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Understanding the relationship between air traffic noise exposure and annoyance in populations living near airports in France

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ABSTRACT

Since the 2000s, increased aircraft noise annoyance has been observed in the populations living near airports. The DEBATS-study compared the exposure–response relationship estimated among airports' residents in France with old and new EU standard curves. It also examines whether non-acoustical factors may explain this annoyance. For 1244 adults living near three French airports, information about demographic and socio-economic factors as well as aircraft noise annoyance, situational, personal and attitudinal factors was collected with a face-to-face questionnaire. Outdoor aircraft noise exposure was estimated by linking home address to noise exposure maps. Logistic regression models were used to investigate the association between annoyance and a broad range of other variables in addition to the L_{den}. Severe noise annoyance was associated not only with increased aircraft noise levels, but also with non-acoustical factors. Annoyance was higher than predicted by the old EU standard curve when estimated with the model including non-acoustical factors in addition to the L_{den}. It was even higher when only noise exposure was considered. However, annoyance was lower in DEBATS than predicted by the new EU standard curve provided by WHO. The increase of noise annoyance does not seem to be explained by the factors already mentioned in the literature as possible explanations. However, it cannot be ruled out that methodological differences in the HA assessment may be the reason for changes in annoyance over the years. For this reason, we argue for a definition of HA derived substantially as recommended by ICBEN. The findings of the DEBATS study also confirm that taking into account non-acoustical factors such as situational, personal and attitudinal factors would improve annoyance predictions.

1. Introduction

The ever-increasing demand for passenger transportation consequently contributes to a multitude of negative impacts, including noise pollution and its subsequent adverse effects on health. Transportation noise represents the second major environmental issue for public health after air pollution (World Health Organization, 2011). According to the World Health Organization (WHO), at least one million healthy life years are lost every year from traffic-related noise in the western part of Europe. Annoyance from this noise source is the second most serious consequence after sleep disturbance, with more than 650 thousand healthy life years lost every year (World Health Organization, 2011).

Noise annoyance has been defined as a feeling of resentment, displeasure, discomfort, dissatisfaction or offence which occurs when noise interferes with someone's thoughts, feelings or daily activities (Passchier-Vermeer and Passchier, 2000). After road traffic and railway noise, aircraft noise is the third most important source affecting human with levels above those considered to be annoying or to have adverse effects on health (European Environment Agency, 2014). Furthermore, aircraft noise is often perceived as the most annoying noise source among all surface transportation airborne noise sources (road traffic noise, railway noise) when standardized for noise exposure level (Miedema and Oudshoorn, 2001; World Health Organization, 1999).

The association between aircraft noise exposure and annoyance has been extensively investigated and documented. In many studies, aircraft noise levels were found to be associated with annoyance in a

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dose–response relationship (Lim, 2007; Quehl and Basner, 2006; Quehl et al., 2017; Sung, 2016). Moreover, several reviews have used these exposure–response relationships quantifying the association between aircraft noise exposure and annoyance to estimate the aircraft noise annoyance level in some populations (Guski et al., 2017; Miedema and Oudshoorn, 2001; Miedema and Vos, 1998). The most commonly exposure–response relationships used until recently was presented by Miedema and Vos in 1998 (Miedema and Vos, 1998) and were updated by Miedema and Oudshoorn in 2001 (Miedema and Oudshoorn, 2001) on the basis of a work initiated at the request of the European Commission and completed in 2000. Using data from cross-sectional surveys carried out between 1967 and 1993 in Europe, North America, and Australia, these authors established separate exposure–response curves for aircraft, road traffic, and railway noise. These dose–response relationships were recommended by the European Commission until March 2020 as the EU standard curves for the assessment and management of environmental noise in the European Union (European Commission, 2002). They were also often used by European Union member states to establish limit values at the operational level.

However, several studies conducted since 2000 have suggested that annoyance has significantly increased over the years, indicating that, at a given level of aircraft noise exposure, people are more highly annoyed now than 30 years ago (Babisch, 2009; Guski, 2004; Guski et al., 2017; Janssen, 2011; Schreckenberg, 2010; van Kempen and van Kamp, 2005). These studies have been taken into account by WHO in developing the new Environmental Noise Guidelines for the European Region published in 2018 (World health Organization, 2018). Therefore, the validity of the Miedema and Oudshoorn curves as EU reference curves has been questioned and Annex III of the European Noise Directive 2002/49 was revised in March 2020 using the recent WHO curves (Official Journal of the European Union, 2020). However, the statistical evidence for an upward trend of the aircraft annoyance exposure–response relationship is still discussed, with some authors arguing that it could be due to changing noise exposure situations around airports or to differences in field study or sample characteristics (Brooker, 2009; Gjestland, 2018; Janssen, 2011).

The EU standard curves model annoyance response as a function of noise exposure only. Although empirical studies showed that noise levels only partly explain the variance of annoyance, these curves do not take into account non-acoustical factors (i.e. all factors other than noise levels, also called moderators or co-determinants) which may contribute to annoyance and modify the relationship between aircraft noise exposure and annoyance. These non-acoustical factors include in particular demographic/socio-economic, personal/attitudinal, social, and situational factors (Guski, 1999; Guski, 2004; Okokon, 2015). They reflect not only the individual characteristics and attitudes of people exposed to noise but also their relations with the operators that are making the noise (social context). Extending the prediction model by adding non-acoustical factors could considerably increase its predictive power.

This paper addresses these key issues in reporting and discussing the results of a social survey on noise annoyance carried out in 2013 as part of the large DEBATS study (Discussion on the health effects of aircraft noise) launched in France to investigate the adverse health effects of aircraft noise among 1244 people living near airports. More precisely, the objective was to estimate an exposure–response relationship between aircraft noise exposure and annoyance due to aircraft noise, and to compare its predictions with the ones based on old (presented by Miedema and Oudshoorn in 2001) and new (presented by WHO in 2018) EU standard dose–response curves in order to confirm or to refute the hypothesis that aircraft noise annoyance has increased. Factors already mentioned in the literature as possible explanations for the increase of this annoyance are also explored. In addition, this paper investigates the contribution of other non-acoustical factors to the variability of aircraft noise annoyance response. For this purpose, the association between annoyance due to aircraft noise and a broad range of other factors in addition to noise exposure was examined. These factors include those previously reported to affect annoyance, such as noise sensitivity, as well as demographic/socio-economic, personal/attitudinal, social and situational factors.

