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Aircraft noise exposure assessment for a case-crossover study in Switzerland

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ABSTRACT

Long-term exposure to aircraft noise has been shown to be associated with increased risk of ischemic heart diseases. However, little is known about the acute triggering effects of noise on cardiovascular diseases (CVD). We use a case-crossover design to investigate the triggering effects of night-time aircraft noise exposure on cardiovascular mortality. To that aim, we identified all death cases from the Swiss National Cohort (22000 CVD; 3000 myocardial infarctions) occurring in the vicinity of Zurich airport between 2000 and 2014. Outdoor noise exposure at participants' home addresses is calculated for the night preceding death as well as 3 to 4 control nights selected within the same month, using calculated aircraft noise impact for each registered flight. Different noise metrics such as LAeq, LAmax or NAT are used to quantify and characterize the noise impact during different night-time exposure windows.

In this contribution we present the methodological approach for the noise exposure assessment and average noise levels in these different time intervals.

Keywords: Aircraft noise, Case-crossover, Cardiovascular diseases, Exposure

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1. INTRODUCTION

Noise from road, railway and air traffic is the most widespread source of environmental stress and discomfort in everyday life. Its impact on health has been increasingly recognized, especially annoyance and sleep disturbance, as well as its long-term impacts on cardiovascular health. A previous study conducted on the Swiss population reported a long term increased risk of death from myocardial infarction of 3.8, 1.8 and 2.6% per 10 dB Lden increase in road traffic, railway and aircraft noise, respectively [1]. Aircraft noise has also been shown to be associated with increased risk of cardiovascular diseases and hospital admissions in London [2]. For ischemic heart disease, the recent WHO environmental noise guideline reports a risk ratio of 1.09 (1.04–1.15) per 10 dB Lden increase in aircraft noise [3].

The Swiss Confederation recently established a national plan, aiming to limit noise at its source, especially in the urban environment, to promote population health [4]. Besides, the Swiss Noise Abatement Ordinance has been in force since 1983 and covers different aspects of noise reduction and protection [5]. Most recent WHO guidelines recommend the average night-time exposure to aircraft noise should be below 40dB [3].

Most of the existing epidemiological studies investigating the role of noise on health are aimed at chronic exposures based on sound exposure metrics which represent long-term averages such as the Lden. Less is known about the acute effects of noise on cardiovascular health. Noise is a complex, manifold exposure with high temporal and spectral variation, where a simple estimate of the daily mean might lead to a loss of important components of noise characteristics when studying short term effects. This has potential consequences on the physiological response, which in turn will reduce explained variance. Improved prediction of short term effects with more detailed noise metrics is therefore desirable.

One aim of the study TraNQuIL (Transportation Noise: Quantitative Methods for Investigating Acute and Long Term Health Effects) is to investigate acute effects of aircraft noise on myocardial infarction, stroke and other ischemic cardiovascular causes of mortality by means of a case-crossover study. More specifically, this study aims to assess the exposure-response relationship for different time-windows of exposure during the night preceding the death event as well as cumulative effects of several nights preceding the event. For that purpose, a reliable and detailed noise exposure assessment is required. This paper presents a detailed description of the aircraft noise exposure assessment developed in the framework of TraNQuIL.

2. METHODS AND RESULTS

2.1 Case-crossover design

A case crossover study is designed to investigate acute health effects for time varying exposures such as air pollution, physical activity, emotional stress, or noise [6]. Exposure levels at the time when an event occurs (case events) are compared with the typical exposure when no event occurred (control events) as presented in Figure 1. It is a case-only study design and is therefore not vulnerable to confounding from individual characteristics that do not vary over time, such as lifestyle factors. The case-crossover study design is also suitable for aircraft noise if there is sufficient temporal variation in noise exposure due to varying flight schemes.

