ORIGINAL RESEARCH

Exposure to traffic noise and gestational weight gain and postpartum weight retention: a cohort study

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ABSTRACT

Objectives Transportation noise has been associated with markers of obesity. We aimed to investigate whether road traffic and railway noise were associated with weight gain during and after pregnancy.

Methods Among the women participating in the Danish National Birth Cohort, 74 065 reported on weight before and during the pregnancy (gestational week 30) and 52 661 reported on weight before and 18 months after pregnancy. Residential address history from conception to 18 months after pregnancy was obtained in national registers, and road traffic and railway noise were modelled for all addresses. Associations between noise and gestational weight gain (GWG) and postpartum weight retention (PPWR) were analysed using the linear and log-binomial regression.

Results A 10 dB(A) higher road traffic noise was associated with an increase in GWG of 3.8 g/week (95% CI 2.3 to 5.3) and PPWR of 0.09 kg (95% CI 0.02 to 0.16). For PPWR, this association seemed confined to women who were overweight (0.17 kg, 95% CI 0.02 to 0.32) or obese (0.49 kg, 95% CI 0.26 to 0.73) before pregnancy. Further adjustment by nitrogen dioxide reduced GWG risk estimates and slightly increased PPWR risk estimates. Railway noise ≥ 65 dB(A) was associated with an increase in GWG of 4.5 g/week (95% CI -2.7 to 11.6) and PPWR of 0.26 kg (95% CI -0.09 to 0.60) compared with levels <55 dB(A).

Conclusions Our findings suggest that road traffic noise is associated with weight gain during and after the pregnancy, which adds to the literature linking transportation noise to adiposity.

INTRODUCTION

Transportation noise is classified as the second worst environmental risk factor.¹ It has been associated with a wide range of diseases and conditions, including adiposity and diabetes.^{2–6} The dominating source is road traffic and although WHO recommends to reduce road traffic noise below 53 dB(A) to prevent adverse health effects,⁷ it is estimated that at least 24% of the population in the European Union are exposed to levels exceeding 55 dB(A).⁸

Road traffic noise is suspected of increasing the risk for adiposity. Studies of both cross-sectional and longitudinal designs have rather consistently found transportation noise to increase waist circumference and obesity among adults, whereas results for body mass index (BMI) are less consistent.^{2–4 9–11} Two recent studies have moreover indicated that traffic noise may affect adiposity in children.^{12 13} Exposure

Key messages

What is already known about this subject?

- Previous studies have indicated that road traffic noise is associated with markers of adiposity among children and elderly populations.

What are the new findings?

- We investigated effects of traffic noise on weight gain in women during and after pregnancy.
- Road traffic noise was associated with an increase in gestational weight gain and postpartum weight retention (PPWR).
- For PPWR, the association seemed confined to overweight and obese women.

How might this impact on policy or clinical practice in the foreseeable future?

- A number of different noise abatement approaches are available.
- The study adds to the existing literature linking traffic noise to risk for adiposity, which is important knowledge to encourage legislation to reduce traffic noise.

to transportation noise is believed harmful through a stress reaction, with activation of the hypothalamic–pituitary–adrenocortical axis, leading to a rise in stress hormones, vascular dysfunction and metabolic abnormalities such as impaired glucose tolerance.^{14–18} Furthermore, exposure to traffic noise during night can disturb sleep,¹⁹ which has been associated with impaired glucose tolerance, reduced insulin sensitivity and dysregulation of appetite-regulating hormones,^{17 18 20} as well as cardiometabolic diseases.^{20–22} Both stress and disturbance of sleep may also lead to an unhealthy lifestyle, and studies have indicated that traffic noise is associated with physical inactivity.^{23 24}

Pregnancy is a period where women naturally gain weight. However, a high gestational weight gain (GWG) is a risk factor for maternal postpartum weight retention (PPWR), overweight and obesity,²⁵ and thus, pregnancy and the period just after pregnancy may be critical time-windows in relation to development of maternal overweight later in life. Studies have indicated that short sleep duration in the postpartum period is associated with a higher PPWR.²⁶ The pregnancy and the postpartum periods are normally characterised by

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marked changes in maternal sleep pattern, with reduced sleep quality and duration,²⁷ and, furthermore, a relatively stressful time period for many women. It is, therefore, possible that exposure to traffic noise in these period may negatively affect maternal mental condition and sleep even further by stressing and/or disturbing the sleep of the child (postpartum period) and/or the mother.

