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Annoyance to different noise sources is associated with atrial fibrillation in the Gutenberg Health Study

Omar Hahad [a], Manfred Beutel [b], Tommaso Gori [a], Andreas Schulz [c], Maria Blettner [d], Norbert Pfeiffer [e], Thomas Rostock [h], Karl Lackner [f], Mette Sørensen [g], Jürgen H. Prochaska [a], Philipp S. Wild [a], Thomas Münzel [a,*]

[a] *Center of Cardiology, Cardiology I, University Medical Center of the Johannes Gutenberg-University Mainz and DZHK Standort Rhein-Main, Mainz, Germany*
[b] *Department of Psychosomatic Medicine and Psychotherapy, University Medical Center of the Johannes Gutenberg-University Mainz, Germany*
[c] *Preventive Cardiology and Preventive Medicine, Department of Medicine II, University Medical Center of the Johannes Gutenberg-University Mainz, Germany*
[d] *Institute of Medical Biostatistics, Epidemiology & Informatics, University Medical Center of the Johannes Gutenberg-University Mainz, Germany*
[e] *Department of Ophthalmology, University Medical Center Mainz, Germany*
[f] *Institute of Clinical Chemistry and Laboratory Medicine, University Medical Center of the Johannes Gutenberg-University Mainz, Germany*
[g] *Danish Cancer Society Research Center, Copenhagen, Denmark*
[h] *Center of Cardiology, Cardiology I, University Medical Center of the Johannes Gutenberg University Mainz, Germany*

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ABSTRACT

Background: Annoyance is a common reaction in populations exposed to environmental noise and is associated with cardiovascular diseases. We investigated for the first time the existence of an association between noise annoyance and atrial fibrillation (AF).

Methods and results: Cross-sectional data from 14,639 participants of the Gutenberg Health Study were collected between 2007 and 2012. Annoyance from road traffic, aircraft, railways, industrial/construction and neighbourhood noise during daytime and sleep were collected from all participants through questionnaires using a 5-point scale. AF was assessed via self-reported medical history and/or documentation of AF on the study electrocardiogram. 80% of the study participants were annoyed by noise to a certain degree. The major sources of annoyance during daytime and sleep were aircraft, road traffic and neighbourhood noise. We found significant associations between annoyance (per point increase) and AF for aircraft noise annoyance during daytime (odds ratio (OR) 1.04; 95% confidence interval (CI) 1.00–1.08) and during sleep (OR 1.09; 95% CI 1.05–1.13), road traffic noise annoyance during sleep (OR 1.15; 95% CI 1.08–1.22), neighbourhood noise annoyance during daytime (OR 1.14; 95% CI 1.09–1.20) and during sleep (OR 1.14; 95% CI 1.07–1.21), industrial noise annoyance during daytime (OR 1.11; 95% CI 1.04–1.18) and railway noise annoyance during sleep (OR 1.13; 95% CI 1.04–1.22). Different degrees of annoyance were not associated with changes in cardiovascular risk factors.

Discussion: The results suggest for the first time that noise annoyance is associated with AF. Further studies are warranted to gain insight in the mechanisms underlying the noise-annoyance-disease relationship.

1. Introduction

The key message of the World Health Organization (WHO) report on the global assessment of the burden of disease from environmental risks is that "an estimated 12.6 million deaths each year are attributable to unhealthy environments, which mean that 23% of all global deaths are linked to the environment" [1]. Like other forms of pollution, environmental noise exposure belongs to environmental hazards and has an important role in their relationship with adverse health outcomes [2]. The WHO estimates that in Western European countries each year nearly 1 million disability-adjusted life years (DALYs) are lost due to noise exposure, while noise-induced annoyance accounts for 587,000 DALYs [3].

