 years of age. This paper estimated the average rate of weight gain in each trimester and assessed potential non-linear associations. The null hypothesis of this study was that there was no association between trajectories of weight gain and child IQ.

MATERIALS AND METHODS

The NICHD Study of Successive Small-for-Gestational-Age (SGA) Births was a longitudinal cohort study of mothers and their children in Norway and Sweden (1986–1988).

[12] Women were eligible if they were parity 1 or 2, of Caucasian origin, spoke one of the Scandinavian languages, had a singleton gestation, and were <17 weeks gestation by enrollment (n=5,722). A 10% random sample of the eligible women representative of the source population were enrolled (n=561). The postnatal follow-up included 384 (69%) children at approximately 5 years of age. All participants provided signed informed consent, and institutional review board approval was arranged at each participating hospital.

Antenatal study visits were targeted at 17, 25, 33, and 37 gestational weeks. Gestational age was calculated based on the first day of the last menstrual period (LMP) if recalled within 3 days and confirmed within 14 days by the second trimester ultrasound estimate calculated from the biparietal diameter (n=468, 83.4%). If LMP was missing or discrepant with ultrasound findings, the ultrasound estimate was used (n=93, 16.6%). [12] Parity was defined as the number of previous births 20 weeks gestation. At the first visit, women reported their prepregnancy weight and height. Women were instructed to bring their personal health record to each visit. This health record contained the woman's weight recorded at each prenatal visit by her regular health care provider and at hospital admission for delivery. Study midwives extracted the weight and date of each measurement. Within-woman consistency checks for reporting errors were performed.

At the first visit, women reported if they smoked at conception, had chronic diseases, including renal disease, chronic hypertension, heart disease, and diabetes prior to pregnancy, and if they had either nausea or vomiting during pregnancy. At the 33 week visit, women reported their alcohol use during pregnancy. Gestational diabetes was recorded at each visit, and in a subset of women, a third trimester oral glucose tolerance test was performed. Preeclampsia was identified using recorded indications for maternal admission to delivery or labor induction. Women's social background, including marital status, economic situation, and education, were collected at the first visit.

When children were on average 5.2 [standard deviation (SD) 0.2] years of age, child cognition was estimated using the Wechsler Preschool and Primary Scales of Intelligence (WPPSI-R) tool revised in Norwegian and Swedish. Full-scale (overall), verbal and performance (non-verbal) IQ were measured. [13] Maternal IQ was assessed at the same visit using the Raven Progressive Matrices, which primarily measures non-verbal problem-solving abilities. [14]

The analysis involved a two-stage approach. The first stage focused on estimating each woman's trajectory of weight gain. This stage was limited to women with at least one antenatal weight measurement (median 12, max 21) and gestational age at delivery (n=552; 98.4%). Empirical trajectories of mothers' weight were examined, with a random sample of 50 women plotted to help visualize patterns (Figure 1). Next, an average rate of weight gain (kg/w) for each trimester was obtained using a linear mixed random effects model, assuming piecewise linear weight gain, with knots at the beginning of each trimesters (14 and 28 weeks). [15] This model accounted for the variation in the timing and number of weight measurements between women.

A model estimated prepregnancy weight was calculated using the fixed and individual random effects. Where prepregnancy weight was available ($n=547$), the correlation between the modeled and self-reported weight was examined to check for potentially incorrect reports of prepregnancy weight. Correlation was very high ($r=0.995$), with self-reported weight being slightly higher [(mean 61.3 kg (SD 9.6)] than modeled weight [(60.8 kg (9.5))]. Modeled prepregnancy weight was used to calculate prepregnancy body mass index (BMI, kg/m^2) and to categorize women as underweight (BMI <18.5), normal weight (18.5–24.9), overweight (25.0–29.9), or obese (≥ 30.0).[16]

The second stage of the analysis was limited to mother-child pairs with child's IQ ($n=380$) and without missing covariate data ($n=344$) and used linear regression to examine the association between maternal rate of weight gain (described above) and child IQ. This approach relies on the assumption that the error from the first model was small and not propagated into the second stage models; we confirmed this and because previous studies have found that this error has little impact on the results of the second stage model, we did not adjust for this error in second stage.[17] Several approaches were employed to classify weight gain. Second and third trimester rates of weight gain were classified as below or above the IOM recommendations (underweight, 0.44–0.58; normal weight, 0.35–0.50; overweight, 0.23–0.33; and obese, 0.17–0.27 kg/w).[2] The area-under-the-curve method was used to account for the cumulative amount and trajectory of weight gained.[18] Lastly, given the interest in the extremes of weight gain, each trimester's rate of gain was classified into quintiles with the lowest quintile as the reference.

Separate models were fit for each trimester and the weight gain in the prior trimester(s) was considered as a potential confounder. Additional a priori covariates included maternal age, prepregnancy BMI, smoking, alcohol, schooling, marital status, economic status, and chronic diseases, and child sex and age at IQ assessment. The analysis also tested for linear and quadratic trends across quintiles. Sub-analyses adjusted for maternal IQ ($n=281$). The main analyses did not adjust for potential mediators, including preterm birth, pregnancy complications (preeclampsia or gestational diabetes), or birth size. However, because the true association between weight gain and preterm delivery remains unclear and gestational age at delivery is a strong predictor of child development, [19] weight gain trajectories were reevaluated in a sensitivity analysis limited to women who delivered full-term (≥ 37 gestational weeks) without gestational diabetes or preeclampsia ($n=494$) and then re-analyzed with the outcome of child IQ in the sample with maternal IQ ($n=247$).

