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Associations of traffic noise and air pollution with birth outcomes in Alpine areas: Results from the UIT and BBT surveys

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ABSTRACT

The present study investigated associations between traffic noise and air pollution and birth outcomes in several Alpine areas. We used data from two representative cross-sectional studies (UIT, n = 573 and BBT, n = 518) in the Tyrol Region (Austria and Italy). Only mothers who had lived in their current residence during the whole pregnancy were included. They completed a questionnaire, and medical records were used to draw data on birth weight, low birth weight (LBW), preterm birth, and small for gestational age (SGA). Road/railway traffic noise (L_{dn}, L_{den}) and air pollution (NO_2) were assessed using a combination of sophisticated modelling and field measurements. In the UIT survey, higher L_{dn} was associated with higher odds of LBW, while no significant associations were observed for NO_2. In the BBT survey, L_{den} was associated with lower birth weight in some subgroups and NO_2 was associated with lower birth weight in preterm babies. Future studies should re-confirm the discovered associations of traffic emissions with birth outcomes in the Alpine region.

Keywords: Pregnancy outcomes, Birth weight, Preterm birth

1. INTRODUCTION

Birth weight and gestational age at delivery not only have critical importance for early-life mortality (1), but also affect long-term programming of health and disease (2). Besides well-known contributors to adverse birth outcomes, such as genetics, sociodemographics, and lifestyle, there is increasing recognition that the surrounding environment also takes its toll on intrauterine growth and development. For example, some air pollutants can cross the pulmonary epithelium entering the circulation, and thus, promote systemic inflammatory responses and oxidative stress, leading to placental dysfunction and restricted fetal growth (3). The biological mechanisms underlying the effect of traffic noise, another related factor, involve neuroendocrine stress reaction in the maternal organism, which in turn may disrupt normal placental function (impaired blood supply, elevated corticotropin releasing hormone secretion), affect the hypothalamic-pituitary-adrenal axis of the fetus, and thereby lead to preterm delivery, small for gestational age, and low birth weight (LBW; < 2500 g) (4). Moreover, a noisy and polluted residential environment is not only stressful in itself but may be perceived as unattractive setting for physical activity and social interactions, limiting the opportunities for outdoor recreation (5).

Multiple studies have looked into effects of air pollution exposure during pregnancy and found a higher risk of LBW/preterm birth in association with increased concentrations of some pollutants (3). Although it is thinner, the epidemiological literature on traffic noise also points to a potential association with poor birth outcomes (4). Results of the few studies that investigated the joined effects of traffic noise and air pollution were inconsistent (6-9). Understanding the interplay between these

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spatially correlated exposures is essential for planning healthy settlements.

Another caveat is that most previous research was undertaken in highly urbanized areas, which means that the findings cannot be directly extrapolated to settings where the spatial relationships between traffic emissions differ. In addition to urbanicity, terrain features, such as steepness and altitude, may confound or modify the effects during pregnancy. For instance, higher altitude has been linked to intrauterine growth retardation and a subsequent reduction in birth weight (10), while living in a hilly area may increase physical activity and protect of type 2 diabetes (11), thereby supporting normal birth weight (12). No previous study has accounted for these factors though.

In the present explorative study, we had a unique opportunity to investigate the association of residential traffic noise and air pollution with birth outcomes in several Alpine areas. The Alps cover 190 959 km^2 and are home to 14 million Europeans (13). Because of the idiosyncratic topography of the region, previous findings may not apply to children born there. Furthermore, given their landform, natural ventilation, and transport infrastructure, some valleys are characterized by temperature inversions and propagation of sound waves over great distances, which can lead to higher levels of air pollution and noise (14). Hence, undertaking a study in this geographic context will help advance the literature on the subject by expanding earlier research.