The noise and stress-reaction model proposed by Babisch describes two general pathways that may result in adverse health effects [4]. The direct pathway is characterised by the direct subcortical interaction between the central auditory system and other regions of the central nervous system in response to very high sound levels. The indirect/non-auditory pathway is mediated by the cognitive elaboration of the sound, followed by cortical activation resulting in emotional responses such as annoyance [5]. In this pathway, the negative perception of the sound acts as psychosocial stressor and activates self-regulatory mechanisms including the sympathetic and neuroendocrine system. The subsequent increases in blood pressure and heart rate, glucose and lipid levels and blood viscosity are some examples of the implications of this pathway [4]. In sum, noise acts at both with the cortical and

* Corresponding author at: University Medical Center Mainz of the Johannes Gutenberg-University, Center of Cardiology I, Langenbeckstraße 1, 55131 Mainz, Germany.
E-mail address: tmuenzel@uni-mainz.de (T. Münzel).

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subcortical level to induce cardiovascular diseases (CVD) [6,7]. Similarly, chronic stress per se has been shown to be associated with an increased risk of CVD [8,9].

Accordingly, annoyance was linked with an increase in risk of CVD [5,10,11], in particular arterial hypertension and ischemic heart disease. Also, we have previously shown noise annoyance to be strongly associated with depression and anxiety [12]. Since annoyance reflects emotional stress, an important risk factor for the development of AF [13], the aim of the present study was to examine the relationship between noise annoyance and AF in the population-based Gutenberg Health study (GHS) [14].

2. Methods

2.1. Study population

The study population included 15,010 participants of the GHS enrolled in the period from 2007 to 2012 at the University Medical Center of the Johannes Gutenberg-University Mainz, Germany. The rationale and design of the GHS have been published previously [14]. Briefly, the GHS is a population-based, single-center cohort study with an age range of 35 to 74 years and a proportion of 49% women. The aim of the GHS is to obtain extensive knowledge about etiology, pathogenesis and risk factors of common diseases. The study population includes the city of Mainz and the district of Mainz-Bingen. The random sample is stratified in equal strata for sex, residence and decades of age, study protocol and documents are approved by the local ethics committee of the Medical Chamber of Rhineland-Palatinate and the local data safety commissioner. Participants are included after informed consent, insufficient knowledge of German language, psychological or physical impairment with regard to participation are the only exclusion criteria. All study investigations are conducted in line with the Declaration of Helsinki and principles outlined in recommendations for Good Clinical Practice and Good Epidemiological Practice. Participants of the GHS undergo a 5-hour standardized baseline examination and comprehensive deep clinical phenotyping including collection of data on lifestyle information, exposure to environmental factors, psychosocial situation, cardiovascular risk factors (CVRFs), laboratory-chemical parameters and clinical data. All operations are performed by trained professionals and in accordance with standard operating procedures. The response to invitation is 60.3%. For the purposes of the present analyses, participants who did not provide complete information about exposure to noise were excluded.

2.2. Data assessment

2.2.1. Annoyance

The main exposure variable was noise annoyance as measured by questions in accordance with Felscher-Suhr, Guski and Schluemer [15]. On a 5-point scale from "not" to "extremely" participants were asked to rate "how annoyed have you been in the past years by …?" Here, noise annoyance resulting from road traffic, aircraft, railways, industrial/construction and neighbourhood were assessed "during the day" and "in your sleep".

2.3. Outcome

We defined AF as either previous diagnosis of AF and/or documentation of AF on the study electrocardiogram (ECG). History of AF was self-reported. Cardiac rhythm analysis was performed automatically (GE Healthcare, CardioSoft v6) and confirmed by at least two cardiologists. ECG-based diagnosis of AF was defined as absolutely irregular R peak intervals and an absence of P waves. Further methodological details have been described elsewhere [16].

2.4. Potential confounders

Selections of confounders were done a priori. Socioeconomic status (SES) was measured in accordance with Lampert and Kroll (score range 3 to 21 with higher values indicating higher SES), which combines information about educational background, current occupation and income [17]. Night shift work was considered as current or noncurrent. Depressive disorder was assessed using the Patient Health Questionnaire (PHQ-9). The questionnaire contains 9 questions (score range 0–27 with higher values indicating increased depressive symptom severity), which are based on diagnostic criteria of major depression from the Diagnostic and Statistical Manual of Mental Disorders. The caseness for depression was based on a PHQ-9 score of ≥10 [18]. Personal medication history was derived from baseline-screening and drug packaging. Diabetes mellitus was defined as self-reported history of diabetes, corresponding medical therapy, or fasting blood glucose ≥126 mg/dL or non-fasting blood glucose ≥200 mg/dL. Mean systolic blood pressure (≥140 mm Hg) or mean diastolic blood pressure (≥90 mm Hg) or use of antihypertensive medications was used for the diagnosis of hypertension. Never and former smokers were defined as nonsmokers and current smokers as smokers. Waist to hip ratio was used for the diagnosis of obesity following the WHO criteria [19]. Dyslipidemia diagnosis was based on present intake of lipid-modifying drugs or a LDL/HDL ratio > 3.5.

