The role of aircraft noise annoyance and noise sensitivity in the association between aircraft noise exposure and saliva cortisol levels

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ABSTRACT

The HYDE study combined HYENA (HYpertension and Exposure to Noise near Airports) and DEBATS (Discussion on the health effects of aircraft noise) datasets. It previously showed significant associations between aircraft noise levels and cortisol outcomes in women, but not in men. The present study aims to assess the role of aircraft noise annoyance and noise sensitivity in these latter associations. Cortisol levels were determined in saliva samples, provided for 439 and 954 participants in HYENA and DEBATS respectively. Information on demographic and lifestyle factors, aircraft noise annoyance, and noise sensitivity was collected during a face-to-face interview. After adjustment for aircraft noise annoyance or noise sensitivity, previous results were unchanged. However, associations between aircraft noise levels and cortisol outcomes tended to be stronger in participants highly annoyed or highly sensitive to noise, showing a flattening in the (absolute and relative) variations per hour in cortisol levels with higher noise levels. These results suggest a modifying effect of annoyance and of noise sensitivity in the association between aircraft noise levels and cortisol outcomes. Nevertheless, they need to be confirmed.

INTRODUCTION

Impacts of aircraft noise exposure on human health are of growing concern, and several adverse effects have been highlighted such as annoyance, sleep disturbance, and cardiovascular disease including hypertension [1–7]. The release of stress hormones with noise exposure has been proposed as biological mechanism between exposure and health outcomes [8, 9]. Cortisol hormone, easy to measure non-invasively, can be viewed as a stress indicator [10], and its concentration can be used to assess the effects of chronic stress due to noise exposure [11].

Only two studies have found significant associations between transportation noise exposure (including aircraft noise) and cortisol levels in adults, towards increases in morning or evening concentrations [12–14].

In previous studies, aircraft noise annoyance and sensitivity to noise have been shown to moderate and/or mediate the relationships between aircraft noise levels and psychological ill-health [15, 16], medication use [17], hypertension [18], and self-rated health [19] in people living near airports. However, the role of aircraft noise annoyance and noise sensitivity in the relationship between aircraft noise exposure and cortisol levels has never been studied. The present study therefore proposes to investigate this role using the HYDE (**HY**ENA + **DE**BATS) dataset, which combines the two main cortisol studies to date in adults exposed to aircraft noise (HYENA (HYpertension and Exposure to Noise near Airports) [20] and DEBATS (Discussion on the health effects of aircraft noise) [4]).

METHODS

Study Population

The HYENA study included randomly-selected 4,861 participants between 45-70 years of age at the time of the interview and living near one of the seven major European airports [London Heathrow (United Kingdom), Berlin Tegel (Germany), Amsterdam Schiphol (the Netherlands), Stockholm Arlanda and Bromma (Sweden), Milan Malpensa (Italy), and Athens Eleftherios Venizelos (Greece) Airports]. Then, nearly 500 participants with the highest and lowest levels of exposure to aircraft noise in each country were selected for saliva sampling. Among them, 439 participants had complete information on their cortisol levels.

The DEBATS study included randomly-selected 1,244 participants over 18 years of age at the time of the interview and living near one of three major French airports (Paris-Charles de Gaulle, Lyon-Saint-Exupéry and Toulouse-Blagnac). Among them, 1,199 participants had complete information on their cortisol levels.

Participants from both studies responded to a similar questionnaire administered by an interviewer at their place of residence. The questionnaire collected in particular demographic and socio-economic information, lifestyle factors such as smoking and alcohol consumption, and personal medical history.

The final pooled analyses were carried out on N = 1,300 participants (359 from HYENA and 941 from DEBATS, including 555 men and 745 women) who had completed information for all the covariates included in the final model.

Cortisol measurements

All the participants received a kit with test tubes and instructions. Participants were asked to collect a saliva sample 30 minutes in HYENA (usually corresponding to the peak in cortisol concentration) or immediately in DEBATS, after awakening, and another one just before going to bed in the evening (which usually coincides with the nadir in cortisol concentration).

Cortisol levels were then determined with the Spectria cortisol coated tube radioimmunoassay kit (Orion Diagnostica, Espoo, Finland) in HYENA, and with the cortisol saliva ELISA kit in DEBATS (IBL international, Hamburg, Germany).