2. MATERIAL AND METHODS

2.1 Study Area

The present study takes advantage of data originally collected to assess relationships between environmental quality and children's well-being within the framework of two epidemiological studies in the Tyrol Region – the UIT survey (conducted in the Lower Inn valley, Unterinntal, in Austria) and the BBT survey (conducted in the Wipp valley, Wipptal, and its side valleys on both sides of the Brenner pass in Austria and Italy, as well as partially in Lower Inn valley). Both valleys are part of the most important access route for heavy goods traffic over the Brenner Pass, which links central and northern Europe's traffic to southern Europe. The settlements consist of densely populated small towns and villages with a mix of industrial, small business, touristic, and agricultural activities. Main transportation lines (a highway and a railway) run through the valleys, with main roads connecting to the various small villages and causing high levels of noise (5). (See Figure 1)

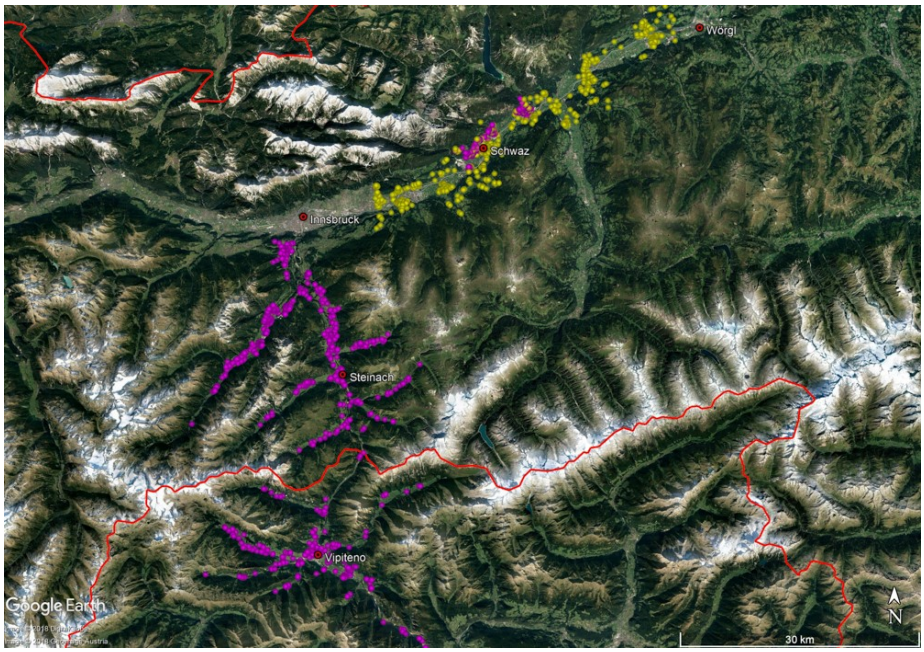

Figure 1 – Participants' home addresses in the UIT (yellow dots) and BBT (purple dots) survey areas. Note. The red lines are the Austrian-German (north) and Austrian-Italian (south) borders.

The UIT survey site extends about 40 km east of Innsbruck towards the Austrian-German border across a relatively broad U-shaped valley floor and up to the foothills of the Alpine comb. The area is

characterized by a combination of high levels of air pollution and traffic noise (15, 16). The narrow V-shaped Wipp valley extends along the river Sill southward from Innsbruck up to the Brenner Pass at the Austro-Italian border. South of the border the Wipp valley stretches along the river Isarco down to Fortezza in Italy. Owing to differences in meteorology (stronger winds versus a lot of temperature inversions) and topography (north-south versus east-west), air pollution levels in the Wipp valley are considerably lower than in the Lower Inn valley.

2.2 Study Design

The UIT survey was undertaken in June 1998 and recruited a total of 1280 children recruited from 26 local schools (grades 3 – 4) with a response rate of 79.5% (17). The BBT survey included complete records of 1251 children (response rate = 85.5%) in the same age group recruited in 2004/2005 from 49 schools (18). In both surveys, children's mothers completed a nearly identical self-administered, standardized questionnaire which asked about sociodemographic information, lifestyle, perinatal data, housing, and duration of residence at the current address. The mothers or legal guardians of all participants provided written informed consent.

In order to reduce exposure misclassification, the present study was limited to children born to mothers who had lived in their current residence during the whole pregnancy. In one of sensitivity analyses, we also present the results for the entire sample. We also excluded all cases for which the exact address could not be geocoded. This resulted in final analytic samples of 573 children in the UIT survey and 518 children in the BBT survey.