2.5. Statistical analysis

Discrete variables were presented as numbers and/or percentages and continuous variables were described by mean values ± standard deviation or median and interquartile range. According to Beutel et al. [12], noise annoyance was defined as the highest annoyance rating from any of the categories of noise, regardless of the specific noise source (aircraft, road traffic, railway, etc.) and time period (daytime or sleep). Source-specific combined daytime and sleep annoyance was defined as the highest annoyance rating during daytime and sleep due to each specific source. Logistic regression models were used to analyze the association between noise annoyance (per point) and AF in three models with increasing adjustment. Adjusted ORs are given with 95% CI and *p*-value.

Model 1: adjustment for age and sex

Model 2: further adjustment for SES, night shift work (yes/no) and depression (yes/no)

Model 3: further adjustment for medication use (antihypertensives, diuretics, beta-blockers, calcium channel blockers, agents acting on the renin-angiotensin-aldosterone system (RAAS), lipid modifying agents, diabetic drugs, antithrombotic agents-all yes/no), diabetes mellitus (yes/no), hypertension (yes/no), smoking (yes/no), obesity (yes/no), dyslipidemia (yes/no) and family history (FH) of MI/stroke (yes/no)

Model 3 is considered the most comprehensive model. Further, the introduction of a night flight ban by the Frankfurt Airport in October 2011 was considered as additional variable by comparing annoyance before and after October 2011 by using the Student's *t*-test. All tests were two-sided with a significance level of 5%. As we pursued an explorative design, no adjustments of *p*-values for multiple testing were done. Relevant *p*-values are highlighted in bold font and the expression "statistical significance" is used for descriptive reasons only. The statistical analyses were performed using the software R version 3.3.1 (R Core Team. R: A language and environment for statistical computing. R Foundation for Statistical Computing. Vienna, 2016. http://www.r-project.org/).

3. Results

Of the study cohort of 15,010 people, a total of 14,639 participants answered the questions about noise annoyance of whom 18% ($n = 2704$) had a diagnosis of AF (ECG documentation $n = 2297$, history of AF $n = 200$, both $n = 207$). The characteristics of this study population weighted for the age and sex distribution of the general population ($N = 210{,}867$; Statistisches Bundesamt, Wiesbaden 2011) and stratified by degree of total noise annoyance are summarized in Table 1.

About 80% of the study participants reported annoyance by noise (no: 20.7%, slight: 26.6%, moderate: 25.0%, strong: 17.3%, extreme: 10.5%). Compared to participants reporting no annoyance, participants who reported extreme annoyance had a higher prevalence of AF (14.6 vs. 23.4%, Fig. 2). The prevalence of depression increased steadily with the degree of total noise annoyance (6.1 to 11.6%). Midregional pro atrial natriuretic peptide (MR-proANP) levels tended to increase with the degree of total noise annoyance (65.7 to 71.5 pmol/L).

Blood pressure, heart rate and CVRFs were not modified by annoyance. Also no differences in cardiovascular medication and social variables were found.

Table 2 summarizes specific sources of noise annoyance (binary > 0) according to the degree of total noise annoyance during daytime and during sleep. On the total annoyance scale, 84% of the persons were extremely annoyed by aircraft noise during daytime (69% during sleep), whereas only 22% were extremely annoyed by railway noise (15% during sleep) (Fig. 1).