Aircraft noise exposure assessment

Exposure to aircraft noise was estimated with a 1-dB(A) resolution at the place of residence of the participants, in front of their buildings, and were provided by the INM (Integrated Noise Model) (10) for almost all the countries of the study. Only the UK used the national Aircraft Noise Contour Model (ANCON v 2) (11), similar to the INM model.

Four noise indicators were derived and used in the statistical analyses: L_{den}, L_{Aeq24h}, $L_{Aeq6h-22h}$, and L_{night}.

Annoyance due to aircraft noise

Aircraft noise annoyance was assessed using the ISO/Icben (International Commission on the Biological Effects of Noise) recommended question [21], both in HYENA and in DEBATS: “Thinking about the last 12 months when you are here at home, how much does aircraft noise bother, disturb or annoy you?”.

Using the standard verbal scale (extremely, very, moderately, slightly or not at all) in the DEBATS study, participants with the two highest categories were considered as being highly annoyed.

Using the standard numeric scale, an average score between night-time and daytime score (range 0-10) was calculated in the HYENA study, and participants with an average score ≥8 were considered as being highly annoyed.

Noise sensitivity

In DEBATS, a 5-point question was used: "Regarding noise in general, compared to people around you, do you think that you are: much less sensitive than, or less sensitive than, or as sensitive as, or more sensitive, or much more sensitive than people around you?".

In HYENA, a 6-rating question on sensitivity to noise (being part of the short-form of the Weinstein scale [22]) was used: “I am sensitive to noise” (from 1 to 6 - disagree to agree strongly). The score to this item was assimilated to the one in DEBATS as follows: 1 corresponds to "much less sensitive", 2 to "less sensitive", 3 and 4 to "as sensitive", 5 to "a little more sensitive" and 6 to " much more sensitive".

Confounders

The major potential confounding factors were obtained from the questionnaire, and a priori included in the models: country (seven categories), gender (dichotomous), age (continuous), body mass index (BMI, continuous), smoking habits (five categories: non-smoker; ex-smoker; 1-10 units/day; 11-20 units/day; >20 units/day), alcohol consumption (four categories: teetotaller; 1-7 units a week; 8-14 units/week; >14 units/week), physical activity (two categories: no or a little; regular), and education level (coded as quartiles of number of years in education previously standardized by country means).

Statistical analysis

Morning (C_1) and evening (C_2) cortisol levels were analysed separately (sampling at time T_1 and T_2 respectively).

As cortisol follows a circadian rhythm, an average relative-variation [REL=(C1-C2)/C1]/(|T1-T2|)] in cortisol per hour between both samplings was also investigated.

C1, C2, REL were log-transformed to compensate for a non-normal distribution, and their relationships with aircraft noise exposure were analyzed using linear regression models, adjusted for the confounding factors.

Statistical analyses were carried out for men and women separately, showing log-linear results e(β) as the multiplier to be applied to the considered cortisol outcome in order to get its expected value with a 10-dB(A) increase in noise level.

Results for the relationships between aircraft noise exposure and the cortisol outcomes adjusted for the confounding factors have been presented elsewhere [14] (see Appendix). In the following, we will refer to the model used to obtain these results as the M0 model.

According to Baron and Kenny's recommendations [23], we alternatively included aircraft noise annoyance (M1) or noise sensitivity (M2) in the M0 model to investigate the mediating role of aircraft noise annoyance and noise sensitivity, and compared the results from M1 and M2 with those from M0.

An interaction term between aircraft noise levels and aircraft noise annoyance (M3) or noise sensitivity (M4) was alternatively introduced in the M0 model to explore the moderating role of aircraft noise annoyance and noise sensitivity.

RESULTS

Table 1 shows the relationships between aircraft noise exposure and cortisol outcomes when aircraft noise annoyance (M1) or noise sensitivity (M2) were included alternatively in the M0 model. The results were similar to those presented for M0 (see Appendix).

Table 2 and Table 3 show the associations between aircraft noise exposure and cortisol outcomes for different levels of aircraft noise annoyance and noise sensitivity, respectively. A significant decrease in the relative variation of cortisol between morning and evening samples was found in men highly annoyed by aircraft noise, but not in those not highly annoyed, although the interaction was not significant. A significant decrease in the relative change in cortisol between morning and evening samples was also observed in women with medium sensitivity to noise, towards an increase in evening cortisol levels.