Comparison between characteristics of those mothers who lived at the residence since the time of conception and pregnancy and those who moved in later (movers and non-movers) indicated some differences. In both surveys, non-movers were older and more often multiparous. They were also more likely to live in a single family home and less likely to be smokers. In the UIT survey, the prevalences of single mothers and those who gave birth to SGA were higher in movers. In the BBT survey, the prevalence of those who gave birth to children of LBW was somewhat higher in non-movers.

2.3 Birth Outcomes Assessment

Prenatal and perinatal data were drawn from doctor's entries in the Mutter-Kind-Pass, which every pregnant woman in Austria receives. In the southern BBT area in Italy (Alto Adige) which has close relations to Austria, the equivalent "Mutterpass" was available. The two primary outcomes were birth weight and LBW (defined as weight less than 2500 g). We also considered preterm birth (birth before the 37th gestational week) and small for gestational age (SGA) (birth weight below the 10th percentile for the gestational age in Tyrol).

2.4 Traffic Noise and Air Pollution Assessment

We only had data on traffic noise and air pollution calculated about 10 years after birth, therefore, they were used as surrogates for exposure levels during pregnancy. For the UIT survey, the three major noise sources (highway, railway, and local main roads) were modelled in 1997 – 1998 at a resolution of 25 m x 25 m, and source-specific and total day-night noise levels (L_{dn}) were assessed for each respondent. Nitrogen dioxide (NO_2) served as a proxy for annual average traffic-related air pollution in 1995, and was calculated at a resolution of 100 m x 100 m using an adapted Gaussian propagation model procedure considering the meteorological and topographic specifics of the study area. The resulting modelled estimates were calibrated against measurements and corrected where needed (19).

In the BBT survey, noise emissions were assessed in 2003/2004. Since there are no railways in the side valleys, road and railway traffic were not considered as separate noise sources. Total day-evening-night noise level (L_{den}) was calculated at the most exposed façade, and reflected only road traffic noise for residents of the side-valleys and combined road traffic and railway noise for those living in the Wipp valley. Annual means for NO_2 were calculated in 2003/2004 at a resolution of 10 x 10 m. Calculations were supplemented with additional traffic counting and micro-simulations, and were evaluated against measurements.

2.5 Covariates

Potential confounders and effect modifiers were selected based on theory and literature precedent (6, 8, 20) and included: mother's education, smoking during pregnancy, house type, season of pregnancy, altitude, slope, duration of residence before conception, maternal age at birth, child's sex, and birth order. In the UIT survey, we also had additional information on single mother status.

2.6 Statistical Analysis

Given the systematic differences between the two survey areas in terms of environmental conditions and year of deliveries, and that the BBT area partially overlaps with the UIT area, we decided to analyze the two samples separately. Because less than ≈ 5 – 6% of values were missing from most of the variables, they were imputed using the expectation-maximization algorithm. Missing values in noise and air pollution were only imputed if other geographic variables were available.

Prior to the multivariate analyses, the linearity of the shape of relationships between L_{dn}/L_{den} and NO_2 and birth outcomes was tested, and no deviation from linearity was detected. Thus, we employed multivariate linear regression models to investigate the association between continuous environmental exposures and continuously-measured birth weight, and multivariate logistic regression models for LBW, preterm birth, and SGA. The models were adjusted for sex of child, age of mother at birth, gestational age, single mother status (only in the UIT models), mother's education, smoking during pregnancy, duration of residence before conception, and house type. Effect estimates of L_{dn}/L_{den} and NO_2 are reported per 10 dB and 10 $\mu g/m^3$ increase, respectively.

In a series of sensitivity analyses, we tested the robustness of our findings for LBW and birth weight. First, the models were repeated on all UIT and BBT mothers (movers and non-movers), hypothesizing that associations would be attenuated due to exposure misclassification. Second, the models were additionally individually adjusted for slope and altitude. Next, we adjusted for birth order. Finally, because of relevant differences in the prevalence of perinatal indicators and air pollution across the BBT region, sensitivity analyses were conducted with models limited to mothers residing in the Lower Inn valley and the northern (Austrian) region of the BBT-study.

Finally, several factors were tested as potential modifiers of the association between the exposures and birth weight: duration of residence, preterm birth, birth order, single mother status, mother' education, and altitude. We conducted moderation analysis using the PROCESS v. 2. 16 macro for SPSS (21). Additionally, we ran interaction analyses.

