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Health effects of pollution on the residential population near a Brazilian airport: A perspective based on literature review



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ABSTRACT

Introduction: Airport is an important source of air and noise pollution. Acute and chronic exposure to air pollution is harmful to human health with proven effects ranging from coryza, to eye irritation, and even to death. Both acute and chronic exposure to noise pollution are harmful to human health and have been related to cardiovascular diseases, hearing loss, cognitive disorders, sleep disorders, tinnitus and respiratory changes. It is plausible to consider that residing near airports increases the likelihood of developing health problems or exacerbate pre-existing conditions. In this study, we review the effects of pollution from airport activity on the health of the resident population located in the city of Guarulhos, near the International Airport of São Paulo.

Methods: To perform this narrative review, a comprehensive search of published scientific literature on PubMed and a search in reference lists of selected papers were applied.

Results: There is a widespread scarcity of international scientific literature relating to health effects of air and noise pollution on residents living near airports; none exists in Latin America. In general, airport activity is an important source of air and noise pollutants. Areas close to airports are usually more polluted.

Conclusions: It is plausible to speculate that residing near airports (including São Paulo International Airport) increases the likelihood of developing health problems or exacerbating pre-existing conditions. Considering the volume and importance of air transport to society, it is incumbent to invest in mitigating alternatives to improve air quality and reduce noise around airports.

RESUMEN

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Introducción: Los aeropuertos son una fuente importante de contaminación atmosférica y acústica. La exposición aguda y crónica a la contaminación del aire es perjudicial para la salud humana, con efectos probados que van desde la coriza hasta la irritación de los ojos e incluso la muerte. De manera similar, la exposición a la contaminación acústica se ha relacionado con enfermedades cardiovasculares, pérdida de audición, trastornos cognitivos, trastornos del sueño, tinnitus y cambios respiratorios. Es plausible considerar que residir cerca de aeropuertos aumenta la probabilidad de desarrollar problemas de salud o exacerbar condiciones preexistentes. En este estudio se revisan los efectos de la contaminación de la actividad aeroportuaria sobre la salud de la población residente en la ciudad de Guarulhos, cerca del Aeropuerto Internacional de São Paulo.

Métodos: Revisión narrativa, basada en búsqueda exhaustiva de la literatura científica publicada en PubMed y adicional búsqueda en las listas de referencias de los artículos seleccionados.

Resultados: Existe una escasez generalizada de literatura científica internacional relacionada con los efectos de la contaminación atmosférica y acústica en la salud de los residentes que viven cerca de los aeropuertos; no existe ninguna en América Latina. En general, la actividad aeroportuaria es una fuente importante de contaminantes atmosféricos y acústicos. Las zonas circundantes a los aeropuertos suelen estar más contaminadas.

Conclusiones: Es plausible especular que residir cerca de aeropuertos (incluyendo el Aeropuerto Internacional de São Paulo) aumenta la probabilidad de desarrollar problemas de salud o exacerbar condiciones preexistentes. Teniendo en cuenta el volumen y la importancia del transporte aéreo para la sociedad, corresponde invertir en la mitigación de alternativas para mejorar la calidad del aire y reducir el ruido en los alrededores de los aeropuertos.

R E S U M O

Introdução: Aeroportos são importantes fontes de poluição atmosférica e sonora. A exposição aguda e crônica à poluição do ar é prejudicial à saúde humana, com efeitos comprovados que vão desde coriza, irritação dos olhos, até a morte. Tanto exposição aguda quanto crônica à poluição sonora são, também, prejudiciais à saúde humana e têm sido relacionadas a doenças cardiovasculares, perda auditiva, transtornos cognitivos, distúrbios do sono, zumbido e alterações respiratórias. É plausível considerar que residir próximo a aeroportos aumenta a probabilidade de desenvolver problemas de saúde ou exacerbar condições pré-existentes. Neste estudo, revisamos os efeitos da poluição da atividade aeroportuária na saúde da população residente próximo ao Aeroporto Internacional de São Paulo na cidade de Guarulhos.

Métodos: Para realizar esta revisão narrativa foi feita uma pesquisa abrangente na literatura científica indexada no PubMed e também nas referências de artigos selecionados.

Resultados: Existe uma escassez generalizada de publicações científicas relacionando os efeitos da poluição atmosférica e sonora à saúde de indivíduos que residem perto de aeroportos; nenhuma conduzida na América Latina. Em geral, a atividade aeroportuária é uma fonte importante de poluentes atmosféricos e sonoros. E áreas próximas a aeroportos são geralmente mais poluídas.