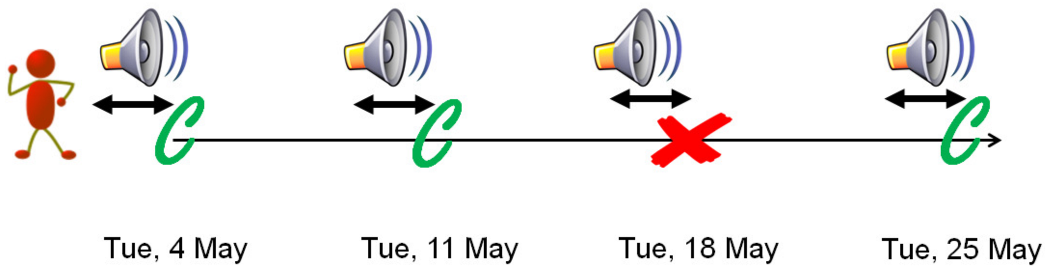

Figure 1 : example of case-crossover design, where exposure (noise level) is assessed in case (red) and control (green) event nights.

2.2 Zürich Airport

Zürich Airport (ZRH) is the largest airport in Switzerland in terms of air traffic. It is composed of a system of three runways, offering 14 departure and 4 approach routes for commercial air traffic (see Figure 2). The assignment of air traffic to routes can change from day to day depending on different factors such as wind. Therefore, noise exposure is expected to vary between cases and control days [7]. ZRH is subject to a flight ban, which limits the flight traffic to permitted exceptions such as emergency flights only. The flight ban was set from 00:30 to 05:00 (approaches) and 06:00 (departures) in 2000 and extended to 23:30 to 06:00 in 2010.

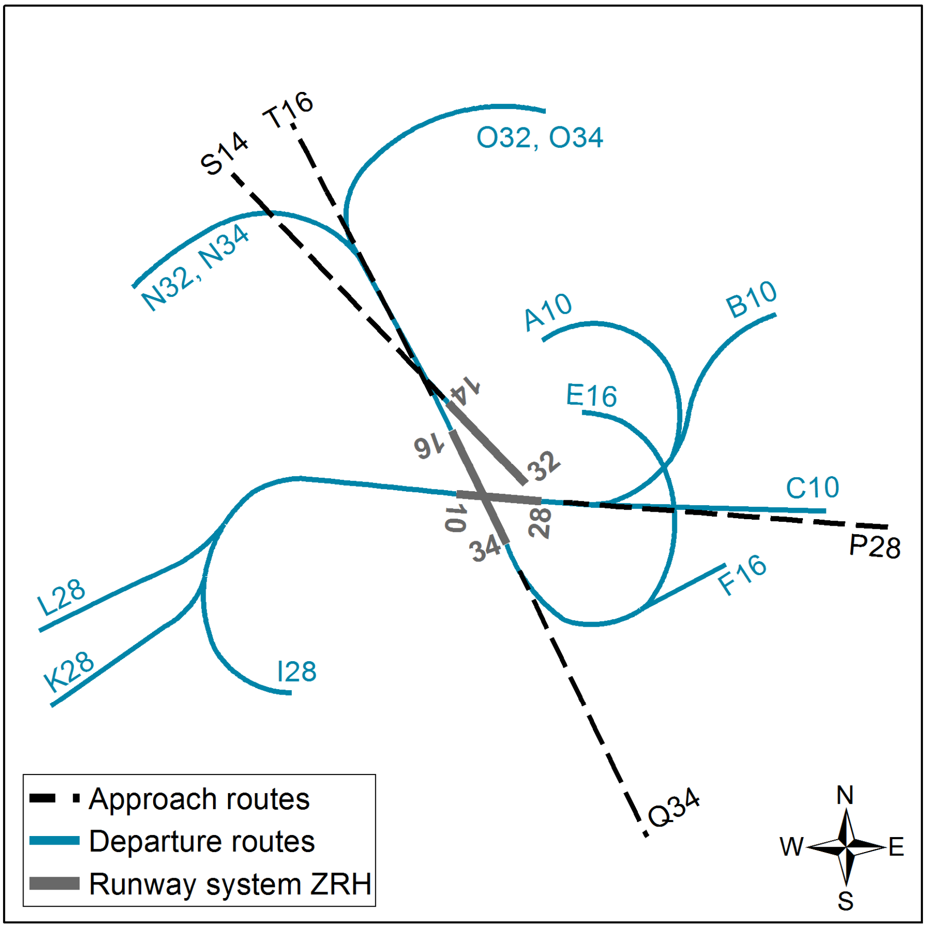

Figure 2 : overview of the runway system and air routes at ZRH.