2. Materials and methods

2.1. Study population

The DEBATS field study population included people aged 18 years and older at the time of the interview in 2013 and living near one of the following three French international airports: Paris-Charles-de-Gaulle, Toulouse-Blagnac, and Lyon Saint-Exupéry. To maximize exposure contrast, the population was stratified using existing noise contours produced for France's largest airports. They represent four categories of aircraft noise exposure in terms of L_{den} (see paragraph Aircraft noise exposure assessment for the L_{den} definition): < 50, 50–54, 55–59 and ≥60 dB(A). Households with home address included in the study area were randomly selected from a phone directory. Once a household was contacted by phone, a participant was randomly selected from within the household. The participant signed and returned an informed consent form by mail.

Finally, 1244 participants were included in the study. They filled out a questionnaire during a face-to-face interview at home. This questionnaire collected in particular demographic and socio-economic information (gender, age, education, occupational activity, homeownership, economic dependency on airport activities, use of the noise source), as well as situational (type of housing, outdoor spaces, windows or roof insulation, expectations regarding the quality of life in the neighbourhood, satisfaction with living environment) and personal and attitudinal factors including noise sensitivity.

2.2. Aircraft noise exposure assessment

L_{den} was shown to be one of the noise metrics best predicting annoyance from aircraft noise (Miedema et al., 2000). It is defined as the weighted average of sound levels during daytime (06:00 to 18:00), evening (18:00 to 22:00), and night-time (22:00 to 6:00). Evening and night sound pressure levels received a 5 dB(A) and a 10 dB(A) penalty respectively to reflect the extra sensitivity to noise during the evening and the night. L_{den} is the "general purpose" indicator defined in the EU-directive 2002/49 relating to the assessment and management of environmental noise and used for the EU standard curves (European Commission, 2002). To facilitate comparability with these curves and with other studies, L_{den} was used in the present study. In sensitivity analyses, L_{den} was replaced by $L_{Aeq,24hr}$, $L_{Aeq,6hr-22hr}$, and L_{night}, corresponding to the average of sound levels during the corresponding periods of time.

Aircraft noise exposure in terms of L_{den} was estimated for each participant's home address using outdoor noise exposure maps obtained from the Integrated Noise Model (He et al., 2007). The maps were produced by the French Civil Aviation Authority for Toulouse-Blagnac and Lyon Saint-Exupéry airports, and by Paris Airports. Aircraft noise exposure was assessed in 1-dBA intervals for each participant with a linkage between noise contours and their home address using a geographic information system (GIS) technique.

2.3. Annoyance due to aircraft noise

Aircraft noise annoyance was assessed using the ISO/ICBEN (International Commission on the Biological Effects of Noise) recommended question (Fields, 2001, 2003): "Thinking about the last 12 months when you are here at home, how much does aircraft noise bother, disturb or annoy you?" The standard verbal scale was used with five possible answers: extremely, very, moderately, slightly or not at all. Severe annoyance was defined by the proportion of highly annoyed people (%HA), i.e. by the proportion of people reporting to be very or extremely annoyed by aircraft noise (Fields, 2001).

In the daily life, severe noise annoyance expressed by people living near airports is first and foremost associated with different kinds of activity interferences (or disturbances) at home, leading often to behavioural changes to reduce their noise exposure or to adapt to the noisy environment that causes annoyance. Therefore information about these activity interferences and these behavioural changes was obtained from the questionnaire.

2.4. Non-acoustical factors

The following factors already identified in the literature as having a possible influence on noise annoyance were also obtained from the questionnaire: age (continuous), gender (dichotomous), education (three categories: less than French high school certificate/French high school certificate/more than French high school certificate), occupational activity (no/yes), homeownership (owner/renter/free accommodation), economic dependency on airport activities (no/yes), use of the noise source (never/rarely/one time a year/several times a year), noise sensitivity (much less sensitive than others/ less sensitive/ as sensitive/ more sensitive/ much more sensitive) and fear of a plane crash (never/sometimes/a lot). Information about the participants' dwelling was also collected: housing type (house/apartment), presence of outdoor spaces (no/yes) and windows or roof insulation (no/yes).

Expectations regarding the quality of life in the neighbourhood was assessed using standardized questions about annoyance due to air pollution and about expected evolution of noise and air pollution in the neighbourhood of the participants in the future (deterioration, improvement or steadiness). A factor analysis was used to decrease correlation between factors and to reduce multicollinearity in further regression analyses. An ascending hierarchical clustering on principal components was then performed to categorize participants in homogeneous groups according to their quality of life expectations. Five groups were derived: optimistic people (air pollution and noise will be reduced) / people with no idea about the evolution of air pollution and noise and not annoyed by air pollution / people thinking that air pollution and noise will remain unchanged and slightly annoyed by air pollution / pessimistic people (air pollution and noise will increase) and moderately or very annoyed by air pollution / pessimistic people (air pollution and noise will increase) and extremely annoyed by air pollution.

Satisfaction with living environment was assessed using four standardized questions about place attachment of the participants to their neighbourhood. A total score from 0 to 10 was calculated by summing up the scores of the individual items (Cronbach's alpha = 0.83): the higher the score, the more satisfied with the living environment the participants.

Source- and authority-related attitudes of people regarding aircraft noise concerns were evaluated. A total score from 0 to 10 was then calculated by summing up the scores of the individual items (Cronbach's alpha = 0.79): the higher the score, the less people were involved in anti-noise actions.

2.5. Statistical analysis

Logistic regression models were used to assess the relationship between aircraft noise levels and severe annoyance (%HA). The proportion of highly annoyed people (%HA) was modelled first as a function of noise levels only (M0 model) in order to facilitate comparability with old and new EU standard curves for the prediction of aircraft noise annoyance. A second model (M1 model) was then used adjusting also for non-acoustical factors having a possible influence on noise annoyance. Non-acoustical factors were encoded in the following way in order to derive prediction based on the fully adjusted regression model (M1 model): age (mean), gender (proportion of women among the participants), education (proportion of participants with at least the French high school certificate), occupational activity (proportion of participants with an occupational activity), homeownership (proportion of home owners among the participants), economical dependency on airport activities (proportion of participants economically dependent on airport activities), use of the source of noise (proportion of participants making either low, moderate or high use of the source of noise versus no use at all), noise sensitivity (mean; based on numbers of response categories, converted into a scale ranging from 0 = much less sensitive to noise than others to 5 = much more sensitive to noise than others), fear of a plane crash (mean; based on numbers of response categories, also converted into a scale ranging from 1 = no fear to 3 = very fearful), type of housing (proportion of participants living in a house), presence of outdoor spaces (proportion of participants with outdoor spaces besides their home), windows or roof insulation (proportion of participants with at least windows or roof insulation), satisfaction with the living environment (mean; based on a score), source- and authority-related attitudes of people regarding aircraft noise concerns (mean; based on a score), and expectation regarding the quality of life in the neighbourhood (proportion of participants considered to be optimistic, neutral or without opinion versus pessimistic).

