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Do outdoor environmental noise and atmospheric NO_2 levels spatially overlap in urban areas?☆

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A B S T R A C T

The urban environment holds numerous emission sources for air and noise pollution, creating optimum conditions for environmental multi-exposure situations. Evaluation of the joint-exposure levels is the main obstacle for multi-exposure studies and one of the biggest challenges of the next decade. The present study aims to describe the noise/NO_2 multi-exposure situations in the urban environment by exploring the possible discordant and concordant situations of both exposures. Fine-scale diffusion models were developed in the European medium-sized city of Besançon (France), and a classification method was used to evaluate the multi-exposure situations in the façade perimeter of 10,825 buildings. Although correlated (Pearson's $r = 0.64$, $p < 0.01$), urban spatial distributions of the noise and NO_2 around buildings do not overlap, and 30% of the buildings were considered to be discordant in terms of the noise and NO_2 exposure levels. This discrepancy is spatially structured and associated with variables describing the building's environment. Our results support the presence of several co-existing, multi-exposure situations across the city impacted by both the urban morphology and the emission and diffusion/propagation phases of each pollutant. Identifying the mechanisms of discrepancy and convergence of multi-exposure situations could help improve the health risk assessment and public health.

1. Introduction

Nearly 15% of the European population are exposed to daily average noise or air pollutant levels exceeding the threshold set by the European community (EEA, 2011; EEA, 2012). Several epidemiological studies have evaluated the health effects of individual exposure to noise or to air pollution (World Health Organization Europe, 2005; World Health Organization Europe, 2011), but it is only recently that studies have really started to take interest in the impacts of multi-exposure (i.e. simultaneous exposure to several pollutants) to noise and air pollution. Results varies amongst studies and the explored heath effect: annoyance (Klaeboe et al., 2000), respiratory health (Ising et al., 2004), cardiovascular health (Allen and Adar, 2011; Huang et al., 2013; Tétreault et al., 2013; Foraster et al., 2014), neurobehavior (Clark et al., 2012; Van Kempen et al., 2012), or pregnancy outcomes (Gehring et al., 2014). Consequently, the exact nature of the joint effects of multi-exposure remains unclear (Foraster, 2013; Foraster et al., 2014; Tétreault et al., 2013).

One of the main obstacles to multi-exposure studies is the difficulty of evaluating the joint-exposure levels. Many of the numerous urban sources for both pollution are shared. Amongst them, road traffic is considered to be the main contributor to both noise and air pollution (EEA, 2009; EMEP/EEA, 2013). Other sources, like railway traffic, contribute mostly to a single pollutant, creating optimum but complex conditions for environmental multi-exposure. The studies quantifying multi-exposure to noise and air pollution have shown variables levels of correlation (Davies et al., 2009; Allen et al., 2009; Weber, 2009; Foraster et al., 2014),

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depending on exposure quantification methodology (Foraster, 2013; Tétreault et al., 2013), temporal scale (Davies et al., 2009; Ross et al., 2012), or local urban environment (Kheirbek et al., 2014; Kim et al., 2012). At the city scale, the diffusion phenomenon highly impacts the distribution and intensity of each pollutant (Ariza-Villaverde et al., 2014; Yuan et al., 2014). The present study is based on the hypothesis that differences in pollutants diffusion phenomenon can create strong discrepancies between pollutants distributions, resulting in different multi-exposure situation linked to urban physical and demographic variables.

Moreover, despite being the most important category of cities in terms of demography, with more than 44% of the European population (Giffinger et al., 2007), medium-sized cities tend to be less studied than bigger cities due to their smaller population sizes and their resulting lower pollution levels (Selden and Song, 1994). Besides, the scheduled lowering of legal threshold limit values should lead major cities' air pollution levels to decline to those currently observed in medium-sized cities, making them of the highest importance for today and future public health studies.

The present study aims to i) describe the noise/NO_2 multi-exposure situations in a European medium-sized city and ii) explore the possible patterns for discordant and concordant exposure situations using urban physical and demographic variables.

