Health effects of aircraft noise: overview of the cross-sectional DEBATS study's results

Anne-Sophie Evrard[1], Marie Lefèvre[1], Clémence Baudin[1], Lise Giorgis-Allemand[1], Ali-Mohamed Nassur[1], Patricia Champelovier[2], Jacques Lambert[2,3], Bernard Laumon[4]

[1] Univ Lyon, Univ Gustave Eiffel, Ifsttar, Univ Lyon 1, Umrestte, UMR T_9405, F-69500 Bron, France
[2] Univ Gustave Eiffel, Ifsttar, AME-DCM, F-69500 Bron, France
[3] Currently retired, F-69100 Villeurbanne, France
[4] Univ Gustave Eiffel, Ifsttar, TS2, F-69500 Bron, France

Corresponding author's e-mail address: anne-sophie.evrard@univ-eiffel.fr

ABSTRACT

DEBATS is the first research to focus on the effects of aircraft noise on the health of people living near airports in France. A total of 1,244 residents (Paris-Charles de Gaulle, Lyon-Saint-Exupéry and Toulouse-Blagnac) were included in 2013. Information about their health, socioeconomic and lifestyle factors was collected by means of a face-to-face questionnaire performed at home by an interviewer. Outdoor aircraft noise exposure was assessed by linking home address to noise maps. The cross-sectional results of the DEBATS study at enrolment confirm those of previous ones conducted abroad. Indeed, they suggest that aircraft noise exposure decreases subjective and objective sleep quality, and increases the risk of hypertension and psychological distress. They also suggest an association between this exposure and a smaller variation of cortisol levels over the day. Moreover, they provide further evidence that community aircraft noise annoyance has increased over the past decades. However, all these results have to be confirmed by longitudinal studies. This is in progress in particular with longitudinal analyses of the data collected in 2013, 2015 and 2017 in the present DEBATS study.

INTRODUCTION

Transportation noise is a major public health issue with one million years of healthy life lost each year in Western Europe [1]. Aircraft noise is the third most important source, after road and rail traffic noise, affecting human exposure above levels considered annoying or with adverse health effects [1]. The health impact of exposure to aircraft noise is of increasing concern [2] due to the constant increase in the number of flights, as well as the growing dissatisfaction of airport residents with this nuisance [3].

In 2004, the High Commission of Public Hygiene in France recommended improving the knowledge of the health situation resulting from exposure to aircraft noise. Following this recommendation, the French Ministry of Health and the Airport Pollution Control Authority (Acnusa) initiated a study called DEBATS (Discussion on the health effects of aircraft noise).

Supervised by the Acnusa and conducted by the Gustave Eiffel University, DEBATS is the first large-scale research program in France to evaluate the possible effects of aircraft noise exposure on the health of airport residents. Participants were first interviewed in 2013 at study inclusion and then at follow-up in 2015 and 2017. This article presents a summary of all the results obtained from the data collected at inclusion in 2013.

MATERIAL AND METHODS

DEBATS was conducted in the vicinity of three major French airports (Paris-Charles-de-Gaulle, Lyon-Saint-Exupéry and Toulouse-Blagnac). It combines three complementary methodological approaches (ecological, individual longitudinal and ancillary sleep study[1]). Each approach considers all known or suspected confounding factors.

Ecological study

The ecological study addressed the issue of an association between the average level of aircraft noise exposure in each of the 161 municipalities located around these airports and mortality for some specific causes of death, such as cardiovascular disease in general, ischemic heart disease, including myocardial infarction, and stroke. These mortality data were provided by the French Centre on Medical Causes of Death (CépiDc-Inserm). Outdoor exposure to aircraft noise was estimated from noise maps produced by Paris Airports for Paris-Charles-de-Gaulle and by the French Civil Aviation Authority for Lyon-Saint-Exupéry and Toulouse-Blagnac.

Longitudinal study

The individual longitudinal study aimed to quantify the relationship between exposure to aircraft noise and the health of local residents, both physically and mentally, but also in terms of annoyance. It involved at baseline, in 2013, 1,244 participants from the 161 municipalities included in the ecological study. Exposure to aircraft noise at the participants' homes was estimated from the same maps used in the ecological study. A face-to-face questionnaire was conducted at home by trained interviewers to obtain information on demographic and socioeconomic characteristics, lifestyle and health status (self-rated health status, psychological distress, annoyance, potential effects on sleep, endocrine and cardiovascular systems).