Conclusões: É plausível especular que residir próximo a aeroportos (incluindo o Aeroporto Internacional de São Paulo) aumenta a probabilidade de desenvolver problemas de saúde ou exacerbar condições pré-existentes. Considerando o volume e a importância do transporte aéreo, cabe investir em alternativas de mitigação para melhorar a qualidade do ar e reduzir o ruído em torno dos aeroportos.

1. Introduction

Located in the Metropolitan Region of São Paulo (RMSP), the municipality of Guarulhos has hosted, since 1985, the airport with the largest international movement in Brazil. Currently known as the GRU Airport, São Paulo International Airport ranks first as Brazilian airfield for total passenger traffic (38,952,335 passengers between January and November 2018) and is the largest for cargo transportation in Latin America (GRU Airport, 2018). Its importance for the socio-economic development of the municipality of Guarulhos and surrounding is unquestionable. Likewise, its relevance for the development of the state of São Paulo, Brazil and Latin America.

Given its size, GRU Airport is also the largest in terms of the magnitude of air pollutant emissions that degrade local air quality, such as carbon monoxide (CO), nitrogen oxides (NOx), sulphur dioxide (SO₂) and particulate matter (PM). Between 2005 and 2013, emissions of these pollutants have grown (ANAC and IEMA, 2014) and the trend for the coming decades is increasing, driven by GRU Airport's goal of increasing its capacity from 16.5 to 60 million passengers by 2032 (Duarte, 2012).

Air pollution is a major environmental impact from airport activity and also a recognized threat to human health. The same is true for noise pollution.

Under Brazilian law, airlines can be held responsible for their environmental impacts caused by harmful emissions. In this context, two postulations are relevant: (i) to what extent airline activity in GRU Airport is contributing to pollution (noise and air)?; and (ii) how detrimental is this activity to the health of nearby residents? The purpose of this review is to answer these questions, based on the scientific knowledge already published.

2. Methods

This narrative review was based on a comprehensive search of published scientific literature on the subject performed at Pubmed database using the terms: (((((Airports[MeSH Terms]) OR airport) OR Aircraft[MeSH Terms]) OR airplane) OR aeronautic)) AND (((((((airport emissions) OR Aviation emissions) OR Aircraft emissions) OR Airport-related pollution) OR Air Pollution[MeSH Terms]) OR particulate matter) OR particulate air pollutant) OR Noise[MeSH Terms]) OR noise pollution) OR aircraft pollution). We also manually searched for studies in the list of references in the review articles. We looked for studies investigating the effects of air and noise pollution on the health of residents nearby GRU airport and other airports. We focused on including studies that measured both exposure (air pollution or noise) and outcomes (health). However, to support our rationale, we also included studies that investigated environmental exposure. Occupational studies were excluded from this review.

After selecting articles, we used the information to draw discussions under five headings: (1) we described the main geographic and population characteristics of Guarulhos, the municipality that hosts the airport studied. In heading (2), we discussed how air pollution from aircraft might impact the health of the community living close to GRU airport. Given the lack of studies that directly investigated health effects of air pollution in the population living near to GRU airport, we discussed general effects of air pollution on health and, we then provided evidence of specific health effects of air pollution from aircraft, in general. Next, we discussed air quality near airports, in general, and in GRU airport surroundings to finally draw conclusions on how the population living close to GTU airport might be affected by air pollution. In heading (3), we discussed noise pollution in a similar structure used to discuss air pollution and in (4), we discussed possible interactions between noise / air pollution and control strategies. Finally, (5) we summarized the possible health effects of pollution (noise and air) on the residential population near GRU airport, in Guarulhos, Brazil.

3. Results and discussion

3.1. Characterization of the municipality of Guarulhos

Guarulhos is a municipality of the Metropolitan Region of São Paulo (RMSP), situated in the state of São Paulo, Brazil (23°27'46"S, 46°32'00"W). Having an urban area of 318.675 km², it is located in the Serra da Cantareira and has vegetation cover of Atlantic Forest. Its average annual temperature varies between 17 °C and 21 °C. The average relative air humidity is 81.1% and the rainfall precipitation is 1,470 mm³ (CPTEC/INPE, 2018).

It has industrial characteristics and is home to more than 2,890 factories in its territory (Ferreira et al., 2011). According to the Municipal Human Development Index (MHDI) of 0.763 in 2010, Guarulhos is in one of the lowest positions in the state ranking for Gross Domestic Product *per capita* (GDP): it is ranked 610 among 645 municipalities (IBGE, 2018). With a population density of 3,828.36 (inhabitants/km²) in 2010, its population is predominantly urban. The greater concentration of people is to the south, on the border with the municipality of São Paulo (estimated population in 2017 of 1,313,169) (Fundação Seade, 2018). The GRU Airport is neighbouring the Cumbica district, second-ranked district by population (population range from 72,001 to 90,000) (Ferreira et al., 2011).