2.3 Study population

The study population is selected from the Swiss National Cohort (SNC) [8] in the vicinity of ZRH. It includes all individuals aged more than 30 years, dying from a cardiovascular cause (ICD10 classification I0 to I99) between 2000 and 2016. Only individuals potentially exposed to increased aircraft noise exposure levels are selected. For this purpose, we use the envelope of the calculation perimeters for the Zürich Aircraft Noise Index (ZFI), which is a noise effect index for the number of highly annoyed and highly sleep disturbed persons (minimum LAeq of 37 dB during the day and/or 47 dB during the night) [9] (see Figure 3).

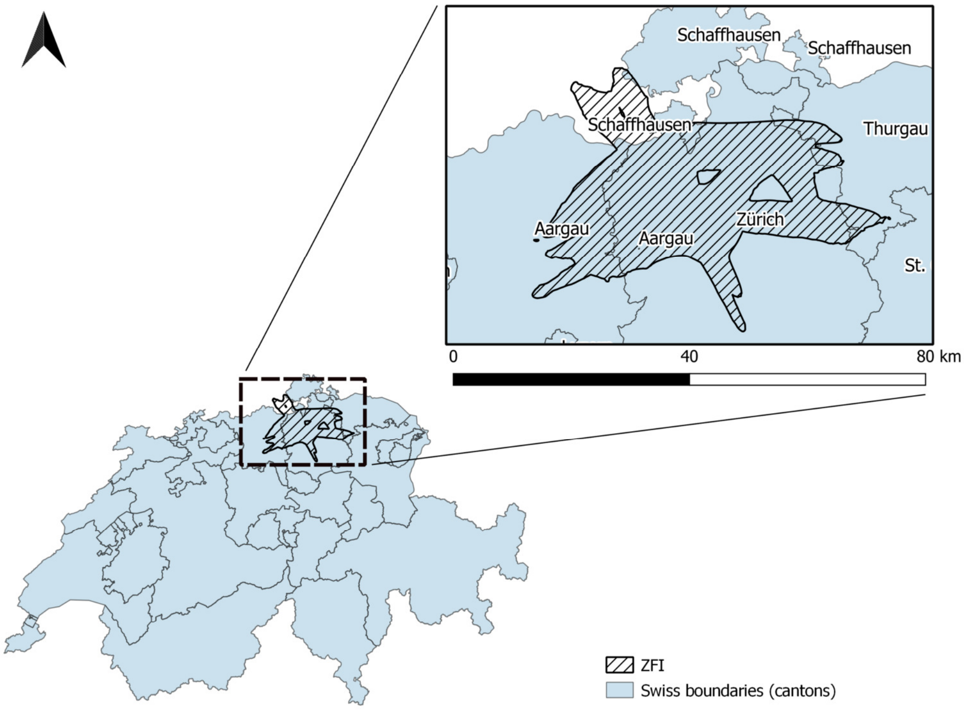

Figure 3: Overview of the study area used to select the study population around ZRH.

Geocoded residence at time of death are available from the SNC, together with other relevant personal information such as cause and time of death [8][10].

For the purpose of developing this exposure assessment framework, which requires explicit linkage to the study population, SNC data from 2000 to 2014 are used. SNC data for years 2015 and 2016 will be included at a later stage. Aircraft movements data are available for the full period 2000 to 2016.