There was missing data on covariates and follow-up (mostly due to the site in Sweden where one of the questionnaires was not given for a large proportion of women and lost to follow-up was common due to long travel times as women were recruited from across the entire country). To evaluate the impact of missing data we performed a sensitivity analysis using multiple imputation for missing data ($M=20$). All analyses were performed using SAS version 9.4 (SAS Institute Inc., Cary, NC) and P -values <0.05 were considered significant.

RESULTS

Sample characteristics are shown in Table 1. There were no differences between the weight gain trajectory sample (n=552), the main child IQ sample (n=344), or the subsample with maternal IQ available (n=281). Women were on average 29 years of age, with 69% having had one prior birth, and the majority had a normal prepregnancy weight (82.3%). On average, children's performance IQ scores [111.1 (14.9)] were higher than verbal scores [103.9 (14.6)], however, the variance was similar between the two measures. Maternal IQ was positively correlated with child IQ ($r=0.32$ to 0.38).

The average rate of weight gain differed across trimesters ($P<0.001$), with the lowest rate in the first [0.24 (0.12) kg/w] and the highest in the third [0.38 (0.10) kg/w]. Weight loss was uncommon, but some women lost weight during the first (n=6, 1.7%) or second (n=1, 0.3%) trimester. During the second trimester, the majority (61.1%) of women gained below the 2009 IOM recommendations and only 29.7% gained within, but the percent of women gaining within guidelines increased to 50.0% during the third trimester.

Overall unadjusted IQ scores tended to be highest among children of women who gained within the recommendations (Table 2). After adjustment there were no significant differences in child IQ by adequacy of weight gain.

Using cumulative weight gain, unadjusted IQ scores were lowest with low weight gain (1st or 2nd quintile) and tended to peak in the range of the 4th quintile (Table 3). After adjustment, only full IQ scores were significantly higher among children of women who gained within the 4th quintile compared the 1st quintile. With additional adjustment for maternal IQ there were no significant differences in children's IQ scores between quintiles of cumulative weight gain.

Because the threshold at which weight gain may be associated with child IQ may be below the current recommended threshold for low weight gain and such relationship may differ by trimester, we evaluated the association using a more sensitive approach based on trimester-specific quintiles (Table 4). Unadjusted IQ scores tended to be lowest among children of women who gained within the 1st quintile and highest among children of women who gained within the 4th quintile in the second and third trimester. After confounder adjustment including maternal IQ, no significant differences in children's IQ scores were observed between quintiles of maternal weight gain. Sensitivity analyses using multiple imputation for missing data resulted in similar results with no meaningful differences in estimates of children's IQ across maternal weight gain (data not shown).

Sensitivity analyses were performed limited to women who delivered at term and without gestational diabetes or preeclampsia and with maternal IQ data available (n=247). Third trimester maternal weight gain was associated with higher children's performance IQ scores, but not verbal scores. Specifically compared to the 1st quintile of weight gain, children of mothers who gained in the 2nd [6.3 (95% CI 0.1, 12.6)], 3rd [5.0 (95% CI -2.1, 12.0)], 4th [9.0 (95% CI 1.3, 16.7)], and 5th [8.6 (95% CI -1.0, 18.3)] quintile had higher IQ scores, although not all quintiles were statistically significant. Of note, there was no difference in

the estimates with further adjustment for gestational age among this term sample (data not shown).

DISCUSSION

In this predominately normal weight cohort of Scandinavian mothers and their children, maternal pregnancy weight gain was not associated with child IQ scores at 5 years of age. Furthermore, with a more sensitive analysis focused on quintiles of weight gain, we observed that even below the threshold for low weight gain there were no differences observed in children's IQ scores across levels of weight gain, particularly after adjustment for maternal IQ. This analysis was unique in that serial measures of maternal weight gain allowed for the examination of trimester specific associations and the analysis accounted for maternal IQ.

Only a few prior studies have examined the association between maternal weight gain and child neurodevelopment and as previously discussed the findings have been inconsistent. Two of the studies relied on total gestational weight gain.[7, 9] Because total weight gain is inherently correlated with length of gestation, outcomes also related to length of gestation—like children's neurodevelopment—may be biased.[20] In contrast, the current study used serial measures of weight gain to model the average rate during each trimester and the cumulative pattern of weight gain across the entire length of gestation using the area under the curve approach.[18] Using either approach there was no significant or meaningful association between weight gain and child IQ scores, particularly after adjustment for maternal IQ. One prior study estimated the rate of weight gain early and late in pregnancy among term deliveries and found that children's cognitive scores increased with increasing weight gain.[8] The current study builds on this earlier paper with trimester specific results by examining for a potential plateau in this relationship or a threshold after which maternal weight gain no longer impacts child cognition and linear gains in IQ are no longer observed. Interestingly, we did not observe a significant association between maternal weight gain and child IQ in the overall sample. However, in agreement with this previous study we found that when the sample was limited to full-term deliveries third trimester weight gain was associated with higher IQ scores than the lowest level in our normal weight cohort, even when accounting for maternal IQ. This discrepancy in findings between the whole sample and term-sample highlights the importance of understanding the relationship between maternal weight gain and preterm delivery. Current evidence has suggested that low weight gain may be associated with preterm delivery, but prior studies have had methodological limitations.[21] If weight gain does cause earlier deliveries then gestational age is a mediator on the pathway between weight gain and child IQ and thus the results of the sample limited to full-term deliveries only may be biased.[22]