[1] "Ancillary sleep study" is understood here to mean a statistical study of limited size.

Self-rated health status was assessed with the question "Overall, do you think your health is excellent, good, poor, fair?" For statistical analyses, responses to this question were dichotomized as follows: "excellent" or "good" versus "poor" or "fair".

Aircraft noise annoyance was assessed using a standardized question with the five-point verbal response scale recommended by the International Commission on the Biological Effects of Noise (ICBEN): "Thinking about the last 12 months when you are here at home, how much does aircraft noise annoy you?" Extremely, very, moderately, slightly or not at all [13]. Annoyance in the study population was described using the percentage of people highly annoyed (%HA) defined by the proportion of people reporting being very or extremely annoyed by aircraft noise [4].

The effects on sleep were characterized using total sleep time and feelings of tiredness when waking up. Total sleep time was assessed by the difference between the time participants reported turning off the light to sleep and the time they reported getting up. It was then dichotomized: "short" (≤ 6 hours) versus "normal and long" (> 6 hours). Indeed, in adults, sleeping less than 6 hours per night during weekdays is generally associated with potential comorbidities (obesity, diabetes, hypertension, cardiovascular pathologies) [5]. Participants also described how they felt after a usual night's sleep: well rested, somewhat rested, somewhat tired, or very tired. This variable was also dichotomized: well or somewhat rested versus somewhat or very tired.

Each participant was required to collect saliva twice: in the morning immediately after waking up (when salivary cortisol concentration is usually highest) and a second time in the evening just before bedtime (when salivary cortisol concentration is usually lowest). Hourly cortisol variation was defined as the ratio of the difference in wake-up and bedtime levels to the number of hours between the two saliva samples.

Blood pressure was measured during the interview of participants by the interviewer. An individual was classified as hypertensive if he or she had a systolic blood pressure (SBP) of 140 mm Hg or higher, or a diastolic blood pressure (DBP) of 90 mm Hg or higher (World Health Organization-WHO definition of hypertension), or if he or she reported that a physician had diagnosed him or her with hypertension in the past 12 months in conjunction with the use of an antihypertensive medication.

Psychological distress was determined using the 12-item version of the General Health Questionnaire (GHQ-12) [6]. A total score between 0 and 12 was calculated and participants with a total score of 3 or more were considered to have psychological distress [7].

Sleep study

The ancillary sleep study aimed to characterize in a detailed and specific way the acute effects of aircraft noise on sleep, while refining the exposure to aircraft noise by individual measurements. It involved 112 individuals selected from the participants in the previous individual longitudinal study. Actimetric and heart rate measurements, analysed by the Sleep and Vigilance Centre of the Hôtel-Dieu Hospital in Paris, were used to determine the objective sleep parameters of these participants. In addition, in order to precisely characterize their exposure to aircraft noise, acoustic measurements were carried out simultaneously by Bruitparif for seven days and seven nights, both inside and outside their bedroom.

RESULTS

The ecological study suggests that an increase in aircraft noise exposure of 10 dB(A) was associated with an 18% higher risk of mortality for all cardiovascular diseases, 24% specifically for ischemic heart disease, and 28% specifically for myocardial infarction. In contrast, no association was found with stroke mortality.

The individual longitudinal study suggests several associations:

- a 55% increased risk of fair/poor self-rated health status in men with an increase in noise level of 10 dB(A) in terms of L_{den}, with no evidence of an increase in women;

- the proportion of highly annoyed people consistently higher than predicted by the old European Union (EU) reference curve (called the Miedema curve [8]), but lower than predicted by the new EU curve provided by the World Health Organization, in March 2020 [9]. For example, at 60 dB(A) in terms of L_{den}, the old EU curve predicts 17% of people highly annoyed by aircraft noise (model adjusted only on noise exposure levels), whereas the curves based on the DEBATS results predict between 22 (model adjusted on noise exposure levels and non-acoustical factors) and 27% (model adjusted only on noise exposure levels), and the new EU curve 36% (model adjusted only on noise exposure levels). This severe annoyance was also associated with non-acoustic factors such as age, satisfaction with living environment, expectations about neighbourhood quality of life, sensitivity to noise, fear of a plane crash, and attitudes related to source and authority;

- a risk of sleeping less than six hours per night increased by 60%, and a risk of feeling tired in the morning when waking up by 20%, with an increase in noise level of 10 dB(A) in terms of L_{night};

- a disruption of the circadian rhythm of cortisol with an increase in noise level of 10 dB(A) in terms of L_{den} (15% decrease in the absolute hourly variation of cortisol, 16% increase in the level of cortisol at bedtime, but no significant variation at wake-up);

- a 34% increased risk of hypertension in men with an increase in noise level of 10 dB(A) in terms of L_{night}, with no evidence of an increase in women;

- exposure to aircraft noise did not appear to be directly associated with psychological distress. However, aircraft noise annoyance was associated with it: compared to participants who were not highly annoyed, the risk of psychological distress was increased by 80% in participants slightly annoyed by aircraft noise, and multiplied by 4 in those who declared being highly annoyed.