We aimed to study associations between residential exposure to road traffic and railway noise and changes in weight during and after the pregnancy in a national birth cohort with self-reported information on maternal weight before, during and after the pregnancy.

METHODS

Study population

The study population consisted of mothers who participated in the Danish National Birth Cohort (DNBC), which is a nationwide survey of 100 419 pregnant women.²⁸ Briefly, pregnant women were invited to participate in the DNBC at their first pregnancy consultation (gestational week 6–10) in the period from 1996 to 2002. Only women who spoke Danish well and had a permanent address in Denmark were invited. The women participated in two telephone interviews during the pregnancy around gestational weeks 16 and 30, as well as a postnatal telephone interview 18 months after birth. All the interviews were conducted by trained interviewers and included questions on height, weight, smoking habits, alcohol consumption, breast feeding and parity. The study base of the present study constituted the 90 903 DNBC mothers who gave birth to live-born singletons.

Outcomes

For the present study, we considered two anthropometric outcomes: GWG and PPWR. GWG was estimated as weight gain in gram/week from conception to around gestational week 30. We assessed this using the following question in the second prenatal maternal interview (≈ 30 th gestational week): 'How many kilos did you gain during pregnancy at the present time?', divided by gestational age at the time of the interview. We excluded women who failed to complete the ≈ 30 weeks interview within an acceptable time frame (± 6 weeks of the median of 31.3 weeks).

PPWR was assessed as weight retention in kilos by subtracting information on maternal weight before pregnancy from the maternal weight reported at the interview around ≈ 18 months after birth ('What is your present weight?'). Self-reported information on prepregnancy weight was obtained in the first prenatal interview ($\approx$ week 12): 'How much did you weigh before you got pregnant?'. We excluded women who failed to complete the ≈ 18 months interview within an acceptable time frame (± 3 months of the median of 18.8 months).

Exposures

We collected all residential addresses for all DNBC mothers from conception to ≈ 18 months after birth (date of the postpartum interview) from the Danish Civil Registration System. For these addresses, we calculated annual levels (for the relevant calendar-years) of road traffic and railway noise using SoundPLAN, which is a calculation programme based on the Nordic prediction method.²⁹ Input variables for the noise model include geocode and height (floor) for all addresses together with all Danish buildings polygons. Furthermore, for estimation of road traffic noise the following input variables on traffic were used:

annual average daily traffic, distribution of light and heavy vehicles, travel speed and road type for all Danish road links (motorway, express road, road > 6 m, road 3–6 m and other road). For estimation of railway noise, the traffic input variables were annual average daily train lengths, train types and travel speed. We included information on railway noise barriers. We had no information on road surface and road noise barriers. Road traffic and railway noise were calculated as the equivalent continuous A-weighted sound pressure levels at the most exposed facade of the building during day, evening and night, and expressed as L_{den} .

We calculated time-weighted mean levels of nitrogen dioxide (NO_2) at all maternal addresses from conception to ≈ 18 months after birth using the Danish AirGIS dispersion modelling system.³⁰ Briefly, AirGIS calculates air pollution each hour at each address as the sum of: (1) air pollution from the nearest street, calculated using information on traffic, geometry of buildings and streets, car fleet emission factors and meteorology; (2) urban background and (3) regional background, estimated from rural monitoring data and national vehicle emissions. AirGIS has been successfully validated.^{31 32} NO_2 is a well-recognised surrogate for a mix of urban traffic-related air pollutants.³³

Statistical analyses

We used linear regression models to calculate associations between exposure to road traffic and railway noise and GWG and PPWR, and log-binomial regression to calculate associations between road traffic noise and risk for retaining ≥ 5 kg at 18 months post partum. For each person, exposure to traffic noise was calculated as a time-weighted mean from conception to the date of the second gestational interview (≈ 30 weeks; GWG analyses) and from conception to the 18 months interview date (PPWR analyses) taking the complete address history (with annual means for all relevant calendar-years for each address) in these periods into account. Data were analysed for noise as continuous variables and as categorical variables (< 50 , 50–55, 55–60, 60–65 and ≥ 65 dB). We calculated Spearman's rank correlation coefficient to investigate associations between exposures and outcomes.