Table 3 (online only) displays the ORs and 95% CI for AF in relation to the five different sources of noise annoyance during daytime and during sleep. There were significant associations between aircraft, neighbourhood noise annoyance and AF after adjustment for age and sex, socioeconomic status, depression, nightshift work, CVRFs and medication (model 3) both during daytime (aircraft: OR 1.04, 95% CI 1.00–1.08; neighbourhood: OR 1.14, 95% CI 1.09–1.20) and during sleep (aircraft: OR 1.09, 95% CI 1.05–1.13; neighbourhood: OR 1.14, 95% CI 1.07–1.21).

Further, road traffic and railway noise annoyance during sleep (road traffic: OR 1.15, 95% CI 1.08–1.22; railway: OR 1.13, 95% CI 1.04–1.22) as well as industrial noise annoyance during daytime (OR 1.11; 95% CI 1.04–1.18) were significantly associated with AF (Table 3).

Associations of road traffic during daytime (OR 1.05; 95% CI 0.99–1.09) and industrial noise annoyance during sleep (OR 1.14; 95% CI 0.99–1.31) with AF showed borderline ($p < 0.10$) statistical significance. No significant association between railway noise annoyance and AF during daytime (OR 1.02; 95% CI 0.95–1.09) was found.

Table 4 (online only) displays the associations between source-specific combined daytime, sleep annoyance and AF. Significant associations between road traffic, aircraft, neighbourhood, industrial noise annoyance and AF were observed, while no association between railway noise annoyance and AF was found.

Since aircraft noise was the major source of (extreme) annoyance in the population (Table 2), we further investigated the introduction of a night flight ban by comparing annoyance before and after October 2011 (Table 5; online only). Interestingly, aircraft noise annoyance during daytime and sleep as well as total noise annoyance were significantly higher after introduction of the ban. Sex age, SES, time of current residence, night shift work and depression did not differ significantly between these groups.

4. Discussion

To our knowledge, this is the first study investigating the association between noise-induced annoyance and the prevalence of AF in a large cohort. We found that aircraft, road traffic and neighbourhood noise are the predominant sources of annoyance and that increases in noise annoyance are associated with a "dose-dependent" increase in AF in the population analysed (during daytime and/or during sleep). Importantly, these associations remained valid after controlling for a broad spectrum of potential confounders.

In our population, we observed a much higher prevalence of AF compared with previous studies [20]. Previous studies made solely based on history the diagnosis of AF, while the present approach combines reported AF and ECG documentation allowing a more reliable assessment. Additionally, we performed a sensitivity analysis considering ECG-diagnosed cases of AF, for which the ORs were similar as compared with the approach of including history- and/or ECG-diagnosed cases of AF. Importantly, history-based diagnosis of AF just accounted for 8% of the total.

Noise is a major source of annoyance in Western European Countries due to growing urbanisation and increasing demand for transportation. Noise annoyance is regarded as a complex multidimensional construct, reflecting the negative connotation that a person attributes to a noise source. Noise annoyance leads to stress, a condition that has been shown to be associated with an increase in CVD [4].

As previously reported, most of the study participants were annoyed by aircraft noise, followed by road traffic noise and neighbourhood noise [12]. Aircraft noise also represented the leading source of extreme noise. These observations go along with previous studies demonstrating

Table 1
Sex- and age-weighted characteristics of the study population stratified by degree of total noise annoyance ($N = 14{,}639$).