For the M0 and M1 models, the percentages of highly annoyed people for different levels of noise were estimated from the predictions to determine the exposure–response relationship.

In sensitivity analyses, the exposure–response relationship was estimated for people between 45 and 70 years of age. The objective was to compare the results with those obtained in the HYENA study that focused on similar outcomes in six European countries but limited its study population to residents aged 45–70 (Babisch, 2009). Moreover, the exposure–response relationship was also estimated for people who had resided at their address for at least 5 years.

Statistical analyses were conducted using SAS version 9.4 (SAS Software [program] 9.4 version, Cary North Carolina, USA, 2014).

3. Results

Overall, the participation rate was 30%. It differed slightly near the three airports: 25% for Paris-Charles de Gaulle airport, 34% for Toulouse-Blagnac airport and 39% for Lyon Saint-Exupéry airport. In contrast, it was similar in the four 5 dB(A)-categories of aircraft noise exposure.

The socio-demographic characteristics were quite similar among participants, people who refused to participate but responded to the short questionnaire about their demographic and socioeconomic characteristics, and the study population (individuals aged 18 and over and living in one of the municipalities of the study area). The distribution of the study population is based on data from the 1999 INSEE (National Institute of Statistics and Economic Studies) census, adjusted in 2007. The participants were a little older and were a little more likely to have executive or superior intellectual occupations.

3.1. Severe annoyance in daily life

In total, 18% of the participants reported to be highly annoyed by aircraft noise (HA), but much more in summer (50%) than in winter (7%). The activities disturbed by aircraft noise that most differentiate between highly annoyed (HA) and non-highly annoyed (non-HA) participants were related to physical and mental recovery (relaxing/resting - sleeping), speech comprehension (conversing - listening), and concentration (reading and intellectual work at home) (Table 1). Thus, highly annoyed people (HA) were four to seven times more likely to be highly disturbed during home activities than non-highly annoyed people (non-HA).

In response to these activity disturbances due to aircraft noise, the main behaviours reported by the participants to limit their noise exposure were: closing window (particularly in the evening), the non-use

Table 1
Aircraft noise annoyance vs. disturbed daily activities at home.

	Annoyance due to aircraft noise				Total
	HA		Non-HA		
	n 226	(%) 18	n 1018	(%) 82	n 1244
Disturbed daily activities at home					
Relaxing, resting	141	62%	96	9%	237
Sleeping	121	54%	92	9%	213
Conversation	129	57%	128	13%	257
Listening to radio, music, TV	114	50%	122	12%	236
Reading, intellectual work, concentrating	74	33%	51	5%	125
Manual work	26	12%	16	2%	42

Table 2
Aircraft noise annoyance vs. avoidance or adaptive behaviours.

	Annoyance due to aircraft noise				Total
	HA		Non-HA		
	n 226	(%) 18	n 1018	(%) 82	n 1244
Avoidance or adaptive behaviours					
Often close windows in the evening	133	59%	170	17%	303
Often close windows during the day	131	58%	157	15%	288
Often close windows during the night	125	55%	188	18%	313
Often turn up the radio or TV volume	106	47%	111	11%	217
Often speak louder	107	47%	105	10%	212
Often stop talking	101	45%	103	10%	204
Often avoid using the garden or the balcony(*)	74	36%	74	8%	148
Often think to move out	54	24%	18	2%	72
Often move away from home as soon as possible	25	11%	4	0%	29
Often move to a quiet room(**)	20	12%	18	2%	38

(*) excluding 23 HA people and 105 not HA people who declared being not concerned.

(**) excluding 61 HA people and 198 not HA people who declared being not concerned.

of outdoor spaces (garden - balcony), and to a lesser extent, moving to a room on the quiet side, moving away from home for a few hours as soon as possible and, as a last resort, thinking to moving out in the near future. In addition to these avoidance behaviours, often perceived by residents as constraints in their daily life, adaptive behaviours, such as turning up the sound of radio or TV to cover aircraft noise, were also reported (Table 2). Thus, highly annoyed people (HA) are three to twelve times more likely to often adopt avoidance or adaptive behaviours than non-highly annoyed people (non-HA).

3.2. Factors influencing severe annoyance

Table 3 presents the distribution of the 1244 participants according to severe aircraft noise annoyance, aircraft noise exposure levels (L_{den}) and non-acoustical factors. The proportion of highly annoyed participants increased when aircraft noise exposure increased: from 8% in the lowest noise levels (< 50 dB(A)) to 31% in the highest ones (≥60 dB (A)). People over 55 years of age were more likely to report to be highly annoyed (22% versus 15% in the less than 55 years group). The participants declaring to be pessimistic regarding the evolution of the quality of life in their neighborhood were much more prone to report to be highly annoyed (29% versus 11% for those who are optimistic, neutral or have no idea). People considering themselves much more sensitive to noise than others more often reported severe annoyance (36% versus 19%, 17% and 19% for those who considered themselves more sensitive, as sensitive or less sensitive to noise than others respectively) as well as people declaring to be afraid of a plane crash (25% versus 11% for those who declared not to be afraid of a plane crash). No difference was found in terms of gender, occupational activity, homeownership, economic dependency on airport activities, use of the noise source or other situational factors.