Table 1: Log-linear results for the relationship between a 10-dB(A) increase in aircraft noise exposure and cortisol outcomes[1], when including aircraft noise annoyance (M1) or noise sensitivity (M2) in the M0 model[1]

		MEN						WOMEN					
		C_1 (nmol.L^{-1})		**C_2 (nmol.L^{-1})**		**REL**		**C_1 (nmol.L^{-1})**		**C_2 (nmol.L^{-1})**		**REL**	
		e(β)	95%CI	e(β)	95%CI	e(β)	95%CI	e(β)	95%CI	e(β)	CI95%	e(β)	95%CI
M1	**$L_{Aeq.16h}$**	0.99	(0.93;1.07)	1.05	(0.96;1.14)	0.95	(0.88;1.02)	1.04	(0.97;1.10)	1.08	(1.00;1.16)	0.94	(0.87;1.00)
	$L_{Aeq.24h}$	0.99	(0.91;1.06)	1.04	(0.95;1.14)	0.94	(0.87;1.02)	1.05	(0.98;1.12)	1.08	(0.99;1.18)	0.94	(0.87;1.01)
	L_{den}	0.99	(0.92;1.07)	1.06	(0.96;1.15)	0.94	(0.87;1.02)	1.03	(0.96;1.10)	1.09	(1.00;1.18)	**0.92**	**(0.86;0.99)**
	L_{night}	1.01	(0.93;1.09)	1.07	(0.98;1.17)	0.93	(0.86;1.01)	1.00	(0.93;1.07)	**1.11**	**(1.02;1.2)**	**0.91**	**(0.85;0.98)**
M2	**$L_{Aeq.16h}$**	0.99	(0.92;1.06)	1.03	(0.95;1.12)	0.97	(0.90;1.04)	1.04	(0.98;1.11)	**1.08**	**(1.00;1.17)**	**0.92**	**(0.86;0.98)**
	$L_{Aeq.24h}$	0.98	(0.91;1.06)	1.02	(0.94;1.12)	0.96	(0.89;1.04)	1.06	(0.99;1.13)	**1.09**	**(1.00;1.18)**	**0.92**	**(0.85;0.99)**
	L_{den}	0.99	(0.92;1.07)	1.04	(0.95;1.13)	0.96	(0.89;1.04)	1.04	(0.97;1.11)	**1.09**	**(1.01;1.18)**	**0.91**	**(0.84;0.97)**
	L_{night}	1.00	(0.93;1.08)	1.05	(0.96;1.14)	0.95	(0.88;1.03)	1.01	(0.94;1.08)	**1.11**	**(1.02;1.20)**	**0.90**	**(0.83;0.96)**

[1] Adjusted for country, alcohol intake, smoking habits, physical activity, education level, age and BMI (statistically significant values in bold)

Table 2: Log-linear results for the relationship between a 10-dB(A) increase in aircraft noise exposure and cortisol outcomes[1], in highly (N_{men}=108; N_{women}=143) and not highly annoyed (N_{men}=447; N_{women}=601) participants

		MEN					WOMEN				
		Highly annoyed		Not highly annoyed		p_{inter}[2]	Highly annoyed		Not highly annoyed		p_{inter}[2]
		e(β)	95%CI	e(β)	95%CI		e(β)	95%CI	e(β)	95%CI	
C_1 (nmol.L^{-1})	**$L_{Aeq,16h}$**	0.88	(0.68;1.14)	0.99	(0.92;1.07)	1.00	1.05	(0.85;1.29)	1.04	(0.97;1.11)	0.88
	$L_{Aeq,24h}$	0.87	(0.66;1.15)	0.98	(0.90;1.06)	0.93	1.04	(0.84;1.28)	1.06	(0.98;1.14)	0.72
	L_{den}	0.91	(0.70;1.19)	0.99	(0.91;1.07)	0.71	1.03	(0.84;1.26)	1.04	(0.96;1.11)	0.81
	L_{night}	0.98	(0.76;1.27)	0.99	(0.91;1.08)	0.45	0.97	(0.79;1.18)	1.01	(0.94;1.08)	0.98
C_2 (nmol.L^{-1})	**$L_{Aeq,16h}$**	1.16	(0.88;1.51)	1.04	(0.95;1.14)	0.83	1.03	(0.77;1.37)	1.08	(1.00;1.17)	0.54
	$L_{Aeq,24h}$	1.21	(0.91;1.61)	1.03	(0.93;1.14)	0.61	1.01	(0.76;1.35)	1.09	(1.00;1.19)	0.46
	L_{den}	1.18	(0.90;1.54)	1.04	(0.94;1.15)	0.61	1.06	(0.80;1.40)	1.09	(1.00;1.19)	0.75
	L_{night}	1.15	(0.89;1.50)	1.06	(0.95;1.17)	0.36	1.12	(0.85;1.46)	**1.10**	**(1.01;1.20)**	0.62
REL	**$L_{Aeq,16h}$**	**0.79**	**(0.64;0.98)**	0.98	(0.90;1.06)	0.17	0.96	(0.74;1.25)	**0.93**	**(0.86;1.00)**	0.42
	$L_{Aeq,24h}$	**0.79**	**(0.63;0.99)**	0.97	(0.89;1.06)	0.24	0.96	(0.73;1.25)	0.93	(0.86;1.00)	0.42
	L_{den}	**0.78**	**(0.63;0.97)**	0.97	(0.89;1.06)	0.18	0.93	(0.72;1.21)	**0.92**	**(0.85;0.99)**	0.57
	L_{night}	**0.76**	**(0.62;0.94)**	0.97	(0.89;1.06)	0.15	0.88	(0.68;1.13)	**0.91**	**(0.84;0.98)**	0.73