	No ($n = 3024$)	Slight ($n = 3895$)	Moderate ($n = 3654$)	Strong ($n = 2536$)	Extreme ($n = 1530$)
Sex (women)	51.5%	51.5%	51.5%	51.5%	51.5%
Age (years)	56.3 (11.0)	56.2 (10.9)	56.3 (11.0)	56.3 (11.0)	56.3 (11.0)
WHtR	0.56 (0.08)	0.55 (0.08)	0.56 (0.08)	0.56 (0.08)	0.56 (0.08)
BMI (kg/m^2)	27.1 (24.2/30.6)	26.5 (23.9/29.8)	26.7 (24.0/29.9)	26.6 (24.0/30.3)	26.5 (23.7/29.9)
SBP (mm Hg)	131.5 (120.5/144.0)	130.5 (120.0/142.5)	130.5 (119.5/142.5)	130.0 (119.5/142.0)	129.5 (120.0/141.5)
DBP (mm Hg)	82.6 (9.6)	82.6 (9.5)	82.8 (9.6)	82.3 (9.4)	82.2 (9.5)
HR (bpm)	69.3 (11.0)	68.9 (11.0)	69.1 (10.8)	68.6 (10.8)	68.9 (10.6)
CVRFs					
Diabetes	11.0%	8.7%	9.5%	9.8%	9.5%
Hypertension	51.9%	51.3%	53.0%	52.0%	50.3%
Smoking	21.8%	17.7%	17.8%	16.5%	20.1%
Obesity	28.4%	23.6%	24.7%	26.9%	24.7%
Dyslipidemia	45.2%	43.8%	45.1%	46.0%	47.5%
FH of MI/stroke	23.7%	20.7%	22.5%	22.1%	22.1%
Comorbidities					
AF	14.6%	17.3%	18.5%	20.6%	23.4%
Depression	6.1%	5.8%	7.2%	9.1%	11.6%
Social					
SES	12.18 (4.44)	13.10 (4.46)	12.73 (4.46)	12.80 (4.54)	12.68 (4.43)
Time at current residence (years)	17.00 (7.00/30.00)	17.00 (8.00/30.00)	18.00 (8.00/31.00)	17.00 (8.00/30.00)	15.00 (7.00/30.00)
Ever worked	92.9%	92.5%	91.5%	93.6%	92.5%
Night shift work	21.5%	20.9%	21.1%	23.3%	23.8%
Humoral biomarkers					
MR-proANP (pmol/L)	65.7 (49.9/89.5)	66.6 (49.9/91.1)	68.5 (50.8/91.7)	68.0 (49.4/93.6)	71.5 (52.7/98.9)
Blood chemistry					
Glucose (mg/dl)	92.0 (86.0/99.0)	92.0 (86.0/99.0)	92.0 (86.0/99.0)	92.0 (86.0/99.0)	92.0 (86.0/98.0)
HbA1c (%)	5.50 (5.20/5.90)	5.50 (5.20/5.80)	5.50 (5.20/5.80)	5.50 (5.20/5.80)	5.50 (5.20/5.80)
LDL (mg/dl)	139.4 (35.4)	141.3 (36.6)	140.2 (35.7)	138.9 (36.4)	138.9 (34.4)
HDL (mg/dl)	57.3 (15.5)	58.2 (15.9)	57.8 (15.8)	57.5 (15.7)	58.0 (15.8)
Total cholesterol (mg/dl)	221.5 (40.3)	223.8 (42.3)	222.4 (41.4)	220.0 (41.5)	221.6 (40.3)
Triglycerides (mg/dl)	107.0 (80.0/149.0)	104.0 (77.4/146.3)	107.0 (79.0/148.0)	106.5 (79.0/148.1)	104.9 (79.0/150.0)
Medication (ATC-code)					
Antihypertensives (C02)	1.1%	1.1%	1.0%	1.2%	1.3%
Diuretics (C03)	6.2%	4.7%	5.8%	6.1%	6.2%
Beta-blockers (C07)	17.9%	17.9%	17.7%	18.6%	18.7%
Calcium channel blockers (C08)	8.2%	7.0%	7.5%	8.3%	8.6%
RAAS modifying drugs (C09)	25.9%	24.2%	25.1%	25.8%	24.6%
Lipid modifying agents (C10)	15.5%	13.4%	14.3%	14.6%	14.3%
Diabetic drugs (A10)	6.9%	5.8%	6.2%	6.8%	6.8%
Antithrombotic agents (B01)	13.8%	11.6%	13.8%	13.1%	13.5%

Data are described as mean ± standard deviation (or with median Q1, Q3 if they are skew >1) or percentage. WHtR stands for waist to height ratio; BMI, body-mass-index; SBP, systolic blood pressure; DBP, diastolic blood pressure; HR, heart rate; CVRFs, cardiovascular risk factors; AF, atrial fibrillation; SES, socioeconomic status (range 3–21); HbA1c, glycated hemoglobin; MR-proANP, midregional pro atrial natriuretic peptide; LDL, low-density lipoprotein; HDL, high-density lipoprotein; ATC, anatomical therapeutic chemical classification system; RAAS, renin-angiotensin-aldosterone system.