This cohort was well-suited for studying weight gain below current recommendations as the weight gain of women in this cohort was often considered inadequate based on the 2009 recommendations (25–35 kg total weight gain for normal weight women). However, it is important to note that recommendations in the 1980s when this cohort was pregnant (9–11.4 kg in total for normal weight women) were lower than the current recommendations.[23] It has long been recognized that low weight gain may adversely impact fetal

neurodevelopment.[24] It has been hypothesized that inadequate maternal weight gain may result in utilization of energy stores; this catabolic process can lead to high levels of ketone bodies which may harm the developing fetal brain.[25, 26] In addition, low weight gain may be associated with a maternal diet that lacks nutrients essential for fetal development.[27] Only a few women in this cohort lost weight during the first or second trimester and these women were in the lowest quintile of weight gain in each trimester. The current data indicate that in mostly normal weight women, low weight gain was not associated with lower cognitive abilities in children.

The impact of weight gain on child neurodevelopment was identified as priority area by the IOM in 2009. Indeed, previous studies have suggested that weight loss during pregnancy among severely obese women may reduce the risk of macrosomia without a concomitant increase in SGA, [5, 28, 29] but data on the impact of such weight loss on neurodevelopment are limited.[2, 30] The current study addresses the effects of low weight gain among a predominantly normal weight population, and it should be noted that the metabolic mechanism associated with weight loss in obese women may affect child IQ differently than weight loss or low gain in normal weight women. Thus, future work should specifically address this contemporary problem in forming appropriate recommendations for obese women to ensure normal neurological development in all children.

Despite the unique advantage of having both repeated weight gain measurements throughout pregnancy allowing us to examine trimester-specific associations and long-term follow up of the children, we were limited by the small sample size. Follow-up of the children at 5 years was highly successful in Norway, but less successful in Sweden where women were recruited from across the entire country and therefore we do not believe that the follow-up was differential by maternal weight gain. Notably, no differences were observed in maternal weight gain or any other covariates among those lost to follow-up and sensitivity analyses using multiple imputation for missing data yielded similar results to the main findings. Many analyses were performed to ensure that our findings were robust and we examined associations by quintiles to examine for non-linear associations. We did not however adjust for multiple comparisons, which could lead to false significant findings, however, in general our findings were null. Lastly, IQ scores only serve as a proxy for children's cognitive development, but by 5 years of age they correlate reasonably with later intelligence.[31]

The major strength of our study was the serial assessment and categorization of maternal weight, which did not rely on total weight gain assessed at delivery.[20] It is notable that when limited to term deliveries our findings are in agreement with the only other study that has utilized serial measures of weight gain to address this important research question:[8] however, these results should be interpreted with caution given that gestational age may be a mediator on the causal pathway between weight gain and children IQ scores. Also, longitudinal measurements of antenatal weights reduced error, especially as self-reported prepregnancy weights were compared to the prepregnancy weight estimated from a model using women's longitudinal trajectory of weight gain, which found only small differences and strong correlation, indicating minimal reporting bias. In addition, the analysis considered maternal IQ as a covariate which may pick up residual confounding for both genetics and shared environment between mothers and their children.[32]

In summary, our findings are reassuring that across levels of maternal weight gain during pregnancy there is little variation in child cognitive development among children born to normal weight women. Further investigation should be conducted in contemporary cohorts that also include obese mothers, who are at the greatest risk for low weight gain.

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ABBREVIATIONS

BMI	Body mass index
CI	Confidence interval
IOM	Institute of Medicine
LMP	last menstrual period
SGA	small-for-gestational-age

References

1. ACOG Committee opinion no. 548: weight gain during pregnancy. *Obstet Gynecol.* 2013; 121(1): 210–2. [PubMed: 23262962]
2. Weight Gain During Pregnancy: Reexamining the Guidelines. Washington, DC: Institute of Medicine and National Research Council; 2009.
3. Hinkle SN, Sharma AJ, Swan DW, et al. Excess gestational weight gain is associated with child adiposity among mothers with normal and overweight prepregnancy weight status. *J Nutr.* 2012; 142(10):1851–8. [PubMed: 22955516]
4. Amorim AR, Rossner S, Neovius M, et al. Does excess pregnancy weight gain constitute a major risk for increasing long-term BMI? *Obesity (Silver Spring).* 2007; 15(5):1278–86. [PubMed: 17495204]
5. Kiel DW, Dodson EA, Artal R, et al. Gestational weight gain and pregnancy outcomes in obese women: how much is. *Obstet Gynecol.* 2007; 110(4):752–8. [PubMed: 17906005]
6. Barbour LA. Weight gain in pregnancy: is less truly more for mother and infant? *Obstet Med.* 2012; 5(2):58–64.
7. Keim SA, Pruitt NT. Gestational weight gain and child cognitive development. *Int J Epidemiol.* 2012; 41(2):414–22. [PubMed: 22314966]
8. Gage SH, Lawlor DA, Tilling K, et al. Associations of maternal weight gain in pregnancy with offspring cognition in childhood and adolescence: findings from the avon longitudinal study of parents and children. *Am J Epidemiol.* 2013; 177(5):402–10. [PubMed: 23388581]
9. Bilder DA, Bakian AV, Viskochil J, et al. Maternal Prenatal Weight Gain and Autism Spectrum Disorders. *Pediatrics.* 2013; 132(5):e1276–e83. [PubMed: 24167172]
10. Rice D, Barone S Jr. Critical periods of vulnerability for the developing nervous system: evidence from humans and animal models. *Environ Health Perspect.* 2000; 108(Suppl 3):511. [PubMed: 10852851]
11. Prado EL, Dewey KG. Nutrition and brain development in early life. *Nutr Rev.* 2014
12. Bakketeig LS, Jacobsen G, Hoffman HJ, et al. Pre-pregnancy risk factors of small-for-gestational age births among parous women in Scandinavia. *Acta Obstet Gynecol Scand.* 1993; 72(4):273–79. [PubMed: 8389514]