3.3. Modelling noise annoyance

Table 4 shows the odds ratios (OR) and their 95% confidence intervals (CI) for severe annoyance due to aircraft noise in relation to aircraft noise exposure, in both univariate (M0 model, n = 1244) and multivariate (M1 model, n = 1234) models. The probability of being highly annoyed by aircraft noise was significantly associated with aircraft noise exposure with an $OR_{univariate}$ = 3.04 (95% CI: 2.30–4.02) and an $OR_{multivariate}$ = 2.80 (95% CI: 2.05–3.84). Additionally, severe annoyance was also associated with some non-acoustical factors. Among demographic and socio-economic factors, only age was significantly associated to annoyance: the older the participants were, the more highly annoyed they were. Others parameters were only marginally associated to severe annoyance due to aircraft noise. Socio-economic characteristics in particular (occupational activity, homeownership, economic dependency on airport activities, and use of the noise source) were not associated with severe annoyance. The situational factors such as type of housing, presence of outdoor spaces, or windows or roof insulation were not associated with severe annoyance either. In contrast, satisfaction with the living environment and expectations regarding the quality of life in the neighbourhood were associated with severe annoyance. The more satisfied the participants, the less they reported to be severely annoyed by aircraft noise (OR = 0.94; 95% CI: 0.88–1.00). People who were pessimistic about the evolution of air pollution and noise in the future and who were also extremely annoyed by air pollution were much more likely to report severe annoyance compared to those who were optimistic towards air pollution and noise evolutions (OR = 5.17, 95% CI: 2.08–12.85). Personal and attitudinal factors were also related to severe annoyance. Participants reporting being much more sensitive to noise than others were more prone to report severe annoyance than others (OR = 2.30, 95%CI: 1.30–4.08). The fear of the noise source was significantly associated with severe annoyance: people who are fearful or very fearful of a plane crash reported more often to be highly annoyed than people with no fear ($OR_{sometimes}$ = 1.92, 95% CI: 1.33–2.78); $OR_{a\ lot}$ = 1.94, 95% CI: 1.17–3.22). Source- and authority-related attitudes were also related to severe annoyance: people who were less involved in actions to protest against aircraft noise were less highly annoyed than those who participated in these actions (OR = 0.82, 95% CI: 0.77–0.88).

These results remained similar when L_{den} was replaced by $L_{Aeq,24hr}$, $L_{Aeq,6hr-22hr}$, and L_{night}, in sensitivity analyses.

3.4. Exposure-response relationships

Fig. 1 shows the exposure–response relationships between aircraft noise exposure in terms of L_{den} and the proportion of highly annoyed people predicted with M0 and M1 models together with old and new EU standard curves (Guski et al., 2017; Miedema and Oudshoorn, 2001). The percentage of highly annoyed people was consistently higher in the present study than predicted by the old EU-curve. The predictions were even higher when severe annoyance was modelled as a function of aircraft noise levels only as done for the EU-curve. In contrast, the percentage of highly annoyed people was consistently lower in the present study than predicted by the new EU-curve. For example, at 60 dB(A), the old EU standard curve predicted 17% of HA whereas M0

Table 3
Distribution of the 1244 participants in the DEBATS study according to severe annoyance (HA) due to aircraft noise, aircraft noise exposure levels (L_{den}) and non-acoustical factors.

	Annoyance due to aircraft noise				p-value	Total
	HA		Non-HA			
	n	(%)	n	(%)		n
Aircraft noise level (L_{den})					< 0.001	
< 50 dB(A)	25	8%	292	92%		317
50–54 dB(A)	40	13%	267	87%		307
55–59 dB(A)	66	21%	248	79%		314
≥ 60 dB(A)	95	31%	211	69%		306
Socio-demographic/economic factors						
Age (years of age)					0.002	
18–34	23	10%	203	90%		226
35–44	38	16%	198	84%		236
45–54	51	19%	215	81%		266
55–64	62	24%	198	76%		260
65–74	34	18%	151	82%		185
> 75	18	25%	53	75%		71
Gender					0.97	
Women	126	18%	569	82%		695
Men	100	18%	449	82%		549
Education					0.23	
< French high school certificate	93	21%	359	79%		452
French high school certificate	34	16%	181	84%		215
> French high school certificate	99	17%	478	83%		577
Occupational activity					0.92	
No	90	18%	409	82%		499
Yes	136	18%	609	82%		745
Homeownership					0.68	
Owner	159	18%	714	82%		873
Renter	60	18%	282	82%		342
Free accommodation	7	24%	22	76%		29
Economic dependency on airport activities					0.87	
No	203	18%	918	82%		1121
Yes	23	19%	100	81%		123
Use of the noise source					0.10	
Never	69	20%	271	80%		340
Rarely	29	13%	195	87%		224
One time a year	80	20%	320	80%		400
Several times a year	48	17%	232	83%		280
Situational factors						
Type of housing					0.18	
Apartment	73	16%	377	84%		450
House	153	19%	641	81%		794
Outdoor spaces					0.94	
No	23	18%	102	82%		125
Yes	203	18%	916	82%		1119
Windows or roof insulation					0.45	
No	19	21%	71	79%		90
Yes	207	18%	946	82%		1153
Expectations regarding the quality of life in the neighbourhood					< 0.001	
Optimistic	12	14%	73	86%		85
No idea and not annoyed by air pollution	19	12%	144	88%		163
Neutral and slightly annoyed by air pollution	53	10%	458	90%		511
Pessimistic and moderately or very annoyed by air pollution	115	27%	315	73%		430
Pessimistic and extremely annoyed by air pollution	27	49%	28	51%		55
Personal and attitudinal factors						
Noise sensitivity (compared to others)					< 0.001	
Much less sensitive	1	2%	46	98%		47
Less sensitive	42	19%	184	81%		226
As sensitive	98	17%	495	83%		593
More sensitive	53	19%	226	81%		279
Much more sensitive	32	36%	58	64%		90
Fear of a plane crash					< 0.001	
Never	63	11%	533	89%		596
Sometimes	115	23%	381	77%		496
A lot	48	32%	104	68%		152

and M1 models predicted 27% and 22% respectively. The new EU standard curve predicted 36% of HA (see Fig. 1).

The M0 exposure–response relationship deriving from the DEBATS study (M0 model adjusted only on noise exposure levels) lead to % HA similar to those of the old EU curve, but for much lower noise exposure levels i.e differences ranging from 5.5 to 13.5 dB(A) (with a median difference of 7.7 dB(A)). Conversely, this M0 exposure–response relationship lead to %HA similar to those of the new EU curve, but for higher noise exposure levels i.e. differences ranging from 2.8 to 9.3 dB (A) (median difference of 8.0 dB(A)). These differences were lower

Table 4
Odds Ratios (ORs) and 95% confidence interval (CI) for severe annoyance (HA) in relation to aircraft noise exposure (L_{den}) and non-acoustical factors.