3.2. Air pollution and health

3.2.1. General aspects of the effects of air pollution on human health

There is a variation of toxicity between the various types of pollutants. Regulatory parameters (maximum permitted concentrations of pollutants) are established separately for each pollutant. Fine particles (with a diameter of less than 2.5µm) are more harmful to health than coarse particulate matter. Therefore, due to its smaller size, fine particulate matter penetrates into more distal portions of the respiratory system. Because of the difficulty in separating the health effects of each pollutant, we will comment on the health effects of air pollution, in general, with the exception of lead, because it is neurotoxic, with very serious and specific effects, extensively described in the literature.

With acute and chronic effects in various systems of the human body, ambient air pollution is responsible for about 3 million annual premature deaths worldwide. It is among the ten risk factors that most contribute to global burden of disease (Lim et al., 2012). The reduction of this risk necessarily depends on the reduction of emissions of these pollutants (Fajersztajn et al., 2013, 2016).

Air pollution is widely recognized as a risk factor for cardiovascular and respiratory diseases (Fajersztajn et al., 2016; Thurston et al., 2017). It was classified as carcinogenic to humans (general pollution, particulate matter and diesel) by the International Agency for Research on Cancer (IARC), a body linked to the World Health Organization (WHO) (IARC, 2014, 2016). Respiratory and cardiovascular effects range from coryza to eye irritation, and even to death, exacerbating symptoms of preexisting diseases and hospitalization, as well as the emergence of new cases of disease. The major cardiorespiratory system disorders, related to air pollution, include asthma, chronic obstructive pulmonary disease, pneumonia, lung cancer, arterial hypertension, deep venous thrombosis, acute myocardial infarction, heart failure, stroke, and arrhythmia (Fajersztajn et al., 2016; Thurston et al., 2017).

Gestational exposure may impair the pulmonary development of the fetus and during childhood (Veras et al., 2016). It has also

Table 1
Characteristics of selected studies on the effects of pollution on health of residents nearby airports.

| Study (year) | Design | Type | Study subjects/Population | Topic/outcome | Effect |
|-----------------------------|--------------------------------------|--------------------------------------------------|-------------------------------------------------------------------------------------------------------------------------------------------------------|----------------------------------------------------------------------------------------------------------------------------------|-----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| Penn et al. (2017) | Ecological | Air (PM2.5, ozone and others) | 66 airports in USA | Health impairment measured indirectly to create health damage functions | Deaths differ from airport to airport. Deaths per 1000 t of precursors for O ₃ precursors ranged from -0.004 to 1.0 and for secondary PM2.5 varied across airports from 0.1 to 2.7. |
| Schlenker and Walker (2015) | Modelling scenarios | Air (CO) | 1 airport in California, USA | Hospital admissions and emergency room visits for respiratory and cardiovascular cases | Increased levels of pollution were associated with higher frequency in respiratory and cardiovascular events |
| Visser et al. (2005) | Survey | Noise | Residents of the area surrounding Schiphol, Netherlands, divided based on aircraft noise contours | Cancer incidence | No effect. The overall cancer incidence in the Schiphol area was similar to the national incidence. |
| Zhou & Levy (2009) | Modelling scenarios | Air (Benzene, 1,3 butadiene and benzo [a]pyrene) | 32 airports in USA | Estimated cancer risk based on formulas from EPA's Integrated Risk Information System (IRIS) database | The population risk within 50 km of the airport varies by two orders of magnitude across airports |
| Lin et al. (2008) | Cross-sectional | Distance | Residents within 12 miles from the center of three airports in Rochester, New York and Long Island in USA | Hospital admissions for respiratory disease | Residential proximity to some airports (< = 5miles) had increases in hospital admissions for respiratory diseases admissions for respiratory disorders (1.47; 95% CI 1.41, 1.52 for Rochester and 1.38; 95% CI 1.37, 1.39 for LaGuardia) |
| Baudin et al. (2018) | Cross-sectional | Noise | 1244 individuals, both sexes, older than 18 and living near three French airports | Investigating the relationship between aircraft noise (dB and annoyance) and psychological (ill) outcomes. | Noise sensitivity and annoyance due to aircraft noise were also significantly associated with psychological ill-health |
| Correia et al. (2013) | Cross-sectional and spatial analysis | Noise | 6 027 363 people aged ≥65 years from USA enrolled in Medicare and residing in the 2218 zip codes close to the 89 airports | The relation between exposure to aircraft noise and the risk of hospitalization for CVD | Exposures > 10dB implied an increase in the risk of cardiovascular hospitalization |
| Dimakopoulou et al. (2017) | Cross-sectional + cohort | Noise | 420 individuals from Artemita, Greece evaluated in 2004/06 and followed up in 2013 | Association of exposure to aircraft and road traffic noise with the incidence of hypertension and other cardiovascular outcomes. | People exposed to aircraft noise, especially nighttime, were more likely to present hypertension at baseline, as well as to become hypertensive. |
| Evraud et al., 2017 | Cross-sectional | Noise | 1244 individuals, both sexes, older than 18 and living near three French airports | Investigated the association among noise exposure and risk of hypertension | Aircraft noise was also associated with another CVD. |
| Eze et al. (2018) | Cross-sectional + cohort | Noise | 7049 individuals from a Swiss cohort study were evaluated at baseline, of which 6377 were followed to investigate the incidence of asthma diagnostics | Respiratory diseases and transportation noise | In the adjusted model, only men presented a risk of hypertension associated with aircraft noise exposure. Analyses of women were omitted. |
| Floud et al. (2013) | Cross-sectional | Noise | 4712 subjects from the UK, Germany, Netherlands, Sweden, Greece and Italy with 35 years and over. | A multicentric study that evaluated the relation between aircraft and road traffic noise and heart disease and stroke. | Physical and psychological experiences with noise were associated with asthma exacerbation as well as respiratory symptoms. |
| Foraster et al. (2018) | Cross-sectional + cohort | Noise | 3796 individuals from a Swiss cohort study evaluated across 10 years | The relation between adiposity markers and obesity and long-term exposition to transportation noise. | Even controlled by air pollution, the night-time aircraft noise was associated with heart disease and stroke (considering individuals living for at least 20 years in the same home). |
| Hansell et al. (2013) | Ecological | Noise | 12 110 census output areas in London merged with hospitalization information (connected by postcode) | Aircraft noise and cardiovascular disease in London - Heathrow airport | Aircraft noise was not associated with adiposity markers. In longitudinal evaluations, the results were similar, where aircraft noise was not associated with changes in BMI. The higher likelihood for stroke, coronary heart disease, and cardiovascular disease in the population of the study. The risk for these |