The ancillary sleep study suggests that exposure to aircraft noise degraded objective sleep parameters. Thus:

- an increase in aircraft noise levels during sleep period in terms of integrated indicators or noise events indicators was associated with a 1.1-1.8-fold increase in the probability of sleeping less than six hours per night (short sleep); and a 1.1-1.6-fold increase in the probability of spending more than nine hours in bed (which can be interpreted as an adaptation mechanism to sleep deprivation);

- an increase in aircraft noise levels during sleep period in terms of integrated indicators was associated with a 1.1-1.3 times higher probability of sleep onset insomnia (i.e. a sleep latency greater than 30 minutes);

- an increase in aircraft noise levels during sleep period in terms of noise events indicators was associated with a probability of sleep-maintenance insomnia (i.e. a total duration of the intra-sleep arousals higher than thirty minutes), from 1.1 to 1.3 times higher;

- finally, a 10 dB(A) increase in the maximum noise level of an event associated with the passage of an aircraft (LAmax,1s) was associated with an increase in the amplitude of the heart rate during this event (0.34 beats per minute.

DISCUSSION

DEBATS is the first large-scale research program in France to assess the possible effects of aircraft noise exposure on the health of airport residents. The participation rate in the individual longitudinal study (30%) was similar to that of studies on the same topic conducted in Germany, Italy and the United Kingdom [10]. In general, the results obtained in DEBATS confirm those obtained by previous studies conducted around other airports in the world and mainly in Europe. They suggest that exposure to aircraft noise:

- decreased subjective and objective sleep [11, 12],

- increased the risk of hypertension in men but not in women [13],

- was not directly related to psychological distress, but was related through annoyance due to aircraft noise and to noise sensitivity [14],

- increased the risk of fair/poor self-rated health status in men, but not in women [15],

- increased the proportion of people who were highly annoyed by aircraft noise [16],

- was associated with a significant decrease in the variation of saliva cortisol [17]. The most exposed individuals would thus tend to regulate their cortisol secretion less. Aircraft noise exposure would thus generate a chronic stress inducing a disturbance of the circadian rhythm of cortisol.

Controlling for a large number of factors that may influence the health events studied did not alter the associations shown here. Furthermore, they remained unchanged when the analyses were restricted to participants living in their dwelling for at least five years at the time of their inclusion in the study.

These findings support the hypothesis that noise is a stressor that activates the sympathetic and endocrine system [18]. Neuroendocrine arousal is itself associated with psychological symptoms such as depression or anxiety [19], or with adverse effects on metabolism that are established risk factors for cardiovascular disease [20].

In DEBATS, some health effects of noise, such as the risk of hypertension, are observed only in men. However, although there are many studies demonstrating the adverse effects of noise on health, and the risk of hypertension in particular, few of them focused more specifically on associations that might be different in men and women [10, 13, 21]. The mechanisms explaining these differences are only partially understood due to the complexity of gene-gene and gene-environment interactions. In particular, these differences could be explained by the interaction of female hormones with regulatory systems, but this hypothesis remains to be confirmed.

The percentage of highly annoyed people was higher in the DEBATS study than predicted with the old standard curve recommended by the EU in 2002 for the assessment and management of environmental noise in the EU [22]. In contrast, this percentage was lower in

DEBATS than predicted with the new European curve of 2020 [23]. Methodological differences in the assessment of highly annoyed people could be the reason why studies conducted since the 2000s found, for the same noise exposure level, higher proportions of highly annoyed people than those observed in the studies conducted before 2000.