[1] Adjusted for country, alcohol intake, smoking habits, physical activity, education level, age and BMI (statistically significant values in bold)

[2] p(inter): p-value for the interaction between noise levels and aircraft noise annoyance

Table 3: Log-linear results for the relationship between a 10-dB(A) increase in aircraft noise exposure and cortisol outcomes[1], in highly (N_{men}=163; N_{women}=271), medium (N_{men}=242; N_{women}=312), and not highly sensitive (N_{men}=145; N_{women}=159)

		MEN							WOMEN						
		Highly sensitive		Medium sensitive		Not highly sensitive		p_{inter}[2]	Highly sensitive		Medium sensitive		Not highly sensitive		p_{inter}[2]
		e(β)	95%CI	e(β)	95%CI	e(β)	95%CI		e(β)	95%CI	e(β)	95%CI	e(β)	95%CI	
C_1 (nmol.L^{-1})	**$L_{Aeq.16h}$**	1.03	(0.90;1.18)	0.93	(0.83;1.04)	1.06	(0.90;1.24)	0.97	1.03	(0.92;1.14)	1.06	(0.95;1.17)	**1.15**	**(1.01;1.32)**	0.43
	$L_{Aeq.24h}$	1.00	(0.87;1.16)	0.92	(0.82;1.04)	1.06	(0.90;1.26)	0.79	1.04	(0.93;1.16)	1.08	(0.96;1.21)	**1.17**	**(1.01;1.34)**	0.46
	L_{den}	1.03	(0.89;1.19)	0.92	(0.82;1.04)	1.07	(0.90;1.28)	0.99	1.02	(0.91;1.14)	1.06	(0.95;1.18)	1.15	(1.00;1.33)	0.40
	L_{night}	1.12	(0.97;1.28)	0.92	(0.82;1.02)	1.05	(0.87;1.26)	0.28	0.96	(0.86;1.08)	1.02	(0.92;1.13)	1.15	(0.99;1.34)	0.17
C_2 (nmol.L^{-1})	**$L_{Aeq.16h}$**	1.12	(0.96;1.29)	1.03	(0.90;1.19)	1.00	(0.85;1.18)	0.14	1.05	(0.93;1.19)	**1.15**	**(1.00;1.31)**	1.14	(0.98;1.32)	0.86
	$L_{Aeq.24h}$	1.13	(0.96;1.32)	1.01	(0.86;1.18)	1.00	(0.84;1.20)	0.12	1.04	(0.91;1.20)	**1.17**	**(1.01;1.36)**	1.15	(0.99;1.35)	0.99
	L_{den}	1.15	(0.98;1.34)	1.03	(0.89;1.19)	1.00	(0.83;1.20)	0.10	1.05	(0.92;1.20)	**1.18**	**(1.02;1.35)**	1.13	(0.96;1.32)	0.89
	L_{night}	1.17	(1.00;1.36)	1.04	(0.90;1.20)	0.97	(0.80;1.18)	0.10	1.09	(0.95;1.24)	**1.17**	**(1.02;1.33)**	1.11	(0.94;1.31)	0.89
REL	**$L_{Aeq.16h}$**	0.94	(0.82;1.08)	0.89	(0.79;1.00)	1.02	(0.89;1.17)	0.54	0.95	(0.86;1.04)	**0.85**	**(0.76;0.95)**	1.01	(0.86;1.19)	0.63
	$L_{Aeq.24h}$	0.92	(0.79;1.06)	0.9	(0.79;1.02)	1.02	(0.88;1.18)	0.39	0.95	(0.85;1.05)	**0.84**	**(0.74;0.95)**	1.01	(0.85;1.20)	0.60
	L_{den}	0.91	(0.79;1.06)	0.89	(0.79;1.01)	1.04	(0.89;1.22)	0.32	0.94	(0.85;1.04)	**0.83**	**(0.74;0.94)**	1.01	(0.84;1.20)	0.60
	L_{night}	0.91	(0.78;1.05)	**0.87**	**(0.77;0.98)**	1.09	(0.93;1.29)	0.38	0.91	(0.82;1.01)	**0.84**	**(0.75;0.94)**	1.01	(0.84;1.21)	0.43