(continued on next page)

Table 1 (continued)

| Study (year) | Design | Type | Study subjects/Population | Topic/outcome | Effect |
|-----------------------|----------------------------|-------|----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|---------------------------------------------------------------------------------------------------|------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| Holt et al. (2015) | Cross-sectional | Noise | 745868 individuals from five USA states were evaluated. It was estimates of airport noise exposure for individuals based on the location of the ZIP code geometric centroid in relation to the airport noise exposure zone | Sleep disturbance and aircraft noise | outcomes was higher among individuals directly affected by aircraft noise. Self-reported sleep insufficiency was not associated with airport noise, controlled by sociodemographic characteristics. |
| Huang et al. (2015) | Meta-analysis | Noise | Five papers from Japan, Sweden, Australia and Netherlands were selected and analysed, considering a total of 16,784 subjects | Incidence of hypertension and aircraft noise exposition | Increased rates of hypertension among individuals exposed to aircraft noise. In this method, the researchers mentioned including cross-sectional studies, which cannot offer incidence information. |
| Pearson et al. (2016) | Time-series | Noise | Considered populations living nearby Heathrow airport, London, UK, timeframe comprised of 66 days. | The closure of the biggest airport in the UK and acute cardiovascular hospital admission | Non-significant evidence of a reduction in emergency cardiovascular admissions during the six-day closure period compared with days before and after. |
| Schmidt et al. (2015) | Randomized crossover trial | Noise | 60 individuals between 30 and 75 years old from France were exposed to simulated aircraft noise and no noise conditions | Endothelial functional and blood pressure affected by night time aircraft noise | Decreased sleep quality, increased blood pressure and attenuated endothelium-dependent vasodilation, giving evidence to explain the association between night-time aircraft noise and arterial hypertension, myocardial infarction and stroke. |
| Seabi et al. (2015) | Cohort | Noise | 178 students from South Africa were followed-up and evaluated for reading comprehension according to noise exposition | Long term exposure to aircraft noise and impairment in cognitive function (reading comprehension) | Not only different in the baseline, but also higher learning slope (incomprehension reading) was observed in the group exposed to lower levels of noise. |
| Thiesse et al., 2018 | Randomized clinical trial | Noise | 26 young adults were monitored in 6 consecutive days and nights (recruited in Europe: Germany, Switzerland and France) | Glucose regulation and night-time transportation time | Sleeping four nights with transportation noise impaired glucose tolerance and insulin sensitivity. However, the pathway of these impairments was not related to quality and quantity of sleep. |

been associated with fertility problems (Veras et al., 2009), hypertension in pregnant women (Zhu et al., 2017), low birth weight, low fetal growth, prematurity (Stieb et al., 2012) and congenital malformations (Thurston et al., 2017). Moreover, it predisposes the newborn to the risk of health problems throughout their lives (Barker et al., 1991).