Table 2
Specific sources of noise annoyance during daytime and during sleep stratified by degree of total noise annoyance among 14,639 participants of the Gutenberg Health Study.

Total noise annoyance	Slight ($n = 3895$)	Moderate ($n = 3654$)	Strong ($n = 2536$)	Extreme ($n = 1530$)
Noise annoyance during daytime due to specific sources (>0):				
Road traffic	38.6% (1504/3894)	55.1% (2015/3654)	63.1% (1600/2536)	59.9% (916/1530)
Aircraft	62.3% (2426/3895)	75.3% (2750/3650)	82.2% (2084/2536)	83.9% (1284/1530)
Railway	13.8% (535/3890)	19.1% (697/3644)	22.1% (559/2533)	21.7% (332/1530)
Industrial	10.0% (390/3892)	16.9% (618/3648)	22.7% (574/2532)	25.2% (385/1530)
Neighbourhood	40.3% (1567/3893)	46.2% (1688/3650)	50.1% (1271/2535)	48.2% (737/1530)
Noise annoyance during sleep due to specific sources (>0):				
Road traffic	9.5% (371/3885)	20.5% (748/3640)	31.1% (788/2532)	31.7% (483/1526)
Aircraft	19.2% (745/3884)	37.4% (1361/3638)	57.0% (1445/2533)	68.7% (1048/1525)
Railway	5.1% (197/3883)	10.3% (373/3634)	14.8% (374/2533)	15.4% (234/1521)
Industrial	1.2% (48/3884)	2.8% (102/3635)	5.3% (135/2531)	6.3% (96/1522)
Neighbourhood	12.6% (490/3884)	20.1% (730/3640)	26.8% (679/2533)	31.1% (474/1523)

Data are described as percentage with proportional numbers in brackets (n/n) indicating the proportion of participants affected by any degree of annoyance (>0) and the source-specific contribution to the degree of total noise annoyance.

a clear increase in annoyance within the last decade in response to aircraft noise while annoyance reactions to road noise remained rather constant [10]. This suggests that different noise sources have a different impact on annoyance, which stresses the importance of focusing on annoyance reactions and not on noise levels.

When comparing the influence of noise annoyance during daytime and during sleep on AF, we could observe a more frequent AF triggering effect of annoyance in response to noise during sleep. This might reflect an adverse effect of noise on sleep quality, which in turn leads to stronger annoyance reactions. Sleep disturbances per se, including short sleep and fragmentation of sleep are among of the most prevalent reasons for noise complaints and are associated with activation of sympathetic nervous system, thus markedly increasing the risk of ischemic heart disease, stroke and arrhythmia [21].

The design of the study does not allow inferring causal associations. There are however, numerous studies linking psychosocial factors with AF. For example, the Framingham offspring study has reported that the traits anger, hostility and symptoms of anger increased the risk of AF substantially [22]. Further evidence was provided by studies in patients with panic disorders and job strain [23]. In addition, negative emotions have been shown to be associated with a 3–6 fold increase in AF, while happiness had a protective effect [24]. Thus it is tempting to speculate that annoyance-induced stress is contributing at least in part to the increased prevalence in AF. Blood pressure and CVRFs did not change in

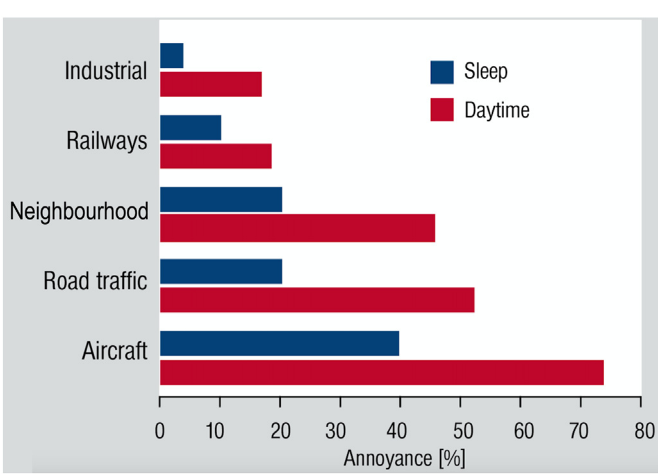

Fig. 1. Proportion of participants (%) affected by any degree of annoyance (>0) in relation to specific noise source during daytime and during sleep ($N = 11,615$).