	Annoyance due to aircraft noise	
	M0 model (n = 1244)	M1 model (n = 1234)
	OR (95% CI)	OR (95% CI)
Noise level		
L_{den} [a]	**3.04 (2.30–4.02)**	**2.80 (2.05–3.83)**
Demographic / socio-economic characteristics		
Age	–	**1.02 (1.00–1.03)**
Gender		
Women	–	1.00
Men	–	1.29 (0.92–1.80)
Education		
< French high school certificate	–	1.00
French high school certificate	–	0.77 (0.47–1.26)
> French high school certificate	–	0.92 (0.62–1.36)
Occupational activity		
No	–	1.00
Yes	–	1.35 (0.91–2.00)
Homeownership		
Owner	–	1.00
Renter	–	1.43 (0.89–2.29)
Free accommodation	–	1.85 (0.71–4.81)
Economic dependency on airport activities		
No	–	1.00
Yes	–	1.05 (0.60–1.84)
Use of the noise source		
Never	–	1.00
Rarely	–	0.57 (0.33–0.99)
One time a year	–	1.06 (0.69–1.61)
Several times a year	–	0.87 (0.53–1.44)
Situational factors		
Type of housing		
Apartment	–	1.00
House	–	1.28 (0.82–2.00)
Outdoor spaces		
No	–	1.00
Yes	–	1.04 (0.56–1.92)
Windows or roof insulation		
No	–	1.00
Yes	–	0.85 (0.45–1.58)
Satisfaction with the living environment	–	**0.94 (0.88–1.00)**
Expectations regarding the quality of life in the neighbourhood		
Optimistic	–	1.00
No idea and not annoyed by air pollution	–	0.99 (0.43–2.29)
Neutral and slightly annoyed by air pollution	–	0.86 (0.41–1.78)
Pessimistic and moderately or very annoyed by air pollution	–	2.00 (0.99–4.06)
Pessimistic and extremely annoyed by air pollution	–	**5.17 (2.08–12.85)**
Personal and attitudinal factors		
Noise sensitivity (compared to others)		
Much less sensitive	–	**0.10 (0.01–0.80)**
Less sensitive	–	1.00 (0.64–1.56)
As sensitive	–	1.00
More sensitive	–	1.02 (0.67–1.55)
Much more sensitive	–	**2.30 (1.30–4.08)**
Fear of a plane crash		
Never	–	1.00
Sometimes	–	**1.92 (1.33–2.78)**
A lot	–	**1.94 (1.17–3.22)**
Source- and authority-related attitudes	–	**0.82 (0.77–0.88)**

OR: Odds-ratio.
CI: Confidence interval.
[a] Per 10 dB(A) increase.

(median difference of 3.4 dB(A)) when M0 model is compared to M1 model (adjusted for noise exposure levels and non-acoustical factors).

In sensitivity analyses, the exposure–response relationship remained very similar for people between 45 and 70 years of age and for people who had resided at their address for at least 5 years (See Fig. 2).

4. Discussion

In total, 18% of the participants in the DEBATS study reported to be highly annoyed by aircraft noise. The protocol was very similar to the one of HYENA study that focused on similar outcomes in six European countries. In HYENA, 29% of the participants reported being highly annoyed during the day and 18% during the night. If we assumed, as the authors did, that the overall annoyance (day + night) is mostly determined by the annoyance during the daytime (Babisch, 2009) or if we assumed that the annoyance in general would be somewhere between the two responses, the percentage of highly annoyed people was much lower in the DEBATS study than in the HYENA study. It should be noted that, while the DEBATS study involved participants aged 18 years and older, the HYENA study included residents aged 45–70 years only, which might have contributed to an increase in annoyance (Babisch, 2009). However, sensitivity analyses limited to people between 45 and 70 years of age in the DEBATS study led to a very similar exposure–response relationship. In addition, the two studies do not use the same annoyance scale: in the HYENA study, the numerical 11-point version of the ICBEN response scale was used to assess noise annoyance whereas the DEBATS study used the 5-point verbal scale. It has been shown that the annoyance scale used was an important source of heterogeneity in annoyance response (Janssen, 2011).

The exposure–response curve for %HA due to aircraft noise in the DEBATS study was higher than the curve of Miedema & Oudshoorn (called here old EU standard curve) (Miedema and Oudshoorn, 2001). One of the reasons provided by some authors to explain this increase in annoyance relates to the changing noise exposure situations around airports (Brooker, 2009; Gjestland, 2018; Janssen, 2011). While the noise emitted by each individual aircraft has been considerably reduced, residents are exposed to an increasing number of overflights, thus leading to steady aircraft noise levels in terms of L_{den}. Therefore, it is worth wondering whether energy-based indicators of exposure such as L_{den} remain the most relevant indicators to describe the relationships between aircraft noise exposure and noise annoyance. In health studies, it is currently recommended to consider event-related indicators such as the number of noise events or the number of events exceeding a certain LAmax level (the maximum A-weighted sound pressure level), especially for the night period regarding the effects of aircraft noise on sleep quality (Lekaviciute et al., 2013). Indeed, previous studies on noise annoyance have shown that the number of noise events was strongly correlated with noise annoyance (Quehl and Basner, 2006). Unfortunately, these indicators are not routinely produced in France (Evrard et al., 2012) because they require measurement campaigns to be carried out. However, such indicators are available for a subsample of 100 participants in the DEBATS study for whom acoustic measurements were performed at home for one week in parallel with objective measurements of sleep quality (Nassur, 2019). Furthermore, as some airports experience abrupt changes in traffic resulting for instance from the opening of a new runway or from the introduction of new flight procedures, some authors have classified airports as “high-rate change or low-rate change” airports. They have showed a higher prevalence of highly annoyed people near high-rate change airports than around low-rate change airports. It is very unlikely that this difference explains the increase in annoyance observed in the DEBATS study compared to the old EU standard curve. Indeed, as the number of movements tended to decrease over the last ten years, Paris-Charles de Gaulle and Lyon-Saint Exupéry airports could be considered as low-rate change airports. On the contrary, Toulouse-Blagnac airport could be classified as “high-rate change” airport as the number of movements rather increased and as