13. Wechsler, D. WPPSI-R: Wechsler Preschool and Primary Scale of Intelligence. Psychological Corporation Harcourt Brace Jovanovich; 1989.
14. Raven, JC. Progressive matrices. London: HK Lewis; 1965.
15. Macdonald-Wallis C, Lawlor DA, Palmer T, et al. Multivariate multilevel spline models for parallel growth processes: application to weight and mean arterial pressure in pregnancy. *Stat Med*. 2012; 31(26):3147–64. [PubMed: 22733701]
16. Obesity: preventing and managing the global epidemic. Report of a WHO consultation. *World Health Organ Tech Rep Ser*. 2000; 894:i–xii. 1–253. [PubMed: 11234459]
17. Zhang J, Kim S, Grewal J, et al. Predicting large fetuses at birth: do multiple ultrasound examinations and longitudinal statistical modelling improve prediction? *Paediatr Perinat Epidemiol*. 2012; 26(3):199–207. [PubMed: 22471679]
18. Kleinman KP, Oken E, Radesky JS, et al. How should gestational weight gain be assessed? A comparison of existing methods and a novel method, area under the weight gain curve. *Int J Epidemiol*. 2007; 36(6):1275–82. [PubMed: 17715174]
19. de Kieviet JF, Zoetebier L, van Elburg RM, et al. Brain development of very preterm and very low-birthweight children in childhood and adolescence: a meta-analysis. *Dev Med Child Neurol*. 2012; 54(4):313–23. [PubMed: 22283622]
20. Hutcheon JA, Bodnar LM, Joseph KS, et al. The bias in current measures of gestational weight gain. *Paediatr Perinat Epidemiol*. 2012; 26(2):109–16. [PubMed: 22324496]
21. Mitchell EM, Hinkle SN, Schisterman EF. It's about time: a survival approach to gestational weight gain and preterm delivery. *Epidemiology*. 2016 Mar; 27(2):182–7. [PubMed: 26489043]
22. VanderWeele TJ, Mumford SL, Schisterman EF. Conditioning on intermediates in perinatal epidemiology. *Epidemiology*. 2012; 23(1):1–9. DOI: 10.1097/EDE.0b013e31823aca5d [PubMed: 22157298]
23. Abrams B, Altman SL, Pickett KE. Pregnancy weight gain: still controversial. *Am J Clin Nutr*. 2000; 71(5 Suppl):1233s–41s. [PubMed: 10799396]
24. Naeye RL. Weight gain and the outcome of pregnancy. *Am J Obstet Gynecol*. 1979; 135(1):3–9. [PubMed: 474659]
25. Herrera E. Metabolic adaptations in pregnancy and their implications for the availability of substrates to the fetus. *Eur J Clin Nutr*. 2000; 54(3)
26. Harding JE. The nutritional basis of the fetal origins of adult disease. *Int J Epidemiol*. 2001; 30(1): 15–23. [PubMed: 11171842]
27. Georgieff MK. Nutrition and the developing brain: nutrient priorities and measurement. *Am J Clin Nutr*. 2007; 85(2):614S–20S. [PubMed: 17284765]
28. Hinkle SN, Sharma AJ, Dietz PM. Gestational weight gain in obese mothers and associations with fetal growth. *Am J Clin Nutr*. 2010; 92(3):644–51. [PubMed: 20631201]
29. Durie DE, Thornburg LL, Glantz JC. Effect of second-trimester and third-trimester rate of gestational weight gain on. *Obstet Gynecol*. 2011; 118(3):569–75. [PubMed: 21860285]
30. Rasmussen KM, Abrams B, Bodnar LM, et al. Recommendations for weight gain during pregnancy in the context of the obesity epidemic. *Obstet Gynecol*. 2010; 116(5):1191–5. [PubMed: 20966705]
31. Braaten EB, Norman D. Intelligence (IQ) testing. *Pediatr Rev*. 2006; 27(11):403–8. [PubMed: 17079505]
32. Plomin R, Daniels D. Why are children in the same family so different from one another? *Int J Epidemiol*. 2011; 40(3):563–82. [PubMed: 21807642]

WHAT IS ALREADY KNOWN ON THIS SUBJECT?

There has been concern that low gestational weight gain may cause poor fetal neurodevelopment, however, prior studies have been inconsistent and most have lacked serial measures of weight gain during pregnancy.

WHAT THIS STUDY ADDS?

Our findings are reassuring that across levels of maternal weight gain during pregnancy there was little variation in child cognitive development among children born to normal weight women. Further investigation should be conducted in contemporary cohorts that also include obese mothers, who are at the greatest risk for low weight gain.