Even if everything was done to avoid them, some selection bias cannot be totally excluded. Indeed, on the one hand, the participants in the study could be different (i.e. beyond their exposure to noise) from the individuals who refused to participate, and on the other hand, the participants could be different according to their level of noise exposure. Regarding the first risk of bias, the demographic and socioeconomic profiles of participants and non-respondents who nevertheless agreed to answer some questions were relatively similar. A few differences appeared, notably a higher proportion of managers and intermediate professions among participants than among non-respondents, as well as a lower proportion of retired people. However, these non-respondents may not be representative of all non-respondents either. On the other hand, it is possible that those who agreed to participate felt more concerned, and thus would tend to report more noise-related health problems. As we could not fully control for this risk of bias, we ensured that participants were not informed of the specific purpose of the study before completing the questionnaire (the study was presented to them as being about their environmental perception and health). Moreover, saliva cortisol and hypertension (for participants without prior medical diagnosis) were objectified during the study. With regard to the second risk of bias, which is perhaps more critical than the previous one, a reasonable assumption is that this risk is low. This is particularly true since the results were adjusted for a range of factors, which are certainly confounding, but which may also constitute factors of selection bias (age, gender or socio-professional category). In fact, any associated selection bias can only be taken into account by these adjustments. This remark also applies to the first risk of selection bias mentioned above.

Moreover, the airport residents included in DEBATS were certainly not representative of all French airport residents (and certainly of the rest of the world). In the absence of data concerning this population, it was not possible to characterize the probable differences between them. Here again, the previous remark, concerning the adjustment of risks on several confounding factors, may be reassuring as to the relevance of the associations highlighted.

Assessing aircraft noise exposure at each participant's home using noise levels modelled by noise maps could be a source of measurement error. However, most of the differences between modelled noise levels and measurements from permanent stations [24] or from specific campaigns [25] were between 0.5 and 1.5 dB(A) in terms of L_{den}. Furthermore, the average aircraft noise levels estimated from the noise maps at the addresses of the 112 sleep study participants were relatively similar to those calculated from acoustic measurements made at the outside facade of these participants' bedrooms, with an average relative difference of 5% and a 95th percentile of 11%. These results showed a close correlation between modelled and measured noise levels, validating the estimate of aircraft noise exposure levels provided from the INM software [26].

Finally, in the longitudinal study, no information regarding their noise exposure was collected when participants were away from their homes, particularly at their workplace or in transportation. This may have led to an inaccurate assessment of the noise exposure level of some of them due to their exposure to other noise sources, especially during the daytime. However, such measurement bias would likely result in an underestimation of the associations studied here.

CONCLUSION

The ecological study confirms the results of other studies suggesting that increased exposure to aircraft noise is associated with higher cardiovascular disease mortality. However, it is inappropriate to extrapolate these results to the individual level. Therefore, two individual studies were also conducted.

The individual longitudinal study and the ancillary sleep study confirm, at baseline, the results of previous studies performed abroad. They suggest that exposure to aircraft noise, in France as elsewhere, has deleterious effects on self-rated health status, psychological distress, annoyance due to aircraft noise, subjective and objective sleep, and the endocrine and cardiovascular systems.

OTHER IMPORTANT INFORMATION

Acknowledgements

The authors would like to thank the Airport Pollution Control Authority (Acnusa), the French Agency for Food, Environmental and Occupational Health & Safety (Anses), the French Civil Aviation Authority, the French Ministry of Environment, the French Ministry of Health and Gustave Eiffel University for funding DEBATS; Paris Airports and the French Civil Aviation Authority for providing noise exposure maps, and the French Centre on Medical Causes of Death (CépiDc-Inserm) for providing the mortality data; Liacine Bouaoun (International Agency for Research on Cancer), Bruitparif, Marie-Christine Carlier (Hospices Civils de Lyon), Aboud Kourieh (Gustave Eiffel University) and Damien Léger (Hôtel Dieu – Sleep and Vigilance Centre) for collaborating on this research program; as well as all the participants in the study and their interviewers.