3. RESULTS

3.1 Characteristics of the UIT and BBT Samples and Bivariate Associations

Characteristics of the UIT and BBT participants are presented in Table 1. The two samples had some notable differences. There was a higher prevalence of LBW and SGA in BBT children compared to UIT children. Altitude and slope were greater than in the UIT survey. The most pronounced difference, however, was in the air pollution levels. Participants of the BBT survey (except for those living in the Lower Inn valley) were exposed to considerably lower air pollution than those of the UIT survey. In addition, noise and air pollution were stronger correlated in the UIT survey (r_s = 0.69 vs 0.50). Results from the tests of the bivariate associations between participants' characteristics and birth outcomes indicate that birth weight was positively related to male sex, higher birth order, and older age of the mother.

3.2 Associations between Traffic Noise and Air Pollution and Birth Outcomes

There were differences in associations between exposure variables and birth outcomes across the study areas (Table 2). In the UIT survey, the single exposure models indicated that higher L_{dn} from all considered sources was associated with higher odds for LBW. Associations with NO_2 were in the same direction as with noise but non-significant.

In the BBT survey, the association of L_{den} with birth weight was in the expected direction but with wide confidence intervals including 0 and 1, respectively. Still, when adjusted for NO_2, L_{den} was associated with lower birth weight. Unexpectedly, we observed lower odds for SGA in relation with higher L_{dn}.

Table 1 – Participant key characteristics in the UIT and BBT surveys

Characteristic	UIT survey (N = 573)	BBT survey (N = 518)
Maternal age (mean years, SD)	28.52 (4.77)	30.07 (4.60)
Male child (n, %)	290 (50.61)	262 (50.58)
Single mother (n, %)	27 (4.71)	-
Smoking during pregnancy (n, %)	45 (7.85)	49 (9.46)
Mother's education (n, %)		
Basic	147 (25.65)	130 (25.10)
Skilled labor	188 (32.81)	168 (32.43)
Vocational	148 (25.83)	128 (24.71)
A-level	90 (15.71)	92 (17.76)
Birth weight (mean grams, SD)	3384.99 (528.76)	3221.72 (564.71)
Low birth weight (n, %)	26 (4.54)	53 (10.23)
Preterm birth (n, %)	81 (14.14)	64 (12.36)
Small for gestational age (n, %)	22 (3.84)	34 (6.56)
$L_{dn\ total}$ (median dB, IQR)	52.26 (10.64)	52.53 (14.39)
$L_{dn\ main\ road}$ (median dB, IQR)	46.36 (13.80)	49.66 (14.30)
$L_{dn\ railway}$ (median dB, IQR)	49.88 (10.32)	-
NO_2 (median µg/m^3, IQR)	31.23 (6.87)	12.32 (9.92)

Table 2 – Multivariate associations between traffic noise and air pollution and birth outcomes

	UIT survey (N = 573)		BBT survey (N = 518)	
	LBW	Birth weight	LBW	Birth weight
	OR (95% CI)	β (95% CI)	OR (95% CI)	β (95% CI)
$L_{dn\ total}$	2.03 (1.16, 3.54)	-17.63 (-71.77, 36.51)	0.96 (0.66, 1.39)	-35.45 (-73.43, 2.53)
$L_{dn\ road}$	1.76 (1.03, 3.00)	-5.50 (-54.58, 43.58)	0.90 (0.61, 1.32)	-31.49 (-72.80, 9.82)
$L_{dn\ railway}$	1.93 (1.11, 3.33)	-11.96 (-67.55, 43.64)	-	-
NO_2	2.04 (0.87, 4.79)	-31.37 (-103.62, 40.9)	1.06 (0.68, 1.65)	11.56 (-33.91, 57.03)
$L_{dn\ total}$ (+ NO_2)	1.99 (0.95, 4.17)	-2.59 (-77.65, 72.48)	0.93 (0.61, 1.40)	-47.05 (-88.49, -5.6)
NO_2 (+ $L_{dn\ total}$)	1.04 (0.34, 3.21)	-28.98 (-129.18, 71.2)	1.10 (0.67, 1.81)	34.26 (-15.22, 83.73)

3.3 Effect Modification and Sensitivity Analyses

In the UIT survey, no effect modification was observed for L_{dn}. For NO_2, the association was more pronounced in first born babies and mothers living with a partner. We saw borderline interactions between L_{dn} and NO_2 – inverse associations with birth weight were only seen when the other exposure was low. In the BBT survey, L_{den} was related to lower birth weight in preterm babies (β = -140.57 g; 95% CI: -260.51, -20.63), as was NO_2 (β = -168.45 g; 95% CI: -321.66, -15.25).