2. Materials & methods

2.1. Study site

The study was conducted in the European medium-sized city of Besançon, the capital of the Franche-Comté, a French administrative region in eastern France (**Lat:** 47.237829, **Long:** 6.024054 in WGS84). The city has approximately 118,000 inhabitants (National Institute of the Statistics and the Economic Studies, 2010) distributed in a 65 km^2 urban area within the municipality boundaries. No significant pollution-producing infrastructure, such as airports, large highways, highly-emitting industries are present in the city. Therefore, the main source for environmental air pollution was the combustion of hydrocarbons due to road traffic, and to a lesser extent collective and individual buildings heating in winter period. For environmental noise pollution, the main sources were road and railway traffic. In this context, NO_2 was retained as the air pollution estimate, and the daily equivalent A weighted sound level ($L_{Aeq,24h}$) as the ambient noise level. Emission-diffusion/propagation models were used. Common and specific sources of the two retained pollutants (noise and NO_2) were simultaneously considered to explore the possible patterns for discordant and concordant exposure situations.

2.2. Models construction

Both noise and air environmental levels have been computed using common inputs presented in Tenailleau et al. (2015b). The inputs were the following: i) meteorological observations (temperature, cloudiness, solar radiation, wind direction and speed) obtained from the French National Meteorological Service (Météo-France) for every day of the year 2011; ii) topographic data obtained from the French National Geographical Institute (IGN) database (BD TOPO® for 2011) in the form of a 4 m^2 raster-grid digital terrain model; iii) shape, size, height and position of both roads and buildings, obtained from the IGN; iv) railway traffic data for each rail segment of the city provided by the National Society of French Railways; and v) traffic data for each road segment of the city. Traffic data were obtained from vehicle counts that were conducted by the city urban services as well as from the vehicle fleet composition provided by the Interprofessional Technical Centre for Studies on Air Pollution (CITEPA). These road traffic data depict the 2011 average annual all-vehicle traffic for three time periods (day 06:00 to 18:00; evening 18:00 to 22:00; and night 22:00 to 06:00) (Pujol et al., 2012a,b).

2.3. Noise pollution model computation

Four types of continuous noise sources have shown strong contribution to environmental noise levels in previous studies: road traffic, rail traffic, pedestrian precinct, and water fountains (Pujol et al., 2012a,b; Tenailleau et al., 2015a). The noise levels were directly calculated on the entire study area by introducing those sources and all aforesaid inputs in the noise-modeling software MITHRA-SIG© (V2) developed by Geomod and the Scientific and Technical Centre for Building (CSTB). MITHRA-SIG© use algorithms based on asymptotic methods, such as ray propagation and adaptive beam propagation, to calculate reliable acoustical trajectories between input sources and each pixels of the study area. Noise propagation is computed in accordance to the European environmental noise directive (2002/49/EC), taking into account the effect of meteorological conditions, multiple 3D reflections, material absorption, and diffraction. Emission spectrums for roadways and railways are natively included in the software, and issued from CSTB measurements.

2.4. Air pollution model computation

The NO_2 levels were calculated using a two-step emission and diffusion modeling (Tenailleau et al., 2015b). First, the daily averaged annual road-traffic emissions were calculated using Circul'Air, software developed by the French air quality monitoring network on the basis of the COPERT4 European standard methodology. This software links emissions factors from the EMEP/CORINAIR Atmospheric Emissions Inventory Guidebook (EMEP/EEA, 2009) with vehicle fleet configuration provided by the Interprofessional Technical Centre for Air Pollution Studies (CITEPA), and with road traffic data (type and number of vehicles/days) and railway configuration (slope, curves, coating, speed limits and number of ways) provided by city agencies. In the meantime, pollution from heating and industrial emissions and long-range sources were evaluated for each census block using the ATMO Franche-Comté databases. Second, all aforesaid inputs, including air pollutant emissions, were introduced in ADMS-Urban©. This pollution diffusion software relies on state of the art algorithms based on traffic flow, meteorological data, background concentrations and buildings morphology. It has been developed in accordance with the WHO guidelines by the Cambridge Environmental Research Consultants company (Cambridge Environmental Research Consultants, 2014) and is widely used in Europe for modeling air quality on scales ranging from large urban areas to the street level.

2.5. Noise and NO_2 pollution maps

Both pollution levels were displayed in ESRI arcGIS© (V9.3.1) following a common 4 m^2 (2 m × 2 m) raster grid with each pixel giving both the air and a noise pollution level at 2 m above ground for the entire city. NO_2 was expressed in microgram/m^3 ($\mu g/m^3$) and noise in decibels (dB(A)) rounded to the nearest decibel unit. The daily equivalent A weighted sound level ($L_{Aeq,24h}$) was used in accordance with the European Network on Noise and Health (Houthuijs et al., 2010).