REFERENCES

1. World Health Organization, *Burden of Disease from Environmental Noise. Quantification of Healthy Life Years Lost in Europe*. 2011, World Health Organization, Regional Office for Europe: Copenhagen, Denmark.
2. Lekaviciute, J., et al., *Final Report of the ENNAH (European Network on Noise and Health) project, FP7-ENV-2008*, in *European Commission, Joint Research Centre. Report no 226442*. 2013.
3. Guski, R., D. Schreckenberg, and R. Schuemer, *WHO Environmental Noise Guidelines for the European Region: A Systematic Review on Environmental Noise and Annoyance.* International Journal of Environmental Research and Public Health, 2017. 14: p. 1539.
4. Fields, J.M., et al., *Standardized general-purpose noise reaction questions for community noise surveys: Research and a recommendation.* Journal of Sound and Vibration, 2001. 242(4): p. 641-679.
5. Léger, D., et al., *Le temps de sommeil, la dette de sommeil, la restriction de sommeil et l'insomnie chronique des 18-75 ans : résultats du Baromètre de Santé Publique France 2017.* Bulletin d'Epidémiologie Hebdomadaire, 2019. 8-9: p. 149-160.
6. Goldberg, D. and P. Williams, *A User's Guide to the General Health Questionnaire*. 1988, London, UK: NFER-Nelson.
7. McDowell, I., *Measuring Health: A Guide to Rating Scales and Questionnaires, 3rd ed.* 2006, Oxford, United Kingdom; New-York, NY, USA: Oxford University Press.
8. Miedema, H.M. and C.M.G. Oudshoorn, *Annoyance from Transportation Noise: Relationships with Exposure Metrics DNL and DENL and Their Confidence Intervals.* Environmental Health Perspectives, 2001. 109(4): p. 409-416.
9. World health Organization, *Environmental Noise Guidelines for the European Region*. 2018, WHO Regional Office for Europe: Copenhagen, Denmark.

10. Jarup, L., et al., *Hypertension and exposure to noise near airports: the HYENA study.* Environmental Health Perspectives, 2008. 116(3): p. 329-33.
11. Nassur, A.M., et al., *Aircraft Noise Exposure and Subjective Sleep Quality: The Results of the DEBATS Study in France.* Behavioral sleep medicine, 2017: p. 1-12.
12. Nassur, A.M., et al., *The impact of aircraft noise exposure on objective parameters of sleep quality: Results of the DEBATS study in France.* Sleep Medicine, 2019. 54: p. 70-77.
13. Evrard, A.S., et al., *Does exposure to aircraft noise increase the risk of hypertension in the population living near airports? Results of the DEBATS study in France. .* Occupational and environmental medicine, 2017. 74: p. 123-129.
14. Baudin, C., et al., *Aircraft Noise and Psychological Ill-Health: The Results of a Cross-Sectional Study in France.* International Journal of Environmental Research and Public Health, 2018. 15(8): p. 1642.
15. Baudin, C., et al., *Self-rated health status in relation to aircraft noise exposure, noise annoyance or noise sensitivity: the results of a cross-sectional study in France.* BMC Public Health, 2021. 21(116).
16. Lefèvre, M., et al., *Understanding the relationship between air traffic noise exposure and annoyance in populations living near airports in France.* Environment International, 2020. 144.
17. Lefèvre, M., et al., *Effects of aircraft noise exposure on saliva cortisol near airports in France.* Occupational and environmental medicine, 2017.
18. Münzel, T., et al., *Cardiovascular effects of environmental noise exposure.* Eur Heart J, 2014. 35: p. 829-836.
19. Zorn, J.V., et al., *Cortisol stress reactivity across psychiatric disorders: A systematic review and meta-analysis.* Psychoneuroendocrinology, 2017. 77: p. 25-36.
20. Babisch, W., *Updated exposure-response relationship between road traffic noise and coronary heart diseases: A meta-analysis.* Noise & Health, 2014. 16: p. 1-9.
21. Eriksson, C., et al., *Aircraft noise and incidence of hypertension - Gender specific effects.* Environmental Research, 2010. 110: p. 764-772.
22. European Commission, *Directive of the European Parliament and of the Council of 25 June 2002 relating to the assessment and management of environmental noise*. 2002, Official Journal of the European Communities: Available at: http://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX:32002L0049; Accessed December 1, 2014. p. 12-25.
23. Official Journal of the European Union, *Commission Directive (EU) 2020/367 of 4 March 2020 amending Annex III to Directive 2002/49/EC of the European Parliament and of the Council as regards the establishment of assessment methods for harmful effects of environmental noise*. 2020.
24. Aéroports de Paris, *Exposition au bruit des avions : Aéroport Paris-Charles de Gaulle - Compte rendu annuel 2006*. 2006.
25. Foret, R., J.C. Bruyère, and N. Yombo, *Etude empirique de la validité du Plan de Gêne Sonore de l'aéroport Lyon St Exupéry. Rapport d'étude*. 2005, Aéroport de Lyon-St Exupéry.
26. He, B., et al., *Integrated Noise Model (INM) Version 7.0 User's Guide*, N.T. Library, Editor. 2007, Federal Aviation Administration: Washington DC, USA.