2.4 Noise exposure assessment

Individual exposure for the study participants at their home location is determined for the night before death and for the control nights using the list of aircraft movements. This includes detailed information on all flight events starting and landing at ZRH between 2000 and 2016, and existing noise calculation results (namely footprints, see below [11]. Only night-time exposure to aircraft noise is assessed, focussing the investigation of the effects of noise on mortality during quiet, sleeping phases. In addition, home exposure is expected to represent the effective exposure more accurately during night-time than day-time. The different steps of noise exposure assessment are schematized in Figure 4.

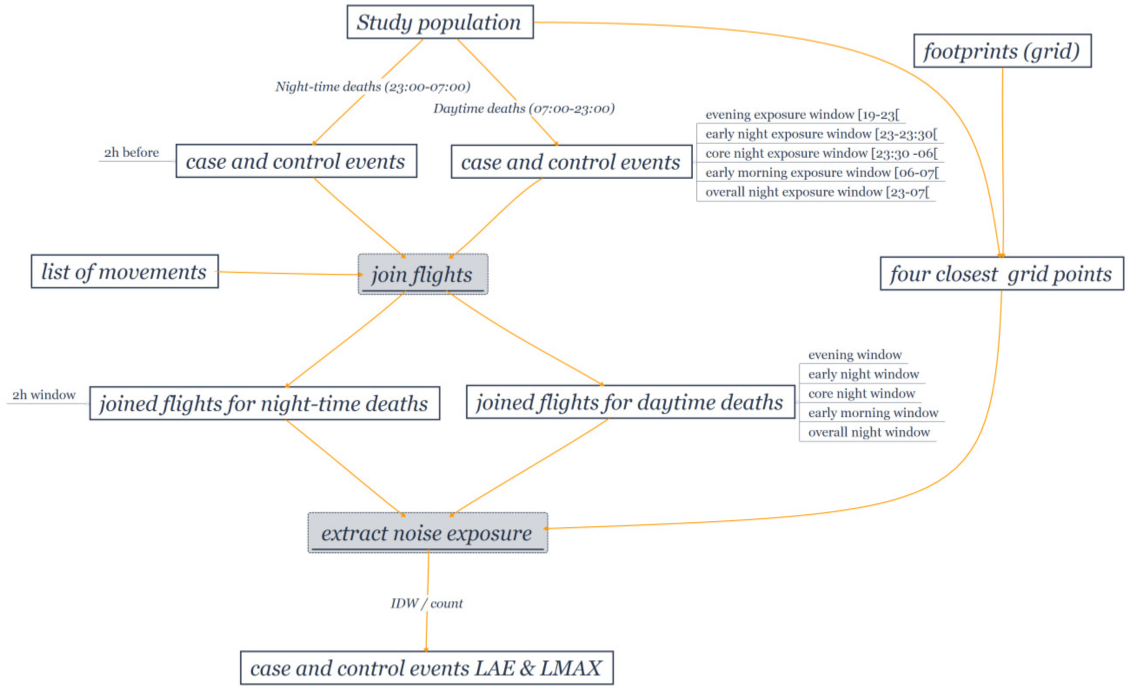

Figure 4: Graphical overview of the exposure assessment procedure

Each death case event is matched with 3 to 4 controls dates, selected on the same day of the week within the same month, following a time-stratified control selection. This is done to minimize time-trend bias and facilitates use of unbiased conditional logistic regression. This method is well adapted to environmental exposures, which are typically not associated with the event [12], [13].

Two separate approaches are followed for death cases occurring in the night and during day. For individuals dying during the night (23:00-07:00), noise exposure is calculated for the two hours preceding the death. For people dying during the day (07:00-23:00), the following exposure windows are considered:

- 19:00-23:00: Evening
- 23:00-23:30: Reduced air traffic
- 23:30-06:00: Flight ban
- 06:00-07:00: morning
- 23:00-07:00: overall night

Case and control events are created for the above described time-windows on all selected case and control dates, for daytime and night-time deaths respectively. To explore effects of cumulative exposure we aggregate noise exposures estimated during the same time windows over several consecutive days.