When all mothers (non-movers and those who moved after delivery) were included, the effects in the UIT survey were no longer there. Adjusting for slope considerably enhanced the observed associations for L_{dn} and NO_2 in the UIT survey. When we limited the analysis to residents of the northern (Austrian) BBT subregion, higher L_{den} was associated with lower birth weight (β = -62.47 g; 95% CI: -115.52, -9.41).

4. DISCUSSION

4.1 General Findings

In the present study, we investigated the associations of traffic noise and air pollution with birth outcomes in several Alpine areas with unique geographic features. Surprisingly, we saw contrast across the study areas. In the Lower Inn valley, noise was associated with higher odds for LBW, and this association was no longer significant after correcting for NO_2. Conversely, in the BBT survey, significant associations were present only in subgroups.

There are a number of possible reasons for this discrepancy. The most apparent difference between the study areas is the much higher air pollution levels in the Lower Inn valley. Another noteworthy difference between the surveys is the higher prevalence of perinatal outcomes (LBW and SGA) in the BBT area, which may reflect other confounding/modifying factors unaccounted for, such as healthcare. Another interpretation of the inconsistent findings could be presence of structural confounding in the data (i.e. systemic differences in covariates related to both the exposure and the outcome across communities). The BBT villages are smaller than the UIT villages, and the relationship between socioeconomic position and residential location differs from village to village depending on the residential layout. We reckon that the stronger (or more pronounced) geographic and traffic heterogeneity of the BBT area with its several side valleys, coupled with heterogeneity in prevalence of birth outcomes, might have contributed to a greater overdispersion in the data, which might have translated into larger standard errors of some estimates making them less precise and not reaching statistical significance. We are also mindful of the temporal difference between the two surveys that could explain part of the differences in the results. Unfortunately, at this point we cannot offer a straightforward explanation of our findings.

Traffic noise was associated with higher risk for LBW in the UIT survey, while in the BBT survey, the association with continuous birth weight was marginally significant for in the main model, and significant only when air pollution was adjusted for, and in subgroups. The recent WHO review on traffic noise and birth outcomes found few studies and low quality evidence that traffic noise leads to LBW, preterm birth, and SGA (4). In general, the evidence is mixed, with some studies pointing to an increased risk (e.g., 6), whereas others were not supportive of such associations (e.g., 9, 20, 23). Nieuwenhuijsen et al. (4) pointed out the need for studies on different sources of noise, but to our knowledge, only a few earlier studies (6, 7, 22) have considered combined exposure to road and railway traffic noise. In the UIT survey, we evidenced associations for both road traffic and railway noise before NO_2 adjustment. Gehring et al. (6) reported a 19 g (95% CI: - 23, - 15) decrease of term birth weight for every 6-dB increase in road traffic noise exposure and similar estimates for combined road, aircraft, and railway noise. Hjortebjerg et al. (7), conversely, did not observe an association of noise with newborn's size indicators.

The evidence from air pollution studies is larger and more convincing. A comprehensive meta-analysis of 14 population-based mother-child cohorts indicated 9% higher odds of term LBW for 10 $\mu g/m^3$ increase of NO_2 (24). In the present study, no consistent associations were observed for NO_2 – in the UIT models, the estimates had the expected sign albeit they were non-significant, but in the BBT survey, such association was observed only in preterm babies. The effect modification of association with NO_2 by preterm birth in the BBT survey is in line with the conjecture that preterm babies may be particularly vulnerable – environmental stressors may be stronger associated with fetal growth restriction during developmental periods before the 37th gestational week (25, 26), whereas infants who have reached full maturity may have had time to “catch-up” on weight gain, thus, partially offsetting the adverse environmental influences. However, this could also be a statistical artefact.