Figure 1.
Trajectories of maternal weight gain among a random sample of 50 women.

Table 1**Maternal and Child Characteristics.**

	Weight Gain Sample (n=552) Mean (SD) or n (%) ^a	Child IQ Sample (n=344) Mean (SD) or n (%)	Child IQ Sub-Sample with Maternal IQ (n=281) Mean (SD) or n (%)
Maternal Characteristics			
Country			
Norway	261 (47.3)	227 (66.0)	212 (75.4)
Sweden	291 (52.7)	117 (34.0)	69 (24.6)
Age at conception, y	29.1 (4.2)	29.0 (4.1)	29.0 (4.1)
Height, cm	166.6 (5.9)	166.6 (5.9)	166.5 (5.9)
Missing, n	3		
Prepregnancy weight, kg	60.9 (9.6)	60.5 (9.2)	60.1 (9.1)
Prepregnancy BMI, kg/m ²	21.9 (3.0)	21.8 (2.8)	21.6 (2.8)
Missing, n	3		
< 18.5	36 (6.6)	20 (5.8)	18 (6.4)
18.5–24.9	441 (80.3)	283 (82.3)	231 (82.2)
24.9–29.9	61 (11.1)	36 (10.5)	27 (9.6)
30.0	11 (2.0)	5 (1.5)	5 (1.8)
Rate of weight gain, kg/wk			
1 st trimester	0.25 (0.12)	0.24 (0.12)	0.24 (0.11)
2 nd trimester	0.32 (0.11)	0.32 (0.11)	0.32 (0.10)
3 rd trimester	0.37 (0.11)	0.38 (0.10)	0.38 (0.10)
2 nd trimester adequacy ^b			
Missing, n	3		
Below	323 (58.8)	210 (61.1)	175 (62.3)
Within	176 (32.1)	102 (29.7)	80 (28.5)
Above	50 (9.1)	32 (9.3)	26 (9.3)
3 rd trimester adequacy ^b			
Missing, n	3		
Below	204 (37.2)	128 (37.2)	103 (36.7)
Within	268 (48.8)	172 (50.0)	142 (50.5)
Above	77 (14.0)	44 (12.8)	36 (12.8)
Education			
Missing, n	91		
9 years	69 (15.0)	51 (14.8)	39 (13.9)
10–11 years	131 (28.4)	96 (27.9)	78 (27.8)
12 years	93 (20.2)	78 (22.7)	62 (22.1)
Trade School/university	168 (36.4)	119 (34.6)	102 (36.3)
Marital status			
Missing, n	91		
Married	350 (75.9)	267 (77.6)	229 (80.6)

	Weight Gain Sample (n=552) Mean (SD) or n (%) ^a	Child IQ Sample (n=344) Mean (SD) or n (%)	Child IQ Sub-Sample with Maternal IQ (n=281) Mean (SD) or n (%)
Cohabiting/single	111 (24.1)	77 (22.4)	55 (19.4)
Economic situation			
Missing, n	98		
Very good	34 (7.5)	30 (8.7)	27 (9.6)
Good	191 (42.1)	153 (44.5)	124 (44.1)
Moderate	208 (45.8)	147 (42.7)	118 (42.0)
Bad	21 (4.6)	14 (4.1)	12 (4.3)
Parity			
1	383 (69.4)	238 (69.2)	195 (69.4)
2	169 (30.6)	106 (30.8)	86 (30.6)
Prepregnancy smoking, cigarettes			
0	354 (64.1)	220 (64.0)	178 (63.4)
1–9	50 (9.1)	33 (9.6)	31 (11.0)
10–19	124 (22.5)	73 (21.2)	57 (20.3)
20	24 (4.4)	18 (5.2)	15 (5.3)
Alcohol use during pregnancy			
Missing, n	112		
Never	215 (48.9)	167 (48.6)	139 (49.5)
Not as often as once a month	145 (33.0)	113 (32.9)	89 (31.7)
About once every month	44 (10.0)	36 (10.5)	27 (9.6)
More than once a month	36 (8.2)	28 (8.1)	26 (9.3)
Prepregnancy chronic diseases ^c	20 (3.6)	11 (3.2)	7 (2.5)
Gestational diabetes	30 (5.4)	21 (6.1)	19 (6.8)
Preeclampsia	9 (1.6)	7 (2.0)	7 (2.5)
Maternal IQ	49.0 (6.6)	48.8 (6.6)	48.8 (6.6)
Missing, n	248	63	
Child Characteristics			
Gestational age, wk	39.9 (1.9)	39.9 (1.4)	39.9 (1.4)
Preterm	22 (4.0)	11 (3.2)	10 (3.6)
Male Sex	278 (50.4)	165 (48.0)	135 (48.0)
Child IQ			
Missing, n	172		
Full scale		108.3 (15.1)	107.7 (15.2)
Verbal		103.9 (14.6)	103.3 (14.6)
Performance		111.0 (14.9)	110.6 (15.2)
Age at IQ assessment, months		62.7 (2.2)	62.3 (2.0)

^aPercentages calculated among non-missing data.

^bSecond and third trimester rates of weight gain were classified as below or above recommendations according to the following ranges: underweight, 0.44–0.58; normal weight, 0.35–0.50; overweight, 0.23–0.33; and obese, 0.17–0.27 kg/w.