We investigated the association between road traffic and railway noise and the two outcomes GWG and PPWR in four models: model 1 with no adjustment. Model 2 with adjustment for maternal age at conception (< 25 , 25–30, 30–35 and ≥ 35 years), parity (nulliparous, uniparous and multiparous), highest attained education at time of conception (basic (7–12 years), vocational (10–12 years, higher (≥ 13 years)), disposable income at time of conception (household income after taxation and interest per person, adjusted for number of persons in the household; in quintiles), cohabitation (married or living with partner; yes, no); municipality-level income at time of conception (quartiles), as well as mutual adjustment for road traffic noise and railway noise. In addition, analyses of GWG were also adjusted for season at conception (winter (December–February), spring (March–May), summer (June–August), autumn (September–November)) and analyses of PPWR were adjusted for breast feeding (< 6 months; ≥ 6 months) obtained from the interview ≈ 18 months after birth. In model 3, we further adjusted for two lifestyle covariates from the first prenatal interview (≈ 12 th gestational week): smoking (yes, no, no but smoked in early pregnancy) and alcohol consumption (no alcohol, > 0 –1 drink/week and > 1 drink/week). In model 4, we adjusted for the model 3 covariates plus residential exposure to air pollution estimated as NO_2 (continuous variables, $\mu g/m^3$, time-weighted mean from

conception to ≈ 30 gestational week for the GWG analyses and from conception to ≈ 18 months after birth for the PPWR analyses).³⁴ These covariates were chosen a priori from review of the literature^{35–37} and obtained from different sources: maternal age, gestational age, parity, smoking, alcohol consumption and breast feeding from the DNBC interviews, and education, income, and cohabitation from the national registers managed by Statistics Denmark.

We evaluated potential modification of the association between road traffic noise and GWG and PPWR by prepregnancy BMI, railway noise, gestational age at the second pregnancy interview (26–29, 30–33 or 34–37 pregnancy week; for GWG), season at second pregnancy interview (for GWG) and GWG (for PPWR), by introducing interaction terms, and tested using the F-test statistic (p values < 0.05 were considered statistically significant). Road traffic and railway noise were included in the models as continuous variables after evaluation with linear spline models with boundaries placed at the nine deciles, which indicated no deviation from linearity. We used SAS V.9.3 (SAS Institute).

RESULTS

The study base for the GWG analyses included 90 903 mothers. From this study base, we excluded 8038 without GWG information (6496 did not participate in the 30-week interview, 1535 reported unknown weight in the 30 weeks and 7 reported implausible GWG); 3464 who failed to complete the 30-week interview within a reasonable time frame (± 6 weeks); 311 with incomplete exposure information and 5025 with incomplete confounder information (3299 because they did not participate in the first prenatal interview), leaving a study population of 74 065 women.

For the PPWR analyses, 64 123 women participated in both the interview at the 12th gestational week and 18 month. Of these, we excluded 6834 who were pregnant again at the 18-month interview, 1706 with unknown prepregnancy or 18-month post-pregnancy weight, 10 with implausible PPWR, 367 with incomplete exposure information, 475 with incomplete confounder information and 2088 women failed to complete the 18-month interview within a reasonable time frame (± 3 months), leaving a study population of 52 661 women.

The characteristics of the GWG and PPWR study populations according to exposure to four categories of road traffic noise as well as according to the two outcomes are shown in table 1 and online supplementary table 1, respectively.

We found prepregnancy BMI, GWG and PPWR to be correlated ($p < 0.0001$), with R_{Spearman} of -0.23 for BMI and GWG, -0.19 for BMI and PPWR, and 0.25 for GWG and PPWR. Both outcomes (GWG and PPWR) distributed normally (online supplementary figures 1 and 2), with a median GWG of 312 g/week (25–75 percentiles (P25–75): 241; 389) and PPWR of 0.0 kg (P25–75: -2.0 ; 2.5). Road traffic noise in the two examined exposure was correlated ($R_{\text{Spearman}} = 0.95$). The distributions of road traffic noise in the two time-windows were slightly skewed to the left (online supplementary figure 3), and median levels of road traffic noise was 57.4 dB(A) (P25–75: 53.1; 62.6) for the GWG analyses and 57.5 dB(A) (P25–75: 53.2; 62.3) for the PPWR analyses. 9.5% women had a PPWR of ≥ 5 kg. Correlations between road traffic noise and NO_2 were moderate, with R_{Spearman} of 0.46 for the GWG exposure window and 0.50 for PPWR exposure window.