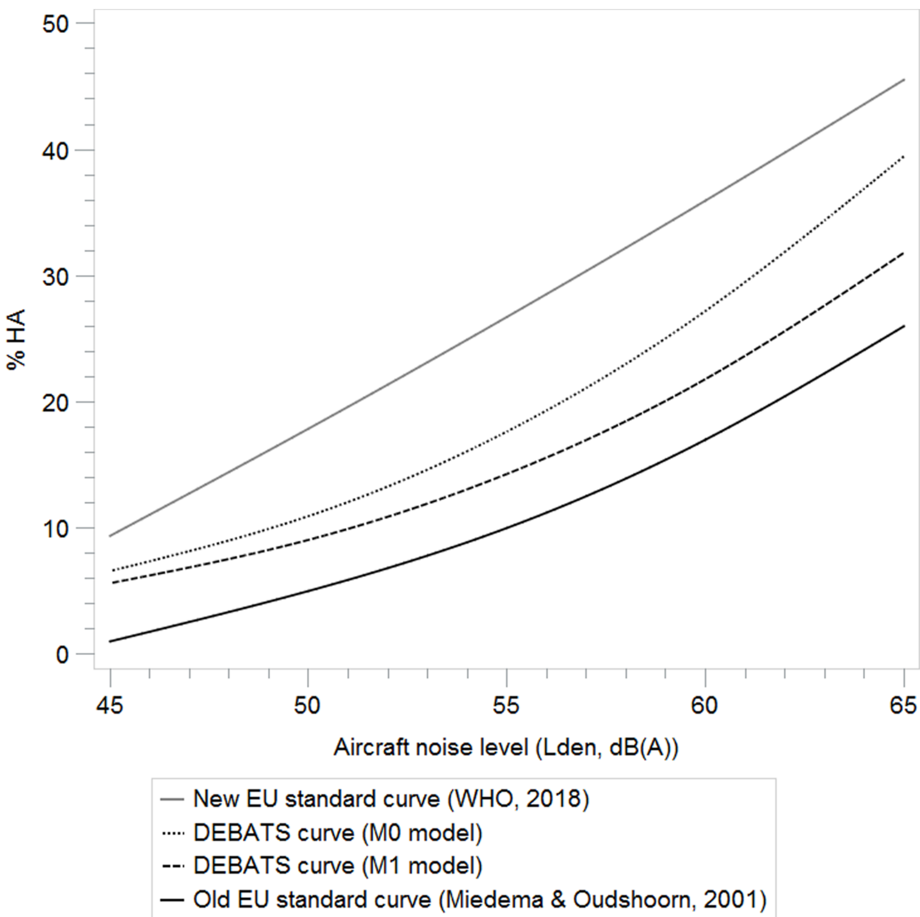

Fig. 1. Exposure-response relationships between aircraft noise exposure and severe annoyance due to aircraft noise (HA): comparison between DEBATS and old and new EU standard curves. HA: Highly annoyed. M0: adjusted on aircraft noise exposure only (in terms of L_{den}). M1: adjusted on aircraft noise exposure and non-acoustical factors (age, gender, education, occupational activity, home-ownership, economical dependency on airport activities, use of the source of noise, noise sensitivity, fear of a plane crash, type of housing, presence of outdoor spaces, windows or roof insulation, satisfaction with the living environment, source- and authority-related attitudes of people regarding aircraft noise concerns, and expectation regarding the quality of life in the neighbourhood). This curve was generated for a population with a mean age of 51 years, 56% of women, 64% of participants with at least the French high school certificate, 60% of participants with an occupational activity, 70% of home owners among the participants, 10% of participants economically dependent on airport activities, 73% of participants making either low, moderate or high use of the source of noise versus no use at all, a mean noise sensitivity of 2.91 on numeric converted scale, a mean fear of a plane crash of 2.36 on numeric converted scale, 64% of participants living in a house, 90% of participants with outdoor spaces besides their home, 93% of participants with at least windows or roof insulation, a mean score of 5.83 for satisfaction with the living environment, a mean score of 9.01 for source- and authority-related attitudes of people regarding aircraft noise concerns, and 61% proportion of participants considered to be optimistic, neutral or without opinion versus pessimistic for expectation regarding the quality of life in the neighbourhood.

there were serious concerns about the prospects for traffic growth among the residents in the years prior to the acquisition by a Chinese consortium in 2015. However, the exposure–response relationships estimated for Paris-Charles de Gaulle and Lyon-Saint Exupéry airports on the one hand and for Toulouse-Blagnac airport on the other hand are both above the old EU standard curve (results not shown).

Another explanation put forward for this increase of annoyance over the years relates to differences in study or sample characteristics (Brooker, 2009; Gjestland, 2018; Janssen, 2011). The type of contact, the response rate and the annoyance scale used in particular could explain the trend in annoyance. Postal surveys showed higher annoyance prevalence than telephone or face-to-face surveys. Using the numerical 11-point version of the ICBEN response scale to assess noise annoyance may be associated with higher annoyance, compared to using the 5-point verbal scale (Janssen, 2011). However, neither of these factors could explain the results of the present study because the questionnaire was administered by a face-to-face interviewer and the 5-point verbal scale was used to assess noise annoyance. The inclusion of a second non-verbal question would have been interesting to compare and confirm our results but it was not possible as the questionnaire was already too long. Higher annoyance rates were also observed in surveys with lower response percentages. It cannot be ruled out that this explains the results of the present study because although the participation rate in the DEBATS study (30%) was similar to aircraft noise studies completed in Germany, Italy and in the UK as part of the HYENA study (30%), it was not so high compared to those of another study in Germany (61%) (Schreckenberg and Meis, 2007) or in Vietnam (84%) (Nguyen et al., 2012).

Selection bias cannot be excluded in the present study. Only minor differences were found between the characteristics of the participants and those of the people who refused to participate but responded to a short questionnaire, particularly in regards to their age and their socio-occupational category. However, these non-participants were not representative of all people who refused to participate, just as the study population was not fully representative of all people living near an airport in France. Nevertheless, due to insufficient information, it was not possible to characterize this latter population. In addition, the response rate, as in many recent studies, is low and might be a source of bias with those most annoyed by aircraft noise being more prone to participate in the study. But one of the strengths of this study is that participants were not informed of the specific purpose of the study before filling out the questionnaire. If participants were able to find out the real purpose of the study, it would be when the questions on non-acoustic factors appeared, well after the question on annoyance due to aircraft noise. This question appeared at the beginning of the questionnaire, just after the section on socio-demographic characteristics.