^cPrepregnancy chronic diseases includes renal disease, heart disease, type I diabetes, type II diabetes, and chronic hypertension.

^cNo significant differences between weight gain sample and child IQ sample with the exception of country ($P<0.001$).

^dNo significant differences between child IQ sample and sample with maternal IQ with the exception of country ($P<0.001$).

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Table 2

Association Between Maternal Rate of Weight Gain Adequacy in the Second and Third Trimesters According to the 2009 Institute of Medicine Recommendations and Child IQ Scores at 5 Years of Age.

Rate of weight gain	Full Scale IQ			Verbal IQ			Performance IQ		
	Unadjusted Mean (SD)	Adjusted β^a (95% CI)		Unadjusted Mean (SD)	Adjusted β^a (95% CI)		Unadjusted Mean (SD)	Adjusted β^a (95% CI)	
Child IQ sample (n=344)									
2 nd trimester rate ^a									
Below	107.1 (15.2)	-0.5 (-3.7, 2.7)		102.9 (14.5)	0.2 (-3.0, 3.3)		109.8 (15.1)	-1.3 (-4.6, 2.0)	
Within	110.9 (14.9)	0.0 (Reference)		105.7 (14.7)	0.0 (Reference)		113.7 (14.1)	0.0 (Reference)	
Above	108.5 (14.9)	2.0 (-3.6, 7.5)		104.6 (14.7)	2.2 (-3.3, 7.6)		110.5 (14.8)	0.8 (-4.9, 6.6)	
3 rd trimester rate ^b									
Below	107.4 (16.2)	0.2 (-3.4, 3.8)		103.4 (15.2)	1.0 (-2.6, 4.5)		109.6 (15.4)	-1.3 (-5.0, 2.4)	
Within	108.9 (14.0)	0.0 (Reference)		103.9 (13.8)	0.0 (Reference)		112.2 (14.3)	0.0 (Reference)	
Above	108.9 (16.4)	-0.8 (-8.1, 6.6)		105.2 (16.1)	0.9 (-6.3, 8.1)		110.3 (15.4)	-3.1 (-10.7, 4.5)	
Child IQ sub-sample with maternal IQ (n=281)									
2 nd trimester rate									
Below	106.6 (15.1)	0.2 (-3.2, 3.6)		102.5 (14.3)	0.8 (-2.6, 4.1)		109.5 (15.4)	-0.5 (-4.2, 3.1)	
Within	110.2 (15.2)	0.0 (Reference)		105.0 (14.9)	0.0 (Reference)		113.4 (14.5)	0.0 (Reference)	
Above	107.4 (15.9)	3.2 (-2.8, 9.2)		103.6 (15.8)	3.5 (-2.4, 9.5)		109.5 (15.8)	1.8 (-4.7, 8.2)	
3 rd trimester rate ^d									
Below	106.9 (16.1)	0.2 (-3.6, 3.9)		103.0 (15.0)	1.0 (-2.6, 4.7)		109.3 (15.6)	-1.3 (-5.2, 2.7)	
Within	108.0 (14.1)	0.0 (Reference)		103.0 (13.7)	0.0 (Reference)		111.7 (14.8)	0.0 (Reference)	
Above	108.6 (17.3)	-0.7 (-8.2, 6.9)		105.1 (17.2)	1.2 (-6.2, 8.7)		109.9 (15.8)	-3.4 (-11.5, 4.7)	

Abbreviations: CI, confidence interval; SD, standard deviation.

^aModels adjusted for maternal age, prepregnancy body mass index, education, economic status, marital status, parity, smoking at conception, alcohol during pregnancy, prepregnancy chronic diseases, nausea and vomiting during pregnancy, and child sex and age at IQ assessment.

^bModels adjusted for maternal age, prepregnancy body mass index, education, economic status, marital status, parity, smoking at conception, alcohol during pregnancy, prepregnancy chronic diseases, nausea and vomiting during pregnancy, 2nd trimester rate of adequacy of weight gain and child sex and age at IQ assessment.

^cModels adjusted for maternal age, prepregnancy body mass index, education, economic status, marital status, parity, smoking at conception, alcohol during pregnancy, prepregnancy chronic diseases, nausea and vomiting during pregnancy, and IQ, and child sex and age at IQ assessment.

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Models adjusted for maternal age, prepregnancy body mass index, education, economic status, marital status, parity, smoking at conception, alcohol during pregnancy, prepregnancy chronic diseases, nausea and vomiting during pregnancy, 2nd trimester rate of adequacy of weight gain and IQ, and child sex and age at IQ assessment.

Table 3

Association Between Quintiles of Maternal Cumulative Gestational Weight Gain Using the Area Under the Curve Approach and Child IQ Scores at 5 Years of Age.