relation to the degree of total noise annoyance, an observation that might be explained by the high prevalence of hypertension, independently of noise annoyance. Moreover, we found elevated levels of the atrial stress marker MR-proANP to be associated with the degree of total noise annoyance. Importantly, this biomarker has been shown to have prognostic value in AF [25].

As already reported, we found an association between noise annoyance and depression [12,26]. Depression and CVD are known to affect each other reciprocally [27]. Depression and noise annoyance are the result of adaptive processes that synergistically interact in determining the risk of AF. There is a large body of evidence showing that psychosocial distress is related to CVD by influencing hemodynamics, hemostasis, inflammatory processes, vascular function and autonomic tone [28,29]. By using the GHS cohort, we recently demonstrated that depression is significantly associated with AF [30]. Importantly, the quantitative effects of annoyance and depression were comparable, but independent of each other as our analysis revealed. Further, we performed a stratified analysis by depression which showed no significant interaction between annoyance and depression. Given this framework of depression and CVD, bidirectional effects between noise annoyance and AF might be conceivable, such that suffering from AF might trigger stress responses and impair adaptation, which may further lead to increased vulnerability to stress and decreased stress resistance in order to cope with an unpleasant noise source. Longitudinal designs are necessary to define further causal pathways.

A recent study investigating the relationship between residential exposure to traffic noise and risk of incident AF found that road traffic noise was significantly associated with higher risk for AF. This association was lost after further adjustment for air pollution (NO_x or NO_2 [31]). Also, no significant association was found with exposure to railway noise. Regarding railway noise, the authors explained the lack of significance due to the circumstance that exposure to railway noise is perceived as less annoying than road traffic noise, revealing the importance of annoyance in this framework. Further, efforts should be made to distinguish adequately between the effects of noise exposure and air pollution on CVD (for review see [32]).

As exposure to aircraft noise was the major source of (extreme) annoyance in the population, we have further investigated the introduction of a mitigation manoeuver such as the night flight ban by Frankfurt Airport in October 2011, by comparing annoyance before and after October 2011. Our results suggest that the introduction of the night flight ban was not effective in order to reduce annoyance. Annoyance reactions during daytime as well as during sleep were rather increased after introduction of night flight ban. Thus, the ban on scheduled movements between 11:00 p.m. and 5:00 a.m. is probably not sufficient to ensure a positive effect on annoyance rates. Of note, parallel to

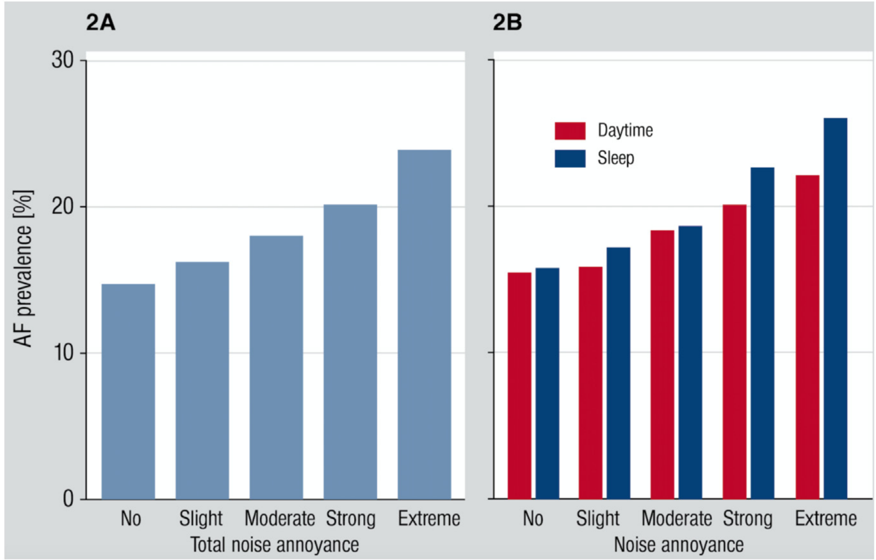

Fig. 2. Effects of total noise annoyance (A) and of noise annoyance during daytime/sleep (B) on the prevalence of atrial fibrillation in the GHS cohort.