A list of movements is available for ZRH for 2000 to 2016. This data contains detailed information for all aircraft departures and arrivals at ZRH, such as aircraft type, air route, runway and time of departure or landing. The departure or landing time is defined as the moment of aircraft touch down or break release.

As acoustic input, we use so-called "footprints" of aircraft noise events, previously calculated on a yearly basis at the authors' institution, Empa. A footprint corresponds to a receiver gid of mean noise exposure levels per aircraft type and air route. Calculations were done with the aircraft noise calculation program FLULA2 [11] using individual flight paths as obtained from large radar data sets [7]. From the level-time-histories LA(t) of the individual flights, the mean maximal event level (LMAX) and event level LAE (resulting total energy of an event) were calculated, from which indicators such as the equivalen continuous sound pressure level (Leq) or the Lden may be derived. FLULA2 considers sound source data (sound emission level and directivity patterns) of individual aircraft types, the statistics of movements, the detailed flight geometries, and the topography. It does not account for changes in the atmospheric and meteorological situation [14]. Footprints are used exclusively for large aircraft types (>8'618 kg), as air traffic of small aircraft is negligible during the night. Each footprint is specific for a certain year, aircraft type (or group of aircraft types that present similar noise exposures), procedure (departure or arrival), flight route, and possibly time of day (e.g., day, night).

Overall, 4'664'132 flights started or landed at ZRH between 2000 and 2016. An additional 10 minutes buffer time is added before landing times and after departure times to better account for the moment when the plane was to be heard by the study population. Some flights have missing information for the aircraft type and/or the air route. Using the tail number of the aircraft and the date of the event, aircraft types can be filled in. Only 216 flights were excluded because of missing flight route information.

Selecting only large aircraft (>8'618 kg) starting or landing during the hours of interest (18:45-07:15) reduces the data to 1'124'748 flights. Figure 5 presents the distribution of the flights during the whole selected period and the core night (00:00–06:00), for 2000 to 2016.

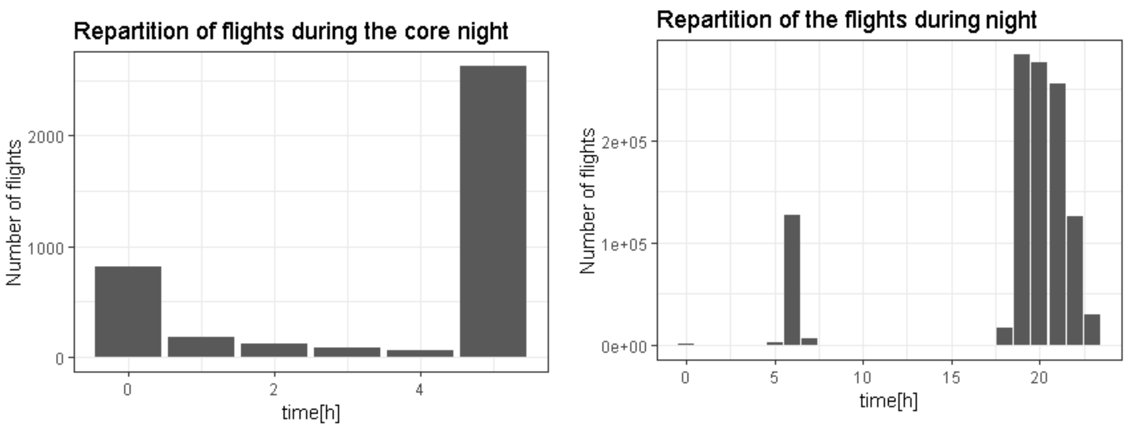

Figure 5: Distribution of the flights during different times of the day and night (flights occurring between 07:15 and 18:45 have already been excluded).

All flights occurring during the previously described time windows are selected and joined to their respective case and control events.

As the extent and resolution of the footprints change between years, a grid is created for each year based on x, y coordinates and the noise exposures (LAE and LMAX). This grid is used to identify the four nearest pixels for each study participant and facilitate interpolation of noise at the residential geocode.