Quintiles of Cumulative Weight Gain	Full Scale IQ			Verbal IQ			Performance IQ		
	Unadjusted Mean (SD)	Adjusted β^a (95% CI)		Unadjusted Mean (SD)	Adjusted β^a (95% CI)		Unadjusted Mean (SD)	Adjusted β^a (95% CI)	
Main sample ^a (n=344)									
Q1	105.6 (15.4)	0.0 (Reference)		101.7 (14.1)	0.0 (Reference)		108.0 (15.7)	0.0 (Reference)	
Q2	106.1 (13.2)	2.2 (-2.3, 6.7)		101.1 (13.0)	-1.1 (-5.4, 3.1)		110.4 (13.6)	0.1 (-4.2, 4.5)	
Q3	109.6 (16.2)	3.0 (-1.2, 7.2)		105.6 (15.9)	3.1 (-1.0, 7.1)		111.3 (15.2)	3.3 (-0.7, 7.4)	
Q4	111.7 (14.0)	4.6 (0.1, 9.0)		106.7 (13.0)	2.4 (-1.8, 6.6)		114.2 (13.8)	3.6 (-0.7, 8.0)	
Q5	109.5 (15.7)	3.4 (-1.0, 7.9)		104.7 (16.0)	0.8 (-3.4, 5.1)		112.3 (15.1)	2.1 (-2.2, 6.4)	
Child IQ sub-sample with maternal IQ ^b (n=281)									
Q1	105.3 (14.5)	0.0 (Reference)		101.7 (12.8)	0.0 (Reference)		107.9 (15.5)	0.0 (Reference)	
Q2	104.9 (13.8)	1.2 (-3.7, 6.1)		100.0 (13.4)	-2.4 (-6.9, 2.1)		109.2 (14.3)	-0.9 (-5.5, 3.7)	
Q3	110.0 (16.7)	3.4 (-1.2, 7.9)		105.9 (16.3)	3.6 (-0.6, 7.8)		111.6 (15.9)	4.2 (-0.1, 8.4)	
Q4	110.1 (13.9)	2.1 (-2.8, 7.0)		105.6 (13.3)	1.0 (-3.5, 5.5)		112.6 (13.8)	1.6 (-2.9, 6.2)	
Q5	108.3 (16.6)	4.3 (-0.8, 9.4)		102.7 (16.6)	0.3 (-4.4, 5.0)		112.2 (16.3)	2.6 (-2.2, 7.3)	

Abbreviations: CI, confidence interval; Q, quintile; SD, standard deviation.

^aModels adjusted for maternal age, prepregnancy body mass index, education, economic status, marital status, parity, smoking at conception, alcohol during pregnancy, prepregnancy chronic diseases, nausea and vomiting during pregnancy, and child sex and age at IQ assessment.

^bModels adjusted for maternal age, prepregnancy body mass index, education, economic status, marital status, parity, smoking at conception, alcohol during pregnancy, prepregnancy chronic diseases, nausea and vomiting during pregnancy, and child sex and age at IQ assessment and maternal IQ.

Table 4
Association Between Quintiles of Maternal Rate of Weight Gain in Each Trimester and Child IQ Scores at 5 Years.

Rate of weight gain, kg/w	Full Scale IQ			Verbal IQ			Performance IQ		
	Unadjusted Mean (SD)	Adjusted β^a (95% CI)		Unadjusted Mean (SD)	Adjusted β^a (95% CI)		Unadjusted Mean (SD)	Adjusted β^a (95% CI)	
Child IQ sample ^a (n=344)									
1 st trimester ^b									
Q1	106.0 (16.6)	0.0 (Reference)		101.8 (14.8)	0.0 (Reference)		108.6 (17.2)	0.0 (Reference)	
Q2	104.3 (12.7)	-1.8 (-6.1, 2.4)		100.2 (12.6)	-2.2 (-6.4, 2.0)		107.9 (12.7)	-0.4 (-4.8, 4.0)	
Q3	111.1 (14.8)	2.9 (-1.4, 7.2)		106.4 (14.8)	2.4 (-1.8, 6.7)		113.3 (14.4)	3.1 (-1.4, 7.5)	
Q4	110.8 (15.9)	3.5 (-0.9, 7.9)		106.5 (15.5)	3.2 (-1.1, 7.5)		112.7 (14.3)	3.3 (-1.3, 7.8)	
Q5	109.9 (14.6)	1.8 (-2.6, 6.1)		105.0 (14.6)	0.6 (-3.7, 4.9)		112.9 (14.7)	3.2 (-1.3, 7.8)	
2 nd trimester ^c									
Q1	106.0 (15.2)	0.0 (Reference)		102.1 (14.2)	0.0 (Reference)		108.3 (16.1)	0.0 (Reference)	
Q2	107.8 (14.7)	0.1 (-5.4, 5.6)		103.0 (13.7)	-1.4 (-6.8, 4.0)		111.1 (14.3)	1.8 (-3.9, 7.4)	
Q3	107.7 (16.3)	-2.1 (-9.5, 5.2)		104.3 (16.5)	-2.7 (-9.9, 4.5)		109.1 (15.1)	-1.4 (-8.9, 6.2)	
Q4	110.6 (13.2)	-2.9 (-11.2, 5.4)		104.3 (13.2)	-5.8 (-13.9, 2.3)		114.9 (12.8)	1.0 (-7.6, 9.5)	
Q5	109.6 (16.5)	-5.5 (-15.5, 4.6)		105.9 (15.9)	-4.6 (-14.4, 5.2)		111.0 (15.8)	-5.6 (-15.9, 4.7)	
3 rd trimester ^d									
Q1	105.2 (14.3)	0.0 (Reference)		101.4 (14.1)	0.0 (Reference)		107.8 (14.6)	0.0 (Reference)	
Q2	109.6 (17.4)	6.7 (1.2, 12.2)		105.4 (16.0)	6.4 (1.0, 11.8)		111.3 (16.1)	5.5 (-0.2, 11.2)	
Q3	106.2 (13.5)	4.0 (-2.5, 10.6)		101.2 (13.7)	2.3 (-4.1, 8.7)		110.4 (14.5)	6.0 (-0.8, 12.7)	
Q4	111.5 (12.8)	6.4 (-0.6, 13.4)		106.1 (12.9)	5.3 (-1.5, 12.1)		114.6 (12.8)	6.7 (-0.5, 14.0)	
Q5	108.6 (16.7)	7.0 (-1.6, 15.6)		104.8 (15.8)	7.7 (-0.7, 16.1)		110.3 (15.9)	4.3 (-4.6, 13.2)	
Child IQ sub-sample with maternal IQ ^e (n=281)									
1 st trimester									
Q1	105.6 (15.7)	0.0 (Reference)		101.4 (13.6)	0.0 (Reference)		108.8 (17.2)	0.0 (Reference)	
Q2	103.3 (13.1)	-1.9 (-6.4, 2.7)		99.4 (12.6)	-2.3 (-6.7, 2.2)		106.8 (13.1)	-0.8 (-5.7, 4.1)	
Q3	111.7 (15.4)	3.6 (-1.0, 8.1)		107.0 (15.3)	3.2 (-1.3, 7.7)		113.6 (15.0)	2.8 (-2.1, 7.6)	
Q4	109.0 (16.3)	2.5 (-2.2, 7.2)		104.8 (16.1)	2.7 (-1.9, 7.3)		111.2 (14.6)	1.6 (-3.5, 6.6)	
Q5	108.9 (14.7)	1.9 (-2.8, 6.6)		103.8 (14.7)	0.6 (-4.0, 5.3)		112.4 (15.4)	3.0 (-2.0, 8.1)	