[1] Adjusted for country, alcohol intake, smoking habits, physical activity, education level, age and BMI (statistically significant values in bold)

[2] p(inter): p-value for the interaction between noise levels and noise sensitivity

DISCUSSION

This study was the first to investigate the mediating and moderating role of aircraft noise annoyance and noise sensitivity in the relationship between aircraft noise exposure and cortisol levels, which can be considered as a bioindicator of stress. The HYENA and DEBATS studies analysed separately had already shown significant associations between aircraft noise exposure and cortisol outcomes [13, 14], towards higher cortisol levels in the evening and a flattening of the usual relative variation per hour.

The present study did not show any mediating effects, neither by aircraft noise annoyance nor by noise sensitivity. In contrast, a moderating effect of aircraft noise annoyance was found in men, whereas a moderating effect of noise sensitivity was shown in women. However, interaction tests between aircraft noise exposure and aircraft noise annoyance or noise sensitivity were not significant. This may be due to the small number of people included in the different categories of annoyance or noise sensitivity, for both genders separately.

The results presented in this paper are based on the Baron and Kenny's recommendations [23]. They need to be improved with statistical tools more adapted to mediation and moderation analyses.

OTHER IMPORTANT INFORMATION

Acknowledgements

For HYENA study: Thanks to Lars Jarup, HYENA principal investigator, and other members of the HYENA study team responsible for conducting the study. Thanks to the aviation administration and the road administration in each of the participating countries for their contribution to the noise exposure assessment.

For DEBATS study: Thanks to the Airport Pollution Control Authority (Acnusa) for requesting the Gustave Eiffel University (the former French Institute of Science and Technology for Transport, Development and Networks, ex Ifsttar) to carry out this study; thanks to Paris Airports and the French Civil Aviation Authority for providing noise exposure maps.

The authors are grateful to all the participants in both HYENA and DEBATS studies and their interviewers.

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APPENDIX

Table S1: Log-linear results for the relationship between a 10-dB(A)-increase in aircraft noise exposure and cortisol outcomes[1]

	MEN						**WOMEN**					
	C_1 (nmol.L^{-1})		**C_2 (nmol.L^{-1})**		**REL**		**C_1 (nmol.L^{-1})**		**C_2 (nmol.L^{-1})**		**REL**	
	e(β)	95%CI	e(β)	95%CI	e(β)	95%CI	e(β)	95%CI	e(β)	95%CI	e(β)	95%CI
$L_{Aeq,6h-22h}$	0.99	(0.92-1.06)	1.04	(0.95-1.12)	0.97	(0.90-1.04)	1.04	(0.98-1.10)	**1.08**	**(1.00-1.16)**	**0.92**	**(0.86-0.98)**
$L_{Aeq,24h}$	0.98	(0.91-1.05)	1.03	(0.94-1.12)	0.96	(0.89-1.04)	1.05	(0.98-1.12)	1.08	(1.00-1.17)	**0.92**	**(0.85-0.98)**
L_{den}	0.99	(0.92-1.06)	1.04	(0.95-1.14)	0.96	(0.89-1.04)	1.03	(0.97-1.10)	**1.09**	**(1.01-1.18)**	**0.90**	**(0.84-0.97)**
L_{night}	1.00	(0.93-1.08)	1.05	(0.97-1.15)	0.95	(0.88-1.02)	1.00	(0.94-1.07)	**1.11**	**(1.02-1.20)**	**0.89**	**(0.83-0.96)**

[1] Adjusted for country, alcohol intake, smoking habits, physical activity, education level, age and BMI (statistically significant values in bold)