We compare two exposure–response models (with and without non-acoustic predictors) for %HA due to aircraft noise in the DEBATS study with the curve of Miedema & Oudshoorn (Miedema and Oudshoorn, 2001) (called here old EU standard curve) and with the recent WHO curve (World health Organization, 2018) (called here new EU standard curve). One concern may be that the curves are based on slightly different definitions of HA. Miedema & Oudshoorn (Miedema and Oudshoorn, 2001) defined an annoyance response as high when the annoyance rating score belongs to the upper 28% of the response scale (i.e. the cut-off value for HA is 72 on a 100-point scale) (Miedema and Oudshoorn, 2001). The WHO curves also follow this definition of HA (World health Organization, 2018). Here, we follow the ICBEN HA definition (Fields, 2001), which means that people choosing the upper two categories of the ICBEN 5-point annoyance scale (4 = very, 5 = extremely) were defined as being highly annoyed. In fact, the upper two categories are the upper 40% of the 5-point response scale

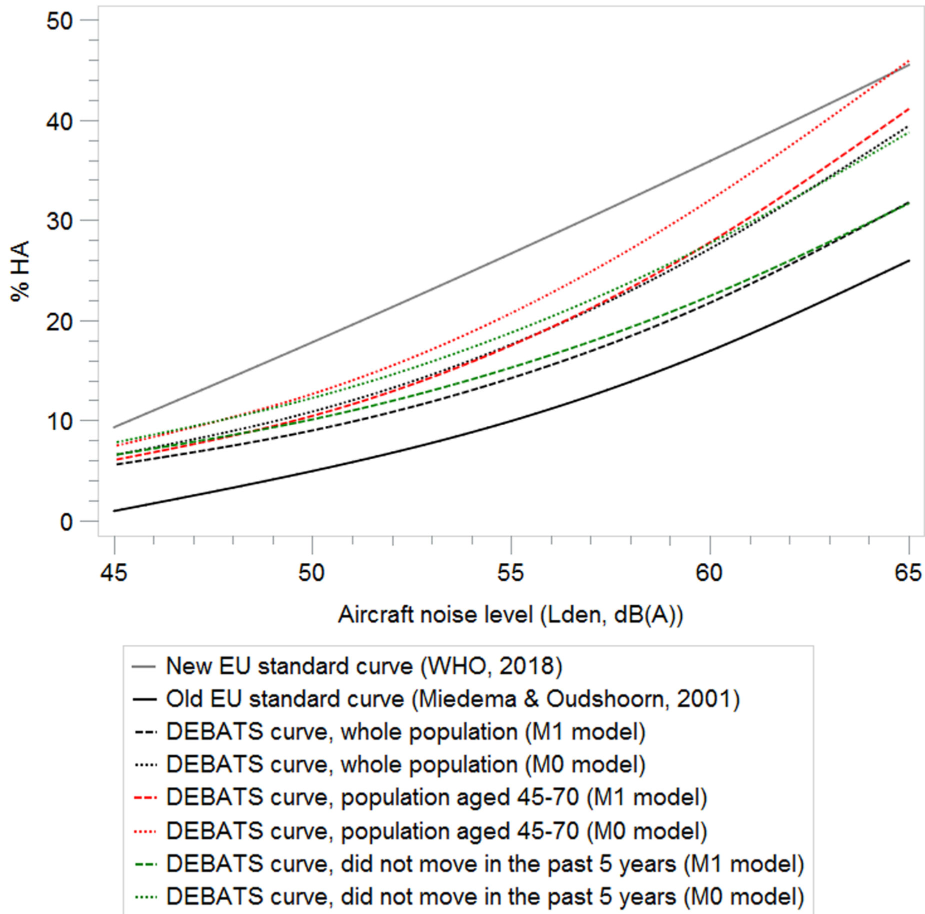

Fig. 2. Exposure-response relationships between aircraft noise exposure and severe annoyance due to aircraft noise (HA) for people between 45 and 70 years of age and for people who had resided at their address for at least 5 years.

(cut-off value = 60). Therefore, the probability of being considered as highly annoyed was higher in the DEBATS study than in the re-analysis of Miedema & Oudshoorn. Therefore, in order to check what would happen with only 40% of the participants choosing 4 = very annoyed considered as HA, we performed a simulation using 1000 datasets. Each dataset contains 1244 participants including: 40 participants always considered as HA (i.e. those choosing 5 = extremely on ICBEN annoyance scale), 1018 participants never considered as HA but as not HA (i.e. those choosing 1 = not at all, 2 = slightly or 3 = moderately on ICBEN annoyance scale), and 40% (n = 74) of the remaining participants (i.e. those choosing 4 = very on ICBEN annoyance scale) were randomly selected to be considered as HA while the 60% (n = 112) remaining participants were considered as not HA. We then performed the univariate (M0) and multivariate (M1) logistic regression models on each simulated dataset. The median of the 1000 logistic regression coefficients obtained from the 1000 simulated datasets was used to estimate %HA by noise level. Both curves were not above the Miedema & Oudshoorn curve. Thus, we cannot rule out that methodological differences in the HA assessment may be the reason for changes in annoyance over the years. However, it seems to us that the debate is not over as to the best way to compare the results of studies using the verbal or the numerical scale for noise annoyance. We have chosen to leave in the Results the curves obtained from the original DEBATS dataset, based on the responses to the ICBEN 5-point verbal scale. Otherwise, this would challenge the ICBEN verbal scale and therefore what the participants reported. Consistent with this ICBEN verbal scale, we consider that those who responded "very" annoyed can legitimately be considered as highly annoyed. Indeed, ICBEN had good reasons for the HA definition, the first being to provide an additional response choice for participants who tend not to choose the extreme response modalities. In addition, the meaning of "extremely" and "very" in all languages is clear and also includes such words as "considerably", "substantially", and "importantly", thus allowing for the identification of degrees of annoyance that cannot be considered moderate (Fields, 2001). Using the ICBEN verbal scale in the questionnaire to assess participants' annoyance and then classifying those who respond "very" randomly as either highly annoyed or not would call into question their response to satisfy methodological considerations. Fields et al. themselves acknowledge that the choice of a verbal scale is based on better understanding and communication with participants, policy makers and readers, whereas the choice of a numeric scale is mainly made to meet statistical requirements (Fields, 2001). We suggest in the future to no longer use HA definitions with arbitrary cut-offs without any content-related substance. Instead, we argue for a definition of HA derived substantially (with very + extremely = highly annoyed) as recommended by ICBEN (Fields, 2001). The consequence is that, according to ICBEN, people are therefore more likely to be considered as highly annoyed, but it also means that people who consider themselves very or extremely annoyed should be taken seriously.

