Risk Assessment of Aircraft Noise on Sleep in Montreal

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ABSTRACT

Objective: Estimate the number of awakenings additional to spontaneous awakenings, induced by the nighttime aircraft movements at an international airport in Montreal, in the population residing nearby in 2009.

Methods: Maximum sound levels ($L_{AS,max}$) were derived from aircraft movements using the Integrated Noise Model 7.0b, on a 28 x 28 km grid centred on the airport and with a 0.1 x 0.1 km resolution. Outdoor $L_{AS,max}$ were converted to indoor $L_{AS,max}$ by reducing noise levels by 15 dB(A) or 21 dB(A). For all grid points, $L_{AS,max}$ were transformed into probabilities of additional awakening using a function developed by Basner et al. (2006). The probabilities of additional awakening were linked to estimated numbers of exposed residents for each grid location to assess the number of aircraft-noise-induced awakenings in Montreal.

Results: Using a 15 dB(A) sound attenuation, 590 persons would, on average, have one or more additional awakenings per night for the year 2009. In the scenario using a 21 dB(A) sound attenuation, on average, no one would be subjected to one or more additional awakenings per night due to aircraft noise.

Conclusion: Using the 2009 flight patterns, our data suggest that a small number of Montreal residents are exposed to noise levels that could induce one or more awakenings additional to spontaneous awakenings per night.

Key words: Noise; sleep; aircraft, risk assessment

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Can J Public Health 2012;103(4):e293-e296.

In recent years, many studies on the adverse effects of environmental noise levels have been published. Increased environmental noise levels are associated with cardiovascular diseases,¹⁻³ annoyance,⁴ cognitive performance⁵ and sleep disturbances.⁶

The assessment and management of adverse health risks associated with community noise levels are usually based on the comparison of measured or estimated sound levels with noise guidelines or standards. For example, the World Health Organization recommends a L_{day} of 55 dB(A) and a L_{night} of 40 dB(A) in residential areas.⁷ Regarding aviation noise in Canada, the assessment of the impact of air traffic noise is based on the Noise Exposure Forecast (NEF). NEF is a complex indicator of noise levels. This noise metric is used for land use planning in order to avoid high levels of annoyance in the population.⁸ Risk assessment methods can also be based on health measures. For example, one additional awakening per night is a value that has been suggested by Basner et al. (2006),⁶ and is currently used by the Leipzig/Halle airport in Germany, to manage the risk of sleep disturbances associated with aircraft noise.⁹

A request from municipal authorities based on the high number of complaints concerning noise from the residents living close to the Montreal airport prompted the Montreal Public Health Department to proceed with a risk assessment of aircraft noise on sleep disturbances. For this risk assessment, the approach proposed by the Institute of Aerospace Medicine in Germany¹⁰ based on the risk function developed by Basner et al. was used to assess the risk of awakening in association with aircraft maximum noise levels ($L_{AS,max}$).⁶

METHODS

Study population

The population residing in a zone covering 28 x 28 km, centred on the airport on the island of Montreal was targeted. All residents living less than 10 km from the airport were thus included in the assessment.

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Acknowledgements: We thank the Direction de la santé publique de Montréal de l'Agence de la santé et des services sociaux du Québec for their financial and logistical support; and Dr. Louis Drouin for his leadership in ensuring that this project was possible.

Conflict of Interest: None to declare.

Abbreviations

dB(A) = decibel with an A weighted sound level

INM = Integrated Noise Model

L_{Aeq} = A weighted equivalent sound levels

$L_{AS,max}$ = maximum A weighted sound level with 1-second time weighting

L_{night} = LAeq for nighttime noise of an 8-h duration

L_{day} = LAeq for daytime noise of a 16-h duration

Figure 1. Equation of the probability of awakenings

$$\text{Probability of awakening} = 1.894 \times 10^{-3} (L_{AS,max} - A)^2 + (4.008 \times 10^{-2} (L_{AS,max} - A) - 3.3243)$$

A: reduction of the noise level according to insulation level.

$L_{AS,max}$: maximum noise level for 1 second outside the residences.

Probability of awakening: The probability of subjects to move from a rapid eye movement sleep stage (REM), a slow wave sleep stage (SWS) or an S2 stage to an S1 or awakened sleep stage.⁶

Night noise exposure

The population's outdoor exposure to maximum aircraft night noise levels ($L_{AS,max}$) was estimated for each aircraft movement (departure and landing) from the airport for the year 2009. The Integrated Noise Model 7.0b (INM), a validated model used worldwide,^{11,12} was used to convert aircraft movements between 23h00 and 7h00 to noise levels. Aircraft movement data from 2009 were purchased from NAVCanada which is in charge of control towers across Canada. Modeling was performed by the engineering firm SNC Lavalin, Canada Inc.