Using information on year, time, aircraft type, air route and procedure contained within the list of movements, the respective footprints can be identified. Each of them is individually imported and the noise metrics of interest collected. The process is repeated for each footprint, so that each identified flight is associated with eight noise exposure values (4 for LAE and 4 for LMAX). In the situation where no footprint is found, it is replaced by a similar footprint from a different year.

For each flight event, the average LAE and LMAX at the residential geocode is calculated from the four nearest noise receiver grid points using Inverse Distance Weighting (IDW) (see Equation 1).

Equation 1: Inverse distance weighting based on four closest grid points.

$$f(d) = \begin{cases} d_i > 0, & L = \dfrac{\sum_{i=1}^{4}(L_i * \frac{1}{d_i})}{\sum_{i=1}^{4}(\frac{1}{d_i})} \\ d_{i,min} = 0, & L = L_i \end{cases};$$

d_i = distance to neighbour i
L = Noise metric (LAE or LMAX)
L_i = Noise level at residential geocode i

For LAE, the averaged noise levels of all events are energetically summed up for case and control exposure time windows using Equation 2.

Equation 2: Sum of i LAE exposure levels

$$LAE_{tot} = \sum_{i=1}^{n}(LAE_i) = 10 * \log(\sum_{i=1}^{n} 10^{(\frac{LAE_i}{10})});$$

i = flight event i
n = number of flight events for each case, control and time window.

Finally, the Leq are calculated for the different time windows using Equation 3. The case and control events for which no flight is found or the final Leq values are negative are set to zero.

Equation 3: Calculation of Leq for the different exposure windows

$$Leq = LAE - 10 * log(T/t_0)$$

T= time within each exposure time-window [second]

t0 = 1 second

For LMAX, the highest level of LMAX observed within each case and control event window is defined as maximum noise level. Additionally, the number of flights with a LMAX value larger than 55 dB is counted, giving the Number Above Threshold, NAT_{55}.

2.4 Results

Figure 6 and Figure 7 show the distribution of the Leq and LMAX exposure levels for all events by time window (case and control events), separately for day and night death events. For both metrics, exposure is highest for the evening exposure window (19:00-23:00) and lowest during the core night (23:30-06:00). For the daytime deaths, average Leq of the different time windows ranges from 20 to 45 dB with highest values about 75dB and LMAX average values from 40 to 60 dB with highest values about 100dB. For the night-time deaths, average Leq(2h) is 36dB with maximum values about 65dB and average LMAX 57dB with maximum values about 85dB.