We found that a 10 dB(A) increase in mean time-weighted road traffic noise during the pregnancy was associated with a 3.8

g/week higher GWG (95% CI 2.3 to 5.3) in the fully adjusted model 3 (table 2). In the categorical analysis, we observed highest estimates among the highly exposed. Further adjustment for air pollution resulted in lower GWG estimates: $\beta = 1.5$ g/week (95% CI -0.3 to 3.3) per 10 dB(A) after NO_2 adjustment. We found no associations between railway noise and GWG, although we observed that in the two highest exposure groups of 60–65 dB(A) and ≥ 65 dB(A) the GWG were 2.7 g/week (95% CI -4.1 to 9.5) and 4.5 g/week (95% CI -2.7 to 11.6) higher, respectively, than in the reference group exposed to < 55 dB(A) (table 2).

A 10 dB(A) increase in mean time-weighted road traffic noise from conception to 18 months post partum was associated with a 0.09 kg higher PPWR 18 months after birth in the fully adjusted model 3 (table 3). There were no associations between railway noise and PPWR. Further adjustment for air pollution in the road traffic noise models, resulted in slightly higher PPWR estimates: 10 dB(A) increase in road traffic noise was associated with 0.11 kg higher PPWR (95% CI 0.03 to 0.20) in models adjusted for NO_2 .

We observed no modification of the association between road traffic noise and GWG by prepregnancy BMI, gestational age, season or railway noise (table 4). In contrast, we found that for PPWR, the association with road traffic noise seemed confined to women reporting prepregnancy overweight (β : 0.17 kg; 95% CI 0.02 to 0.32 per 10 dB(A)) or prepregnancy obesity (β : 0.49 kg; 95% CI 0.26; 0.73 per 10 dB(A)). Similar tendencies were found when investigating whether the association between road traffic noise and PPWR changed according to different GWG. Here, we observed that the association seemed confined to women gaining ≥ 386 g/week during the pregnancy (β : 0.18 kg), although the interaction was insignificant.

We found no significant association between road traffic noise and risk of retaining ≥ 5 kg 18 months post partum in the whole population, with a risk ratio of 1.03 (95% CI 0.99 to 1.08) per 10 dB(A) (table 5). When investigating this association among women reporting to have a prepregnancy BMI within the normal, overweight or obese range, respectively, we observed some differences.

DISCUSSION

We found that residential exposure to road traffic noise was associated with slightly higher GWG and PPWR in a Danish cohort, although for GWG adjustment by NO_2 lowered the estimates. For PPWR, the association with road traffic noise seemed confined to women reporting prepregnancy BMI within the overweight or obese range, as well as women with a high GWG during the pregnancy. We found suggestions of an association between high levels of railway noise and GWG or PPWR.

The results of the present study are in line with most previous studies, which rather consistently found road traffic noise to be associated with markers of adiposity.^{2–4 9–13} However, our study population of women during and after pregnancy (mean age of 30 years) differs from populations used in previous studies, which focused on either children^{12 13} or older populations.^{2–4 9–11} Pregnancy and postpregnancy are for many women periods associated with stress and disturbance of sleep,²⁷ and it is likely that exposure to traffic noise may exacerbate these, by disturbing/stressing the child, the mother or both, thereby potentially increasing risk for gaining weight. We found that road traffic noise was associated with a slightly higher GWG, and although weight gain during the pregnancy is mainly associated with the growing fetus (including placenta and uterus), a high GWG is a risk factor for overweight in women after the pregnancy.²⁵