This study also investigates whether non-acoustical characteristics of the population may explain the variability in aircraft noise annoyance response. The results suggest that annoyance is determined partly by acoustical factors and partly by personal, attitudinal and situational characteristics such as noise sensitivity, residential satisfaction or environmental expectations. The relevance of non-acoustical factors on noise annoyance has been demonstrated in a large number of empirical research. In relation to noise annoyance, the literature indicates that only 30 percent of the variability in ratings can be explained by noise exposure level. The remaining variability is likely to be partly (at least 30%) explained by a collection of multiple individual variables such as age (Van Gerven, 2009), noise source and attitude to the noise source (Fields, 1993; Guski, 1999; Maris, 2007), personality (Belojevic et al., 2003; Guski, 1999), and noise sensitivity (Guski, 1999; Okokon, 2015; Paunovic, 2011; van Kamp, 2004). This study confirms the association between severe annoyance and some non-acoustical factors such as noise sensitivity, satisfaction and expectations regarding the living environment, and attitude to the noise source. Age was the only demographic characteristic that has been found to be (positively) associated with severe annoyance. None of the socio-economic characteristics (occupational activity, homeownership, economic dependency on airport activities, and use of the noise source) studied or of the housing factors were associated with severe annoyance. Since the main objective of the DEBATS study was to evaluate the relationships between aircraft noise exposure and the health status of populations living near airports (sleep disturbance, cardiovascular effects, psychological ill health and annoyance), it was not possible to focus the questionnaire on all non-acoustical factors possibly related to annoyance. Noise sensitivity in particular could have been determined in more details, with a specific and validated questionnaire such as the Weinstein scale (Weinstein, 1978) or the Schütte NoiSeQ (Schütte, 2007). However, such a questionnaire was too long to be used in this study. Nevertheless, the assessment of extensive covariates made it possible to evaluate the association between annoyance due to aircraft noise and a large number of possible confounding factors and co-determinants of noise annoyance.

An important elaboration of this paper was to estimate a model of aircraft noise annoyance based on theory that includes non-acoustical and acoustical variables. Although the physical level of noise exposure could predict community noise annoyance, it could not account for the individual variability in noise annoyance. We can so reasonably think that the predictions of severe annoyance (HA) based on acoustical and non-acoustical factors is certainly more sophisticated and better suited for our population than both the old and new EU reference models. If the relevance of non-acoustical factors in relation to noise annoyance were shown in this study/here, the causal pathway leading from noise exposure to noise annoyance is still complex and undetermined. The evidence related to the influence of non-acoustical factors on noise annoyance is based on the assumption that these factors cause noise annoyance and not the other way around. For structural variables such as age and sex, the direction of causation is evident. However, the direction of the relation between social or psychological variables and noise annoyance, which are both subjective in nature, are difficult to distinguish. This could suggest that noise annoyance is partly due to non-acoustical factors acting like moderating variables in the relation between aircraft noise annoyance and noise exposure.

The results of the DEBATS study are significant with regard to the applicability of generalized exposure–response relations in the prediction of the annoyance response. They provide a basis for decisions on whether these need to be updated. In view of our results, it seems attractive to consider some individual factors as public tools to reduce general aircraft noise annoyance in conjunction with noise abatement programs. For example, expectations regarding the quality of life in the neighbourhood was associated with severe annoyance. The more satisfied the participants, the less they reported to be severely annoyed by aircraft noise. Thus, implementing territorial planning and development policies that would allow to have a better quality of life in their neighbourhood could reduce this annoyance.

5. Conclusions

The results of the DEBATS study provide further evidence that community annoyance due to aircraft noise has significantly increased over the past decades and indicate that the old EU standard curve presented by Miedema and Oudshoorn in 2001 had to be updated. This was done in March 2020 with the revision of the Annex III of the EU Directive 2002/49 based on the recent WHO curves (Official Journal of the European Union, 2020). Neither changing noise exposure situations around airports nor study population characteristics seem to explain this increase in annoyance responses. However, it cannot be ruled out that methodological differences in the HA assessment may be the reason for changes in annoyance over the years. For this reason, we argue for a definition of HA derived substantially as recommended by ICBEN. The results of the DEBATS study also highlight the relevance of a number of non-acoustical factors in relation to aircraft noise annoyance, and the need to take them into account in the prediction models. Furthermore, as two recent studies have shown (Haubrich et al., 2019; Spilski et al., 2019), analyses should be undertaken on additional relevant noise indicators such as event-related indicators that could be introduced in the dose–response relationships. Finally, the results highlighted in this first survey have yet to be confirmed by the upcoming longitudinal analysis of the annoyance responses to noise based on the data collected in the DEBATS three-wave survey carried out first in 2013, then in 2015 and finally in 2017.

CRediT authorship contribution statement

Marie Lefèvre: Data curation, Formal analysis, Investigation, Writing - original draft. **Agnès Chaumond:** Formal analysis. **Patricia Champelovier:** Methodology. **Lise Giorgis Allemand:** Formal analysis. **Jacques Lambert:** Methodology, Writing - original draft. **Bernard Laumon:** Funding acquisition, Supervision. **Anne-Sophie Evrard:** Funding acquisition, Investigation, Methodology, Project administration, Supervision, Writing - original draft.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Author contributions

Data curation, Marie Lefèvre; Formal analysis, Marie Lefèvre, Agnès Chaumond and Lise Giorgis Allemand; Funding acquisition, Anne-Sophie Evrard and Bernard Laumon; Investigation, Marie Lefèvre and Anne-Sophie Evrard; Methodology, Patricia Champelovier, Jacques Lambert, Bernard Laumon and Anne-Sophie Evrard; Project administration, Anne-Sophie Evrard; Supervision, Bernard Laumon and Anne-Sophie Evrard; Writing – original draft, Marie Lefèvre, Jacques Lambert and Anne-Sophie Evrard.

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Declaration of Competing Interest

None.

Ethics approval

Two national authorities in France, the French Advisory Committee for Data Processing in Health Research and the French National Commission for Data Protection and the Liberties approved the present study.

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