Ours is one of the few attempts to disentangle the interplay of traffic noise and air pollution (cf. 6, 7, 8, 27). For instance, in a population-based cohort study in London, an increase in NO_2 was associated with 3% increased odds for term LBW and 1% increased odds for term SGA (8), while the effect of road traffic noise was strongly attenuated when adjusted for primary traffic-related air pollutants. According to Hjortebjerg et al. (7), traffic noise was not related to newborn's size at birth in Denmark, whilst in Canada (6), joint air pollution-noise models revealed that associations between noise and term birth weight were robust to adjustment for air pollution but not the other way around. It stands to reason that the interplay between the exposures is complex and area-specific.

4.2 Strengths and Limitations

The present study has several novel features. First, the Alpine region is a unique setting which

differs from settings of previously reported studies. In addition, this study relied on high-quality biomedical data and state-of-the-art noise and air pollution modeling tailored to the Alpine region.

We also recognize several limitations of the current study. The sample sizes were modest, which could explain some null findings. Concerns about raising type II error prevented us from controlling for the increase in familywise error across the reported statistical analyses. Furthermore, excluding mothers whose address at the time of pregnancy was unknown could have resulted in residual self-selection bias and undermined the representativeness of the reduced analysis samples.

In terms of exposure assessment, noise and air pollution levels were originally calculated for the year of the surveys, that is, about 9 – 10 years after children's birth. This inherent design feature could not be overcome. Traffic volume has steadily increased in the period 1995 – 2005 in most segments, with some 20 – 30% along the Inn valley study area and 30 – 40% across the BBT area (http://tirolatlas.uibk.ac.at/). This gives us reason to suggest that it increased in a homogeneous manner possibly preserving spatial contrasts in traffic immissions. A further limitation is that we assigned annual mean air pollution to each pregnant woman's address, rather than using time-varying season-specific NO_2.

Various air pollutants have been linked to adverse birth outcomes (24), but we only considered NO_2. Unaccounted for residual confounding could have led to counterintuitive findings.

5. CONCLUSIONS

Our findings provide inconclusive evidence that traffic noise might be associated with adverse birth outcomes in mountainous areas. Given the disparate associations across the study areas, further research with larger representative samples is warranted.

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REFERENCES

1. McCormick MC. The contribution of low birth weight to infant mortality and childhood morbidity. N Engl J Med. 1985;312(2):82-90.
2. Barker DJ. The origins of the developmental origins theory. J Intern Med 2007;261(5):412–17.
3. Sapkota A, Chelikowsky AP, Nachman KE, Cohen AJ, Ritz B. Exposure to particulate matter and adverse birth outcomes: a comprehensive review and meta-analysis. Air Qual Atmos Health 2012;5:369-381.
4. Nieuwenhuijsen MJ, Ristovska G, Dadvand P. WHO Environmental Noise Guidelines for the European Region: A Systematic Review on Environmental Noise and Adverse Birth Outcomes. International Journal of Environmental Research and Public Health. 2017;14(10):1252.
5. von Lindern E, Hartig T, Lercher P. Traffic-related exposures, constrained restoration, and health in the residential context. Health Place. 2016;39:92-100.
6. Gehring U, Tamburic L, Sbihi H, Davies HW, Brauer M. Impact of noise and air pollution on pregnancy outcomes. Epidemiology. 2014;25(3):351-8.
7. Hjortebjerg D, Andersen AM, Ketzel M, Pedersen M, Raaschou-Nielsen O, Sørensen M. Associations between maternal exposure to air pollution and traffic noise and newborn's size at birth: A cohort study. Environ Int. 2016; 95:1-7.
8. Smith RB, Fecht D, Gulliver J, Beevers SD, Dajnak D, Blangiardo M, et al. Impact of London's road traffic air and noise pollution on birth weight: retrospective population based cohort study. BMJ. 2017;359:j5299.
9. Barba-Vasseur M, Bernard N, Pujol S, Sagot P, Riethmuller D, Thiriez G, et al. Does low to moderate environmental exposure to noise and air pollution influence preterm delivery in medium-sized cities? Int J Epidemiol. 2017;46(6):2017-2027.
10. Waldhoer T, Klebermass-Schrehof K. The impact of altitude on birth weight depends on further