Table 1 Study population characteristics by exposure to road traffic noise

	Gestational weight gain (n=74 065)				Postpartum weight retention (n=52 661)			
	<55 dB(A) (n=27 248)	55–60 dB(A) (n=18 799)	60–65 dB(A) (n=16 073)	≥65 dB(A) (n=11 945)	<55 dB(A) (n=19 011)	55–60 dB(A) (n=14 170)	60–65 dB(A) (n=11 791)	≥65 dB(A) (n=7689)
Age*								
<25 years	11	13	14	15	9	11	12	13
25–30 years	40	41	44	45	39	41	43	44
30–35 years	36	34	32	31	38	35	33	32
≥35 years	12	11	10	9	14	12	12	11
Parity								
Nulliparous	39	46	51	59	34	41	47	54
Uniparous	42	38	35	30	44	41	38	34
Multiparous	19	17	14	11	22	18	15	12
Highest attained education*								
Basic (7–12 years)	13	14	13	14	12	13	13	13
Vocational (10–12 years)	51	50	49	49	51	50	50	49
Higher (≥13 years)	36	36	37	37	37	37	38	38
Disposable income (quintiles)*								
Q1 (low)	9	11	12	13	8	10	11	12
Q2	11	12	13	13	11	12	12	13
Q3	23	22	21	20	23	22	22	21
Q4	32	29	29	26	33	30	29	28
Q5 (high)	26	26	25	28	25	26	28	26
Cohabitation (incl. marriage)*								
Yes	90	86	84	82	91	88	86	83
No	10	14	16	18	9	12	14	17
Area-level income*								
Q1 (low)	26	24	22	19	26	24	23	20
Q2	20	21	31	33	20	21	29	32
Q3	26	26	23	23	26	26	24	23
Q4 (high)	27	29	24	25	28	29	25	26
Smoking†								
No	76	74	73	72	77	75	74	72
No, but smoked in early pregnancy	8	9	10	12	8	9	9	11
Yes	16	16	17	16	15	16	17	17
Alcohol consumption†								
No alcohol	75	76	76	76	74	75	76	75
>0 to ≤1 drink/week	13	13	13	13	13	13	13	13
>1 drink/week	12	11	11	11	12	12	11	12
Breast feeding‡								
<6 months	–	–	–	–	39	39	39	38
≥6 months	–	–	–	–	61	61	61	62
Prepregnancy BMI, kg/m ²								
Normal (<25)	71	72	74	75	71	72	73	75
Overweight (25–30)	21	20	19	17	20	20	19	18
Obese (≥30)	9	8	8	7	8	8	8	8

Values are given as percentage.

*At conception.

†At first prenatal interview.

‡Information from the fourth interview (app. 18 months after birth).

BMI, body mass index.

We also found an association between road traffic noise and PPWR, which is more likely to reflect an actual increase in body fat, indicating that exposure to road traffic noise during these periods may be associated with development of adiposity.

When comparing our results with the results of the three previous longitudinal studies on road traffic noise and adiposity in adults, some differences were observed: One study found road traffic noise to be associated with a wider waist circumference and

risk of central obesity, but no associations with weight gain.³ The authors argue that cortisol would be expected to result primarily in central obesity, although they add that effects of noise on sleep may result in general obesity. Similarly, another study found no associations between road traffic and changes in BMI, although they did report an association with risk for obesity, but not with overweight.⁴ Lastly, a study from Denmark found associations between road traffic noise and changes in both weight and waist

Table 2 Associations between residential exposure to traffic noise and gestational weight gain (g/week)

Exposure from conception to ≈30 gestational week (L_{den})	N	Model 1* β (95% CI)	Model 2† β (95% CI)	Model 3‡ β (95% CI)
Road traffic noise				
<55 dB(A)	27 244	0 (reference)	0 (reference)	0 (reference)
(55–60) dB(A)	18 801	3.9 (1.4 to 6.3)	2.2 (–0.2 to 4.6)	1.7 (–0.7 to 4.1)
(60–65) dB(A)	16 073	7.8 (5.3 to 10.4)	5.5 (3.0 to 8.0)	4.6 (2.1 to 7.1)
≥65 dB(A)	11 947	11.4 (8.6 to 14.2)	7.4 (4.6 to 10.2)	5.9 (3.1 to 8.7)
Linear (per 10 dB(A))	74 065	7.0 (5.6 to 8.5)	4.7 (3.2 to 6.1)	3.8 (2.3 to 5.3)
Railway noise				
<55 dB(A)	69 321	0 (reference)	0 (reference)	0 (reference)
(55–60) dB(A)	2092	0.8 (–4.8 to 6.5)	–1.8 (–7.5 to 3.8)	–2.7 (–8.2 to 2.9)
(60–65) dB(A)	1404	6.9 (0.1 to 13.8)	4.0 (–2.8 to 10.8)	2.7 (–4.1 to 9.5)
≥65 dB(A)	1248	8.4 (1.1 to 15.6)	5.1 (–2.1 to 12.3)	4.5 (–2.7 to 11.6)
Linear (per 10 dB(A))	74 065	0.5 (–1.6 to 2.6)	0.7 (–1.4 to 2.8)	0.4 (–1.6 to 2.5)