Recently, the European Respiratory Society updated the statement on the effects of air pollution on human health to include effects on the central nervous system (Alzheimer's, Parkinson's, depression, behavioural and learning disorders in children, among other disorders), endocrine (type 2 diabetes and obesity) and reproductive health, as well as skin aging (Thurston et al., 2017). Groups that present greater vulnerability include people with low socioeconomic status, sufferers of chronic disease, pregnant women and those belonging to specific age groups (fetuses, children and the elderly) (Fajersztajn et al., 2016; Thurston et al., 2017).

3.2.2. Residential proximity to airports, air pollution and health

Only five studies (Penn et al., 2017; Schlenker and Walker, 2015; Lin et al., 2008; Visser et al., 2005; Zhou and Levy, 2009) have evaluated the health effects of air pollution on populations living near airports (Table 1). All of them were conducted in developed countries (four in the United States of America and one in the Netherlands). American studies reported a significant and positive association between living in the proximity of an airport and an increase in general mortality (Penn et al., 2017), hospitalization for respiratory diseases (Schlenker and Walker, 2015; Lin et al., 2008) and cancer incidence (Visser et al., 2005; Zhou and Levy, 2009). The study carried out in the Netherlands (Visser et al., 2005), measured noise as a proxy from air pollution and did not find differences between the incidence of cancer in resident populations near the Amsterdam airport and the rest of the population. Although the methods used in these studies do not allow for causal inferences, the majority of their conclusions corroborate the vast literature that consistently attests exposure to air pollution is detrimental to human health. However, some of these studies have limitations because they work with estimates rather than primarily collected data for both exposure and outcome (Penn et al., 2017; Zhou and Levy, 2009).

It is worth highlighting the study conducted in the United States of America (USA) (Miranda et al., 2011) with 125,197 children that shows those who lived near an airport (radius up to 1km) had higher lead levels in the blood, compared to residents in other regions, even after controlling to additional sources of lead. The presence of lead was attributed to the activity of small aircraft using aviation gasoline (avgas), as the exposition data were based on the annual lead emissions from selected airports. Although the study has not measured for a specific health outcome, the exposure to lead is recognized as a serious health problem. It accumulates in different organs such as the brain, liver, kidneys and bones.

According to WHO, there are no safe limits for exposure to lead. Early life exposure (during fetal and childhood development) can lead to irreversible learning and behavioural problems, even at low doses (Canfield et al., 2003; Chiodo et al., 2004; Miranda et al., 2007). In the USA, the estimated annual cost of intellectual development problems in children exposed to lead from avgas is about one billion dollars (Wolfe et al., 2014).

In line with what pertains in the US aircraft market, the Brazilian market, under the regulation of the National Agency of Petroleum, Natural Gas and Biofuels, use avgas-100LL gasoline. Although "LL" designates low lead content, it can still contain up to 0.56 g/L of lead and be within regulatory standards (ANP, 2009). The US National Environmental Protection Agency (EPA) estimates that people who live up to 1km from airports are at greater risk of being exposed to lead originating from avgas (Hitchings, 2010). The volume of aircraft that use avgas in the GRU Airport is unknown and also any specific measures of lead concentration in the Guarulhos region. Such information is highly desirable to aid the protection of the population's health.

3.2.3. Air pollution and airports

Airports are a major source of pollutant emissions with increasing projections around the world. A share of these emissions remain close to the airports resulting in local air pollution and a share of these pollutants are responsible for climate change. The aviation sector contributes directly to worsening local air quality (Barrett et al., 2010). A better understanding of these relationships would contribute to the development of mitigation strategies.

In 2009, the aviation sector accounted for 12% of total fuel consumption used for transportation worldwide, and projections indicate a growth of 16.7% for the year 2035 (The World Bank, 2012).

Most of the air pollution at airports originates from the burning of aircraft fuel and auxiliary equipment used for the operation of airplanes. The pollution generated inside the airports is modulated by the type of fuel used and by the quality of the combustion process of the aircraft and equipment. In Brazil, the types of fuels for regulated aircraft are kerosene (Jet-A1) and Avgas-100LL. The Jet-A1 is the fuel used in commercial jets and Avgas-100LL is used in small airplanes. Pollutants resulting from the burning of aviation fuel are similar to those resulting from combustion in automotive vehicles. These pollutants include particulate matter, black carbon, organic carbon, volatile organic compounds, compounds of nitrogen and sulfur, as well as lead in the case of Avgas-100LL (ANP, 2009).