$L_{AS,max}$ were modeled with a resolution of 0.1 km × 0.1 km in the 28 km × 28 km grid, centred on the airport. Aerial trajectories of the aircrafts were estimated based on the runways used, the destinations, the periods of the day and the types of aircraft. $L_{AS,max}$ levels for each flight departing from the airport were modeled five times, with different aerial trajectories, to take into account the variation in trajectories associated with winds, pilot habits, air traffic control, etc. According to normal procedures, a weight was then applied to each departing and landing trajectory.

In order to estimate the maximum indoor noise levels from the outside noise levels modeled, the $L_{AS,max}$ were decreased to take into account the residential sound insulation (Figure 1). As stated by WHO,⁷ residential sound insulation would reduce outdoor noise levels by 30 dB(A) if all windows were closed and by 15 dB(A) if windows were open. WHO proposes a yearly average reduction of 21 dB(A), after taking into account the window-opening patterns of the population. These values were established for noise levels from all sources in Europe, not specifically from aircraft noise. Nonetheless, in a study conducted by the Canadian National Council of Research on Canadian buildings¹³ where aircraft noise was measured inside and outside residences, similar attenuation values were observed.

In our assessment, we examined two scenarios to estimate the impact of the aircraft noise on the population sleep disturbances:⁷ a yearly attenuation of 21 dB(A) of the outdoor noise level, and an attenuation of 15 dB(A) (windows constantly open). The latter scenario was used to compare our results with those of Basner et al. for the Leipzig/Halle airport.⁶

Probability of awakening associated with aircraft $L_{AS,max}$

Probabilities of awakenings were estimated based on the risk function of Basner et al.,⁶ which is similar to a function proposed by the American National Standard Institute.¹⁴ We chose this risk function according to the systematic review written by Perron et al. (2012).¹⁵ The function developed by Basner et al. is based on a field study in which aircraft noise was recorded in the bedroom and sleep stage was simultaneously recorded using polysomnography. It was developed for indoor noise levels ranging from 32.7 dB(A) to 73.2 dB(A). The number of awakenings at sound levels below 32.7 dB(A) was considered to be lower than the number of awakenings observed spontaneously.

The function assesses the probability of awakenings due to individual noise events. Hence the probabilities of awakening created by each aircraft noise event occurring in the year 2009 were cumulated for each grid point to obtain a number of awakenings per year, which was divided by 365 to produce the average number of awakenings per night.¹⁰ We then computed the number of dwellings affected and individuals awakened once per night as suggested by Basner et al. All residential dwellings located in the zone of the study were geographically located using the 2010 Montreal property tax assessment database. The population was approximated using the average number of people per dwelling in those municipalities as reported in the 2006 Canadian census.¹⁶ The relationship giving the probability of awakenings for an individual aircraft noise at one location is given by the equation in Figure 1.

RESULTS

Quantification of the risk

The average outdoor night (23h00-7h00) $L_{AS,max}$ levels that were modeled fluctuated from 38 dB(A) to 104 dB(A) between grid points (Figure 2). More than half of the noise events were generated by aircraft movements occurring either at the beginning (23h00-00h00) or the end of the night (06:00-07:00) (data not shown).

According to the 21 dB(A) attenuation scenario, no one would be exposed to noise levels that result in one or more awakenings per night. However, with an attenuation of 15 dB(A), 590 persons would, on average, experience one or more awakenings per night. Most of the population who would experience one or more awakenings per night are located at the south and southwest corner of the airport (i.e., the Dorval municipality, see Figure 2).

DISCUSSION

This risk assessment approach used $L_{AS,max}$ from each airplane landing or departing at the airport in 2009, to model the number of awakenings per night in residential neighbourhoods around the airport. When modeled with an indoor attenuation of 21 dB(A), no home was exposed to noise levels generating one or more awakenings per night. An indoor attenuation of 15 dB(A) showed that 3% of the population of Dorval (19,013 inhabitants),¹⁷ a municipality on the Montreal island (1,934,082 inhabitants),¹⁸ were awakened on average once or more per night in 2009. This criterion of one awakening per night calculated with an attenuation of 15 dB(A) has been suggested in Basner et al.⁶ and is currently used by the Leipzig/Halle airport to manage the risk of sleep disturbances associated with aircraft noise. The 15 dB(A) attenuation cannot realistically apply for a whole year in Montreal, considering the Canadian climate. However, the estimations with the 15 dB(A) attenuation can be an indicator of the summer noise levels when people keep (or would like to keep) their windows open. This lower attenuation scenario can also be used to take into account that cer-

Figure 2. Average maximum night (23h00-7h00) noise levels modelled based on aircraft movements at an international airport in 2009

tain individuals are more vulnerable to the effects of noise exposure (e.g., the elderly, shift workers, individuals under stress).⁷