*Model 1: unadjusted.

†Model 2: adjusted by age, parity, education, disposable household income, cohabitation, area-level income, season and mutual adjustment for noise from road traffic and railway.

‡Model 3: model 2 plus adjustment for smoking and alcohol consumption.

circumference as well as increased risk of gaining ≥ 5 kg.⁹ Therefore, although the overall picture when comparing these longitudinal studies is that traffic noise is associated with development of adiposity across different age groups, more epidemiological studies and research into the biological mechanisms behind the observed associations are needed to disentangle whether noise primarily is associated with central obesity, general obesity or both.

Interestingly, we found that the association between road traffic noise and PPWR seemed confined to women who were overweight or obese before pregnancy, as well as an indication of an association between road traffic noise and the risk of gaining ≥ 5 kg mainly among obese women. This suggests that obese women represent a susceptible group when it comes to the hazardous effects of traffic noise. Part of the explanation might be that obese women generally have poorer sleep than women with a BMI within the normal range,³⁸ and therefore, might be more easily disturbed and/or stressed by traffic noise. In support of our findings, a longitudinal study on elderly Danes found similar results, with stronger associations between road traffic noise and increases in weight and waist circumference among

people who were obese at baseline compared with people with a BMI below 25 kg/m².⁹ In contrast, a Swedish longitudinal study found no differences in associations between road traffic noise and weight or waist circumference changes according to baseline BMI (<25, 25–30 and ≥ 30 kg/m²).³ Therefore, more studies are needed to clarify the role of existing obesity in the noise–adiposity association, as identification of susceptible groups is important from a prevention perspective.

In the analyses of road traffic noise, we found that adjustment by air pollution (estimated as NO₂) reduced the GWG risk estimates and slightly increased the PPWR risk estimates. Disentangling effects of road traffic noise and air pollution in relation to disease are often challenging, because the two exposures correlates, reflecting that road traffic is an important input variable for both exposure models. Although studies investigating the association between air pollution and adiposity are currently inconclusive with both positive, negative and null findings,³⁴ we cannot rule out that for GWG some of the observed association with road traffic noise can be ascribed to air pollution, whereas for PPWR the association with road traffic noise seemed independent from air pollution exposure. In the present study, we

Table 3 Associations between residential exposure to traffic noise and 18 months postpartum weight retention (kg)

Exposure from conception to 18 months after birth (L_{den})	N	Model 1* β (95% CI)	Model 2† β (95% CI)	Model 3‡ β (95% CI)
Road traffic noise				
<55 dB(A)	19 011	0 (reference)	0 (reference)	0 (reference)
(55–60) dB(A)	14 170	0.18 (0.07 to 0.29)	0.14 (0.03 to 0.24)	0.13 (0.03 to 0.24)
(60–65) dB(A)	11 791	0.25 (0.14 to 0.36)	0.18 (0.07 to 0.30)	0.19 (0.07 to 0.30)
≥65 dB(A)	7689	0.24 (0.11 to 0.37)	0.15 (0.01 to 0.28)	0.14 (0.01 to 0.27)
Linear (per 10 dB(A))	52 661	0.16 (0.09 to 0.23)	0.09 (0.02 to 0.16)	0.09 (0.02 to 0.16)
Railway noise				
<55 dB(A)	49 256	0 (reference)	0 (reference)	0 (reference)
(55–60) dB(A)	1557	–0.16 (–0.41 to 0.09)	–0.21 (0.46 to 0.04)	–0.22 (–0.46 to 0.03)
(60–65) dB(A)	1027	0.12 (–0.18 to 0.43)	0.07 (–0.23 to 0.38)	0.08 (–0.23 to 0.38)
≥65 dB(A)	821	0.30 (–0.04 to 0.64)	0.25 (–0.09 to 0.60)	0.26 (–0.09 to 0.60)
Linear (per 10 dB(A))	52 661	–0.06 (–0.15 to 0.03)	–0.04 (–0.13 to 0.05)	–0.04 (–0.12 to 0.05)

*Model 1: unadjusted.