Emissions of pollutants vary depending on the operation modes of the aircraft. Stages that lead to the most energy demand and higher emissions are 'acceleration for take-off' and 'climb'. Strangely, although the ground operation requires less energy, it produces more particulate matter (Mazaheri et al., 2011).

The technological advancement of aviation engines and fuels directly influences the emission of pollutants. The average life of an airplane is about 25 years. There may be a mismatch between technological improvement and practical implementation. Thus, regulation of the age of the fleet at an airport is an important mitigation tool for improving air quality (Barrett et al., 2012). Encouraging airports to use less polluting forms of transport would be a major mitigation strategy. Airport activity requires an intense flow of motor vehicles in its surroundings, thus contributing to the worsening of air quality in the region. Less polluting options, such as rail and electric vehicle transportation, for the movement of people, cargo and services alike, would contribute to the reduction of

pollutant emissions.

Few studies have quantified the impact of airport activity on air pollution and its local surroundings. Psanis et al. (2017), found concentrations of particulate matter in a Greek airport's surroundings to be 2.5 times greater than the concentration measured 3 km away from it. In the same study, iron, lead and magnesium also had higher concentrations in the airport's surroundings (a difference of 78%, 26% and 28%, respectively). The effects of air pollution are dose-dependent, which means they depend on the concentration of the pollutants and the time of exposure. The airport's operating time may interfere with nearby residents' exposure to the pollutants, thus exposure to air pollution would be higher during the hours that the airport is under high activity, and lower during low activity periods. A study conducted in New York highlighted a direct relationship between higher particulate matter concentration and active airport operating hours. The study also showed a percentage increase of particulate matter inversely related to the distance from the airport (Cohen et al., 2017).

It should be noted that the concentration of pollutants in an environment is modulated by local geographic and meteorological conditions. These determine the dispersion and formation of secondary pollutants. A study by Hu et al. (2009) showed that the dispersion of ultrafine particulate matter emitted by an airport in USA varied by up to 2.6 times, depending on wind direction.

3.2.4. Air pollution in the vicinity of GRU airport

Little is known about the concentration of pollutants around GRU Airport. Guarulhos city has two air quality monitoring stations operated by the Environmental Company of the State of São Paulo (CETESB). The closest station to GRU Airport is Guarulhos-Paço Municipal Station (3.65 km southwest from the beginning of 09R runway) and there is another station in the city, Guarulhos-Pimenta Station (4.25 km southeast from the beginning of 27R runway) (Fig. 1). In 2015, the station Guarulhos-Pimenta was ranked fourth among the most polluted in the Metropolitan Region of São Paulo (MRSP), reaching an annual average concentration of $32\mu\text{g}/\text{m}^3$ of particulate matter with size less than $10\mu\text{m}$ (PM10). Meanwhile, the station Guarulhos-Paço Municipal ranked 16th position, with an average annual concentration of PM10 of $27\mu\text{g}/\text{m}^3$ (CETESB, 2016). Both monitoring stations in Guarulhos attempts the annual average regulated level for the State of São Paulo, current set at $40\mu\text{g}/\text{m}^3$ (Alesp, 2013), but not the World Health Organization (WHO) set at $20\mu\text{g}/\text{m}^3$ for PM10 annual mean (WHO, 2006). Guarulhos-Pimenta station fine particulate matter (PM with diameter of $2.5\mu\text{m}$ or less - PM2.5) annual average also ranked fourth among the most polluted in the MRSP, below the regulated level for the State of São Paulo currently set at $20\mu\text{g}/\text{m}^3$ for this pollutant (Alesp, 2013), but also not in accordance to WHO health standard limit of $10\mu\text{g}/\text{m}^3$ (WHO, 2006). Moreover, Guarulhos-Paço Municipal station does not measure fine particulate matter.

GRU Airport is surrounded by residential and commercial areas (Fig. 1), 61% of downwind between 1996 and 2007 flowed from the east, southeast and south (30.9% from the east) with a wind speed mean of 9.3, 8.6, and 9.2 km/h, respectively (Costa, 2008).