Rate of weight gain, kg/w	Full Scale IQ			Verbal IQ			Performance IQ		
	Unadjusted Mean (SD)	Adjusted β^a (95% CI)		Unadjusted Mean (SD)	Adjusted β^a (95% CI)		Unadjusted Mean (SD)	Adjusted β^a (95% CI)	
2nd trimester									
Q1	105.4 (13.9)	0.0 (Reference)		102.2 (12.2)	0.0 (Reference)		107.6 (16.0)	0.0 (Reference)	
Q2	107.6 (15.5)	1.2 (-4.9, 7.2)		102.3 (14.2)	-2.7 (-8.7, 3.2)		111.5 (15.0)	4.8 (-1.6, 11.3)	
Q3	107.3 (16.4)	0.5 (-7.4, 8.3)		104.4 (16.7)	-1.8 (-9.6, 5.9)		108.4 (15.2)	2.1 (-6.2, 10.5)	
Q4	109.3 (13.3)	-1.2 (-10.0, 7.6)		103.0 (13.3)	-6.5 (-15.1, 2.2)		114.2 (13.3)	4.4 (-5.0, 13.7)	
Q5	108.7 (17.3)	-3.0 (-13.8, 7.8)		104.7 (16.4)	-5.4 (-16, 5.2)		110.7 (16.8)	-1.3 (-12.8, 10.2)	
3rd trimester									
Q1	105.7 (14.0)	0.0 (Reference)		102.2 (12.7)	0.0 (Reference)		108.1 (15.2)	0.0 (Reference)	
Q2	108.3 (17.7)	2.5 (-3.5, 8.5)		104.3 (16.7)	2.9 (-3.0, 8.8)		110.3 (16.2)	1.3 (-5.0, 7.7)	
Q3	104.9 (13.5)	-0.5 (-7.6, 6.7)		100.3 (14.2)	-1.6 (-8.6, 5.4)		108.9 (14.8)	1.8 (-5.8, 9.4)	
Q4	110.6 (12.9)	3.3 (-4.1, 10.8)		105.0 (12.7)	2.4 (-4.9, 9.7)		114.3 (13.3)	4.2 (-3.8, 12.1)	
Q5	108.1 (17.4)	3.6 (-5.6, 12.7)		103.9 (16.5)	4.6 (-4.3, 13.6)		110.3 (16.6)	1.3 (-8.4, 11.1)	

Abbreviations: CI, confidence interval; Q, quintile; SD, standard deviation.

^aConfounding variables considered included maternal age, prepregnancy body mass index, education, economic status, marital status, parity, smoking at conception, alcohol during pregnancy, prepregnancy chronic diseases, nausea and vomiting and child sex and age at IQ assessment.

^bFirst trimester quintile cutpoints: Q1, -0.15 to <0.16; Q2, 0.16 to <0.22; Q3, 0.22 to <0.27; Q4, 0.27 to <0.32; Q5, 0.32 to 0.75.

^cSecond trimester quintile cutpoints: Q1, -0.11 to <0.23; Q2, 0.23 to <0.30; Q3, 0.30 to <0.34; Q4, 0.34 to <0.40; Q5, 0.40 to 0.74.

^dThird trimester quintile cutpoints: Q1, 0.01 to <0.29; Q2, 0.29 to <0.35; Q3, 0.35 to <0.39; Q4, 0.39 to <0.46; Q5, 0.46 to 0.70.

^eConfounding variables considered included maternal age, prepregnancy body mass index, education, economic status, marital status, parity, smoking at conception, alcohol during pregnancy, prepregnancy chronic diseases, nausea and vomiting, and IQ, and child sex and age at IQ assessment.

^fAll linear and quadratic tests for trend were non-significant.