†Model 2: adjusted by age, parity, education, disposable household income, cohabitation, area-level income, breast feeding and mutual adjustment for noise from road traffic and railway.

‡Model 3: model 2 plus adjustment for smoking and alcohol consumption.

Table 4 Modification of the association between residential road traffic noise and differences gestational weight gain by prepregnancy BMI and in postpartum weight retention (18 months) by prepregnancy BMI, gestational age, season and gestational weight gain

	Difference in gestational weight gain rate (g/week) per 10 dB(A) higher pregnancy L_{den}			Difference in postpartum weight retention (kg) per 10 dB(A) higher L_{den} *		
	N	Model 3 β (95% CI)†	P value‡	N	Model 3 β (95% CI)§	P value‡
Prepregnancy BMI (kg/m ²)			0.49			<0.001
<25	53 590	3.0 (1.4 to 4.6)		38 171	−0.01 (−0.09 to 0.07)	
25–30	14 399	1.0 (−2.2 to 4.1)		10 238	0.17 (0.02 to 0.32)	
≥30	6076	1.6 (−3.2 to 6.5)		4252	0.49 (0.26 to 0.73)	
Gestational age at second pregnancy interview			0.39			
Week 26–29	26 467	2.4 (0.0 to 4.9)		–	–	
Week 30–33	25 556	4.8 (2.4 to 7.3)		–	–	
Week 34–37	22 042	3.6 (0.9 to 6.2)				
Season at second pregnancy interview			0.99			
Winter	16 744	3.6 (0.8 to 6.7)		–	–	
Spring and autumn	36 659	3.8 (1.8 to 5.9)		–	–	
Summer	20 662	3.7 (1.0 to 6.4)		–	–	
Gestational weight gain week 30 (g/week)						0.11
Quartile 1 (<239)		–		12 165	0.03 (−0.11 to 0.17)	
Quartile 2 (240–310)		–		12 308	0.04 (−0.10 to 0.18)	
Quartile 3 (311–385)		–		12 335	−0.06 (−0.20 to 0.08)	
Quartile 4 (≥386)		–		12 266	0.18 (0.05 to 0.32)	
Exposed to railway noise (dB(A))			0.44			0.85
No	13 464	3.5 (1.9 to 5.1)		10 521	0.09 (0.01 to 0.17)	
Yes	60 601	5.0 (1.6 to 8.3)		42 140	0.10 (−0.05 to 0.26)	

*Time-weighted mean from conception to 18 month post partum.

†Adjusted by age, parity, education, disposable household income, cohabitation, area-level income, smoking, alcohol consumption, season and railway noise.

‡P value for interaction.

§Adjusted by age, parity, education, disposable household income, cohabitation, area-level income, smoking, alcohol consumption, breast feeding and railway noise. BMI, body mass index.

did not have information on exposure to $PM_{2.5}$, which is a limitation as particles have been shown to be a key air pollutant in relation to development of disease.

We found some suggestions of an association between high levels of railway noise and GWG or PPWR. Three previous longitudinal studies on railway noise and markers of adiposity found no or rather weak indications of associations between railway noise and changes in weight and/or waist circumference.^{3 4 9} A potential explanation for the weaker association compared with road traffic noise is that most trains operating in Denmark and other countries are passenger trains, which do usually not run during the night, and may therefore not be associated with disturbance of nocturnal sleep, in the same degree as road traffic noise which continue during night.

Major strengths of our study include the longitudinal design and the large study population, with information on weight and changes in weight over time, together with information on potential confounders from questionnaires and high-quality nationwide registers.^{39 40} Furthermore, we had access to residential address histories (before outcome) that enabled us to estimate residential exposure in the relevant time periods taking residential mobility into account.