Rocco Junior (2008) analysed the epigenetic effects of pollution emitted from GRU Airport on a herbaceous plant (recognized for its use as a bioindicator of air pollution) in 2008. The mean concentration of particulate matter in a nearby neighbourhood ($48.35\mu\text{g}/\text{m}^3$) and at the airport (lane $45.87\mu\text{g}/\text{m}^3$ and control tower $48.71\mu\text{g}/\text{m}^3$) were worryingly similar. Whereas, in Serra da Cantareira, the value obtained was lower ($14.97\mu\text{g}/\text{m}^3$). The author did not consider information on wind direction and topography.

The State of São Paulo, through its Environmental Agency, it regulates limits for lead levels at an annual average of $0.5\mu\text{g}/\text{m}^3$ (Alesp, 2013), but it is unclear which regions are monitored.

To our knowledge, there are no known specific measures of the concentration of lead in the region of Guarulhos. This is essential information relevant to the protection of population health. One report (CETESB, 2016), comparing the years 2002, 2006, 2009 and 2012, indicates that there was a decrease in lead levels between 2002 and 2009 and an increase in the following period. Unfortunately, the region around GRU Airport was not evaluated.



Fig. 1. GRU Airport surrounding with air pollution monitoring station sites.

3.3. Noise pollution and health

3.3.1. General aspects of the effects of noise pollution on human health

Noise pollution is defined as unwanted sound whereby its continuous exposure can lead to the occurrence of various adverse effects on health and hearing. Moreover, extra-auditory effects (Kwak et al., 2016) are also considered an important concern affecting public and environmental health (WHO Regional Office for Europe, 2011). There is epidemiological evidence that relates population noise exposure to cardiovascular diseases, hearing loss, cognitive disorders, sleep disorders, tinnitus and respiratory changes (Domingo-Pueyo et al., 2016; Dzhambov and Dimitrova, 2016; Recio et al., 2016; Haralabidis et al., 2008).

For European Union countries, WHO estimated that the burden of disease attributed to environmental noise exposure measured in disability-adjusted life years (DALYs) was 61000 years for ischemic heart disease, 45000 years for cognitive impairment in children, 903000 years for sleep disorders, and 22000 years for tinnitus (WHO Regional Office for Europe, 2011).

3.3.2. Noise pollution and airports

Aviation-related noise is an increasingly serious environmental problem due to the growing increase in air traffic (Kwak et al., 2016). At airports, sources of noise pollution should be considered according to the type of vehicle from which it is emitted. For vehicles driving on roads that provide access to the airports and for those circulating inside airports for supporting activities, noise emerges from the engine operation and from the contact of the vehicle with the ground.

In the case of aircraft, in addition to the engine, noise is also produced from the aircraft structure, mainly during landings and take-offs and in its detachment on the ground.

Compared to air pollution, the literature investigating the health effects of air pollution is more robust (Table 1). Acute exposure to noise in areas close to four major European airports was associated with an increase in blood pressure (Haralabidis et al., 2008). In areas near the six major European airports, Jarup et al. (2008) found a relationship linking chronic exposure to noise with an increased risk of hypertension among residents (in situ for at least five years) in the vicinity of these airports. This result was also confirmed by Huang et al. (2015), where individuals living near to airports were more likely to develop hypertension than individuals not constantly exposed to aircraft noise. A curious fact was that only males showed a higher risk to develop hypertension (Eriksson et al., 2010). However, this topic (gender) needs more attention, considering the lack of references.

In France, an ecological study (Evrard et al., 2015) showed evidence of an association between increased mortality from cardiovascular disease and exposure to airborne noise in 161 *communes* (the smallest administrative unit in the country) neighbouring the three largest airports in the country. Noise coming from airport activity has also been associated with mental illness, such as anxiety disorders (Italy) (Hardoy et al., 2005), increased prevalence of insomnia (South Korea) when compared to a control population study (Kwak et al., 2016), and dysregulation of cortisol levels, directly associated with psychological stress (Lefèvre et al., 2017).

Considering the emergent interest in association between aircraft noise and health outcomes, scholars are showing this can go beyond a “simple” noise pollution, it entangles under the skin, promoting different disturbances, i.e. sleep disturbance, and physiological changes that could be precursors of chronic conditions, i.e. elevated levels of epinephrine - hormone related with blood pressure and vascular function (Schmidt et al., 2015).

3.3.3. Noise pollution and airports: evidence from Brazil

We did not find evidence quantifying noise pollution nearby GRU Airport, but it is important to notice that GRU Airport operates 24 h a day, seven days a week and the population living nearby do not have breaks.

We are unaware of any studies that evaluated health effects related to noise exposure and those who reside adjacent to airports. There is evidence, recorded in literature, that the surroundings of Brazilian airports experience unacceptably high levels of noise.