mother- and infant-related factors: a population-based study in an altitude range up to 1600 m in Austria between 1984 and 2013. J Perinatol. 2015;35(9):689-94.
11. Fujiwara T, Takamoto I, Amemiya A, Hanazato M, Suzuki N, Nagamine Y, et al. Is a hilly neighborhood environment associated with diabetes mellitus among older people? Results from the JAGES 2010 study. Soc Sci Med. 2017;182:45-51.
12. Kc K, Shakya S, Zhang H. Gestational diabetes mellitus and macrosomia: a literature review. Ann Nutr Metab. 2015;66 Suppl 2:14-20.
13. Onida M. The Alps: eight countries, a single territory. Permanent Secretariat of the Alpine Convention. Innsbruck (Austria); 2009. Available at: http://www.alpconv.org/en/publications/alpine/Documents/AlpenkonventionsBuch.pdf
14. Heimann D, de Franceschi M, Emeis S, Lercher P, Seibert P. (Eds.). Air Pollution, Traffic Noise and Related Health Effects in the Alpine Space – A Guide for Authorities and Consulters. ALPNAP comprehensive report. Università degli Studi di Trento, Dipartimento di Ingegneria Civile e Ambientale, Trento, Italy; 2007, p. 335.
15. Lercher P, Kofler WW. Behavioral and health responses associated with road traffic noise exposure along alpine through-traffic routes. Sci Total Environ. 1996;189:85-89.
16. Lercher P, Schmitzberger R, Kofler W. Perceived traffic air pollution, associated behavior and health in an alpine area. Sci Total Environ. 1995;169(1-3):71-74.
17. Lercher P, Evans GW, Widmann U. The ecological context of soundscapes for children's blood pressure. J Acoust Soc Am. 2013;134(1):773-81.
18. Lercher P, Eisenmann A, Dekonick L, Botteldooren D. The relation between disturbed sleep in children and traffic noise exposure in alpine valleys. Proceedings of the 42nd International Congress and Exposition on Noise Control Engineering, InterNoise, Innsbruck, Austria, 15–18 September; 2013.
19. Lercher P, Widmann U, Thudium J. Hypotension and environmental noise: a replication study. Int J Environ Res Public Health. 2014;11(9):8661-88.
20. Dadvand P, Ostro B, Figueras F, Foraster M, Basagaña X, Valentín A, et al. Residential proximity to major roads and term low birth weight: the roles of air pollution, heat, noise, and road-adjacent trees. Epidemiology. 2014;25(4):518-25.
21. Hayes A. Introduction to mediation, moderation, and conditional process analysis: A regression-based approach. New York: Guilford Press; 2013.
22. Cusack L, Sbihi H, Larkin A, Chow A, Brook JR, Moraes T, et al. Residential green space and pathways to term birth weight in the Canadian Healthy Infant Longitudinal Development (CHILD) Study. Int J Health Geogr. 2018;17:43.
23. Wallas A, Ekström S, Bergström A, Eriksson C, Gruzieva O, Sjöström M, et al. Traffic noise exposure in relation to adverse birth outcomes and body mass between birth and adolescence. Environmental Research 2019;169:362–367.
24. Pedersen M, Giorgis-Allemand L, Bernard C, Aguilera I, Andersen AM, Ballester F, et al. Ambient air pollution and low birthweight: a European cohort study (ESCAPE). Lancet Respir Med. 2013;1(9):695-704.
25. Iñiguez C, Ballester F, Estarlich M, Esplugues A, Murcia M, Llop S, et al. Prenatal exposure to traffic-related air pollution and fetal growth in a cohort of pregnant women. Occup Environ Med. 2012;69(10):736-44.
26. Wu H, Jiang B, Zhu P, Geng X, Liu Z, Cui L, et al. Associations between maternal weekly air pollutant exposures and low birth weight: a distributed lag non-linear model. Environ. Res. Lett. 2018;13:024023.
27. Nieuwenhuijsen MJ, Agier L, Basagaña X, Urquiza J, Tamayo-Uria I, Giorgis-Allemand L, et al. Influence of the Urban Exposome on Birth Weight. Environ Health Perspect. 2019;127(4):47007. doi: 10.1289/EHP3971.