The main limitation of the present study is that GWG and PPWR were estimated from self-reported information on weight and weight gain, which will inevitably result in misclassification. A validation study based on a Danish cohort of elderly participants (>50 years at enrolment) indicated that participants tended to under-report their weight, and that this underestimation was

Table 5 Association between residential road traffic noise and risk of weight retention of ≥5 kg at 18 months post partum for all and among women with BMI within the normal, overweight and obese range

L_{den} road from conception to 18 months after birth	All		Normal BMI		Overweight		Obese	
	N cases	RR (95% CI)*	N cases	RR (95% CI)*	N cases	RR (95% CI)*	N cases	RR (95% CI)*
Categorical								
<55 dB(A)	1674	1 (ref)	1092	1 (ref)	427	1 (ref)	155	1 (ref)
55–60 dB(A)	1368	1.05 (0.98 to 1.12)	881	1.03 (0.95 to 1.12)	352	1.08 (0.95 to 1.23)	135	1.13 (0.91 to 1.40)
60–65 dB(A)	1177	1.06 (0.99 to 1.14)	785	1.05 (0.96 to 1.15)	286	1.11 (0.96 to 1.28)	106	1.09 (0.86 to 1.37)
≥65 dB(A)	770	1.03 (0.95 to 1.12)	541	1.06 (0.96 to 1.17)	156	0.94 (0.79 to 1.12)	73	1.16 (0.89 to 1.51)
Linear, per 10 dB(A)	4989	1.03 (0.98 to 1.07)	3299	1.04 (0.99 to 1.10)	1221	0.99 (0.90 to 1.08)	469	1.08 (0.94 to 1.25)

*Adjusted by age, parity, education, disposable household income, cohabitation, area-level income, smoking, alcohol consumption, breast feeding and railway noise. BMI, body mass index.

highest among participants with high BMI,⁴¹ which may lead to bias of the results. However, the focus of the present study was gain in weight, which might be less affected by such biased misclassification compared with a cross-sectional design, at least if the under-reporting of weight is systematic over time for each woman. Also, pregnancy and the period just after pregnancy are periods with increased focus on weight, as the women in these periods attend a number of healthcare visits where their weight are measured, which probably results in a more precise self-reporting of weight. Furthermore, reporting of BMI might be associated with noise exposure, through an impact of socioeconomic status (SES) on both, but we observe only minor differences in SES according to noise suggesting that this is not a major problem.

A limitation in the GWG assessment is that the time of the second pregnancy interview varied from gestational week 26 to 37. The weight gain rate is higher during second and third trimester compared with first trimester, and therefore, the GWG estimated in our study will tend to be higher for women interviewed late compared with early. However, we found that gestational age at the second interview did not modify the noise–GWG association, indicating weak or no influences on the estimates. In addition, environmental exposures such as air pollution have been found to have different impacts in different trimesters. However, as noise estimates in the present study were based on annual estimates, trimester-specific analyses were not possible.

Other limitations include lack of information on various individual factors that might influence the personal exposure, for example, information on time at home and window opening habits. We observed that adjustment by SES and lifestyle confounders resulted in a marked decrease in estimate size, suggesting that residual confounding may be an issue. However, including smoking and alcohol as potential confounders may result in overadjustment, as they have been suggested to be mediators rather than confounders.⁴² We did not have information of ethnicity, but inclusion of only women who spoke Danish well enough to complete the long interviews virtually excluded all other ethnicities than Danish through generations. Lastly, the results cannot be readily generalised to the whole population, as only 30% of the eligible pregnant women in Denmark participated in the cohort, and they have been indicated to have higher SES than non-participants.⁴³

In conclusion, we found that exposure to road traffic noise and possibly high levels of railway noise was associated with slightly higher GWG and PPWR, although for GWG some of the observed association may possibly be ascribed to air pollution. The association between road traffic noise and PPWR seemed confined to women who were overweight or obese before pregnancy, suggesting that these women constitute a susceptible population that may benefit from noise preventive initiatives.

Contributors MS, OR-N and TIAS conceived the present study. MK geocoded addresses and estimated air pollution. MS conducted the statistical analyses and wrote the first manuscript draft. All authors commented and contributed to the final manuscript.

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