Our results can be compared to the assessment presented in the Leipzig (518,862 inhabitants)¹⁹ airport noise mitigation plan. In this German city, a much larger proportion of the population, assessed with the same method and an attenuation of 15dB(A) (33%, population residing in a 6 km by 45 km area around the airport), were awakened at least once per night.¹⁰ This difference may be attributed to the higher number of air movements occurring during the night at the Leipzig/Halle airport than at the international airport in Montreal and to higher population density in proximity to the airport.⁶

The proportion of individuals awakened on average once or more per night around the Montreal airport may seem negligible (3% of the Dorval municipality), however, the function used assesses the probability of awakenings for an average individual. It is likely that vulnerable individuals are woken up more than once per night by aircraft noises in areas that may not be judged to be problematic. Furthermore, these individuals are also exposed during daytime to a higher number of aircraft movements and thus, to more noise episodes. More than 90% of the flights at the Montreal airport occur during the day.²⁰ The noise generated by these flights could

likely cause annoyance and other health effects. This is especially likely for the individuals living in the NEF 30 zones, where according to Transport Canada guidelines, no new buildings should be built.⁸ According to our estimation, approximately 1,056 persons were living in the NEF 30 zone in 2009.

There are limitations to our risk assessment. First, it is based on a study (Basner et al., 2006) a) with a possible selection bias (the subjects reported to be annoyed by aircraft noise), and b) performed in a different setting, which may limit its generalization. Furthermore, all individuals selected in the Basner et al. study were healthy and were between 19 and 61 years of age.⁶ This is not the case for our exposed population, which includes individuals from all ages and health conditions. Consequently, Basner et al.'s risk function may not apply to the Montreal population. The function used may underestimate awakening probabilities for vulnerable people subjected to sleep disturbances. On the other hand, it is also possible that Basner et al.'s risk function overestimates the number of awakenings. Indeed, the more annoyed individuals residing near the airport may have moved away, leaving a population less sensitive to aircraft noise. In an ideal situation, a study would have been performed to assess both exposure and probabilities of awakening in the population residing near the airport.

Second, there is also some imprecision in our estimation of exposure caused by the fact that we did not know the exact location of bedrooms, if windows were open, and the degree of noise insulation in each residence. Such assessment for a representative random sample of the population would be costly.

Third, the crude way in which we assessed the population exposed to the aircraft noise levels (i.e., using the average number of persons per residence from the 2006 census) could affect the precision of the results obtained.

Further studies should address these limitations and aim to consider the effect of other noise sources when assessing risks. The aircraft noise is not the only source of environmental noise; our model could underestimate the possible excess awakenings produced by environmental noise.

CONCLUSION

Based on our risk assessment, a small number of individuals living near the airport were exposed in 2009 to aircraft maximum noise levels that would, on average, cause one awakening or more per night. Our results can be subject to variations due to the increase in population residing near the airport and to the possible fluctuation of aircraft movements. Studies are needed to develop Canadian risk functions in order to better assess risks associated with aircraft noise in Canada, including risks of cardiovascular diseases and annoyance, and to fully comprehend the impact on the population living near Canadian airports.

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Received: December 15, 2011

Accepted: April 28, 2012

RÉSUMÉ

Objectif : Estimer le nombre de réveils additionnels aux réveils spontanés, générés par les mouvements aériens nocturnes, de la population résidant à proximité d'un aéroport international sur l'île de Montréal en 2009.

Méthode : Les niveaux sonores maximaux ($L_{AS,max}$) ont été déterminés à partir des mouvements aériens suite à l'aide de l'*Integrated Noise Model* 7,0b pour une grille de points de 28 x 28 km centrée sur l'aéroport à une résolution de 0,1 x 0,1 km. Les $L_{AS,max}$ extérieurs ont été convertis en $L_{AS,max}$ intérieurs en les réduisant de 15 dB(A) ou 21 dB(A). Ensuite les $L_{AS,max}$ de chaque point de grille ont été transformés en probabilité de réveils additionnels à l'aide d'une fonction développée par Basner et coll. (2006). Les probabilités de réveils additionnels calculées ont été associées au nombre de résidents se trouvant à chaque point de grille afin d'estimer les réveils additionnels liés aux mouvements aériens à Montréal.

Résultats : En utilisant l'atténuation sonore de 15 dB(A), 590 individus auraient, en moyenne, un réveil additionnel ou plus par nuit en 2009. Cependant, en utilisant l'atténuation sonore de 21 dB(A), en moyenne, aucun individu n'aurait eu un réveil additionnel ou plus par nuit.

Conclusion : Selon nos résultats, issus des mouvements aériens de 2009, un nombre restreint de Montréalais seraient exposés à des niveaux sonores pouvant induire un réveil additionnel aux réveils spontanés ou plus par nuit.

Mots clés : bruit; sommeil; avion; analyse de risque