Nykiel (2009) ranked 36 Brazilian airports in terms of noise impact and concluded that the four most critical are GRU Airport (SP), Recife International Airport (PE), Rio de Janeiro International Airport (RJ) and Congonhas Airport (SP), respectively. Another study showed that noise levels in the surroundings of Congonhas Airport (SP) were above the limits set by the National Civil Aviation Agency (ANAC), even at night, when the airport has less activity (Scatolini and Alves, 2016).

3.3.4. The interaction between air pollution and noise, and possible control actions

Air and noise pollution are strongly correlated and their coexistence in the region of airports potentiates the occurrence of health problems (Lin et al., 2008). This correlation makes it difficult to separate these factors when analysing the isolated effects of each type of pollution on different health outcomes (Lim et al., 2012; Fajersztajn et al., 2013, 2016; Thurston et al., 2017).

Urban planning is needed to mitigate the exposure of the local resident population to the noise coming from an airport. This is especially so given the prospect of the projected increase in activity in airports throughout the country (Nykiel, 2009). Unlike air pollution, more mitigating actions can be taken to reduce noise pollution. Suitably designed buildings and fences can combat the probable negative impact.

In Brazil, there are at least 5 technical standards (Brazilian Regulatory Standards - NBRs) that regulate noise from airports and can serve as a basis for actions to reduce damage: i) NBR 11.415/90 defines the terms and magnitudes for aeronautical noise; ii) NBR 10.856/89 determines the effective noise level perceived from aircraft overflight; iii) NBR 13.368/95 establishes the method for monitoring noise generated by aircraft; iv) NBR 10.151/2000 establishes the assessment and acceptability of noise in communities, and; v) NBR 10.152/87 sets noise levels compatible with acoustic comfort (Nykiel, 2009).

The development of cleaner and more protective technologies are important features that can minimize the impact of noise and

air pollution on the environment and consequently on human health. The alternatives for less polluting fuels are still restricted. Biodiesel tends to freeze at low temperatures and ethanol has high volatility, not making them substitutes for aviation kerosene. Bio-SPK (Synthetic Paraffinic Kerosene derived from biofuel), FT-SPK (Fischer-Tropsch Synthetic Paraffinic Kerosene) and Hydroprocessed Renewable Jet fuel (produced by hydroprocessing renewable oils) are potential alternatives for the near future (Lee and Mo, 2011; Kallio et al., 2014).

Public policies, local and international regulations, should strengthen the development of urban plans that regulate street/highway traffic and air travel, thus committing to the reduction of the emission of harmful gases and noise (IARC, 2014, 2016).

4. Final considerations

Based on the aforementioned arguments, it is possible to affirm that the activity of the airlines at GRU Airport is polluting the catchment area. This presents potential harm to the health of the local inhabitants.

Although there are few studies in the scientific literature relating human exposure to air and noise pollution of residents near an airport, the deleterious effects of these exposures on health are demonstrably evident. This review was based in the scientific literature and available public data, thus some relevant questions, such as the exact number of people at risk, or the exposure level at home, cannot be answered precisely.

In the absence of evidence on the actual concentration and dispersion conditions of pollution produced at GRU Airport, it is worth mentioning that the areas of other cities close to airports are more polluted. It is justifiable to draw the conclusion that the pollution produced by GRU Airport has toxins no different from those pollutants already widely recorded. Thus, it is plausible to assume that people living near GRU Airport are highly likely to develop health problems or aggravate pre-existing health conditions. With the exception of lead, the pollutants produced by aircraft and ancillary activities of GRU Airport do not appear to differ significantly from the pollution produced by motor vehicles and other widely studied sources. Given the high demographic density surrounding this airport, it increases the significance of the problem in terms of public health, notwithstanding the magnitude of the risk.

The social and economic costs of the environmental impacts of airport activity are relevant. Airport activity is very important to society. Consequently, it is appropriate to focus on mitigation alternatives that improve air quality. This would include improving the combustion process of aircraft, the use of cleaner fuels and the regular renewing of the air fleet.

Air pollution mitigation measures should also focus on reducing the pollution produced by ancillary mobile sources associated with airport activity. At a macro level, it is important to encourage the use of less polluting public transport, such as rail transportation, ethanol-fueled vehicles, electric vehicles, among others, for employees, passengers and companions. All of which would contribute to reducing the emission of pollutants. The same goes for freight transport.

Although not subject to this review, the pollution produced at GRU Airport affects the fauna and flora that surrounds the municipality of Guarulhos (Serra da Cantareira and remnants of Atlantic forest).

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Disclaimers

This paper is a product of academic research giving the views of the authors, and not necessarily the position of the institutions enrolled.

Appendix A. Supplementary data

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