the night flight ban, a new runaway was implemented in 2011, resulting in increased flight movements during daytime and heavy aircraft traffic load in the hours immediately before and after the no-fly time period (10 to 11 p.m., 5 to 6 a.m.). Nevertheless the total number of flights during 24 h did not change. In addition, annoyance reactions may have been enhanced by increased sensitivity and awareness for this specific issue secondary to discussion of environmental policy and strong attention to this topic by media. Thus, people are getting more aware that traffic noise has adverse effects for their health, which of course may further increase their level of annoyance in a positive feedback fashion. Nevertheless, the introduction of the night flight ban was not associated with a reduction in annoyance. Therefore, protected nighttime should be prolonged and flight movements during daytime should be reduced, to decrease the annoyance of population and thus adverse effects for their health.

A strength of the present study is the large sample size of the population-representative GHS. The comprehensive and standardized assessment of noise annoyance, AF and potential confounders represents a unique resource enabling analysis of subgroups (e.g. coverage of multiple annoyance sources during daytime and during sleep). Moreover, a further strength is the definition of AF through ECG-based diagnosis in addition to a physician-diagnosed history of AF, and the inclusion of a wide range of age groups. In addition, we were able to adjust the results for a broad spectrum of associated variables in order to ensure the validity of the results.

The prevalence of AF was higher compared with previous studies [20], which might be explained by the fact that our diagnosis also included incidental findings of AF at the time of inclusion in the study, thus allowing a more reliable assessment. In a sensitivity analysis including ECG-diagnosed cases of AF only the ORs were similar to the overall cohort. Importantly, history-based diagnosis of AF accounted for only 8% of the total. A limitation of the study is the cross-sectional design, which hampers causal interpretations. Longitudinal studies would provide useful information to further determine causal links. The prevalence of AF should be treated with caution because AF is often subclinical and asymptomatic and therefore remain undiagnosed. We cannot rule out the possibility of selection, recall and self-report response bias. Although the present study had a high response rate of 60%, selection bias might still have occurred due to self-selection of people based on motivational differences for participating in the GHS, e.g. people with chronic conditions are more likely to participate in a health study. Self-report response bias targets the participants' abilities for introspection and tendency to respond in certain ways. Also, there is a risk for recall bias due to the circumstance that cases potentially recall noise annoyance and associated variables different than non-cases. We also cannot exclude that air pollution annoyance may have interacted with noise annoyance although more recent studies indicated that both may impact health independently [33]. Lastly, as the present study relies on noise annoyance as a proxy for the actual noise exposure, exposure misclassification has most likely occurred. Also, misclassification may differ between people with or no disease simply because they are more noise sensitive, all of which may have biased our results. On the other hand, there is an ongoing debate in the current literature whether the noise level or the annoyance to noise is a more eligible indicator or maker of CV risk. Noise annoyance reflects an individual cognitive-evaluation of a noise source and thus may be more suitable for assessing noise-induced impairment, while its direct biological impact remains still unclear. In turn, there are non-acoustical factors, notably noise sensitivity, which has been shown to moderate negative health impacts and affects annoyance reactions [34]. The present study cannot resolve this issue as no data were available on noise levels and sensitivity.

In summary, the current study describes a significant association between noise and the arrhythmia AF. Although hypotheses about the emotional reactions and the development of arrhythmia are reasonable, this is to our knowledge the first paper to show an association between annoyance and AF. Thus, future studies addressing the pathophysiology of annoyance-induced AF should be conducted and interventions to prevent annoyance-induced AF should be implemented.

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Conflicts of interest

There are no conflicts of interest.

Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.ijcard.2018.03.126.

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