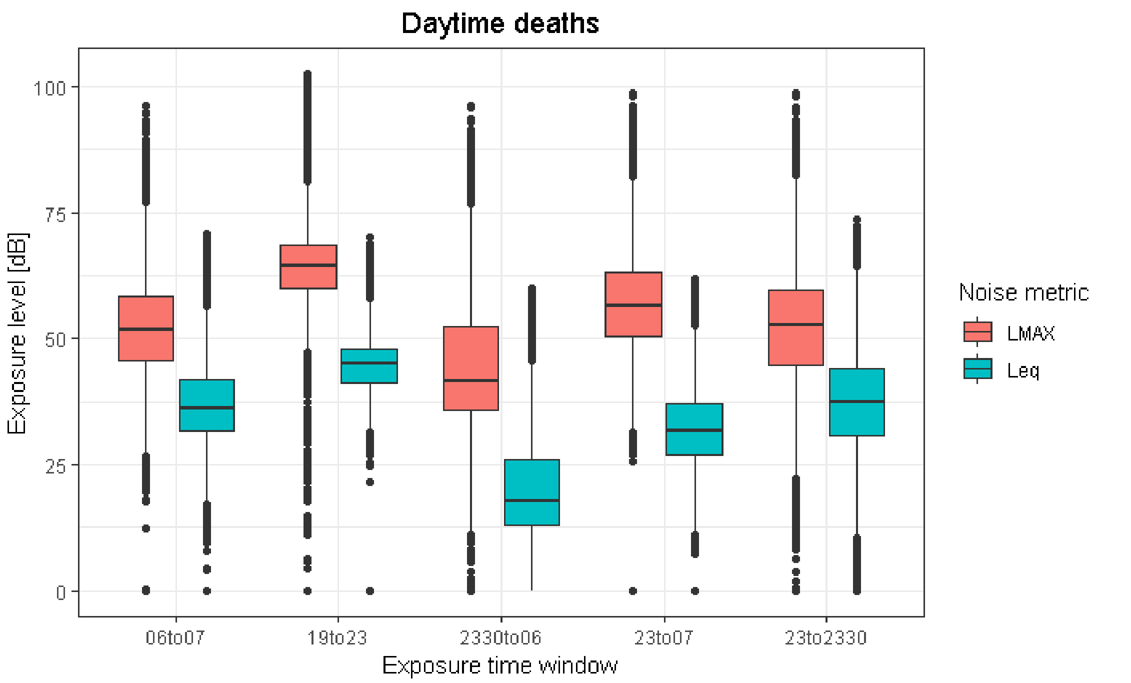

Figure 6: Boxplot of the noise exposure levels LMAX and Leq for the different time windows among all events (case and control) for day-time deaths, years 2000–2014. The central line represents the median value, the squares the interquartile range (IQR), and the whiskers the lower and upper limits (lower IQR value -1.5*IQR / upper IQR value + 1.5*IQR).

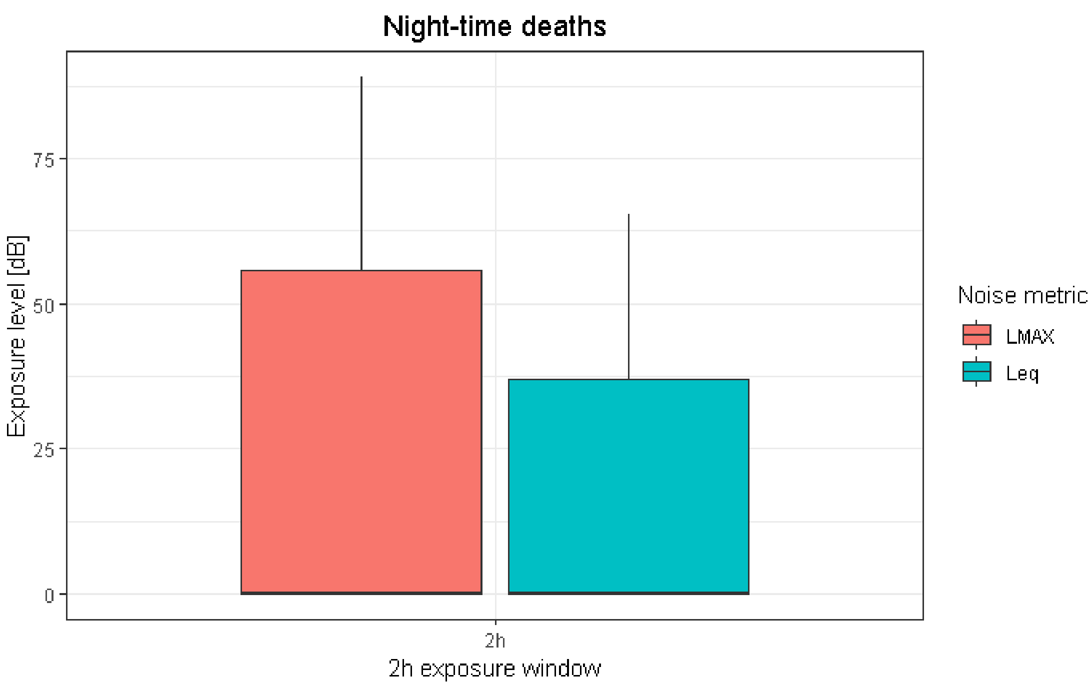

Figure 7: Distribution of the noise exposure levels LMAX and Leq for the 2 hour exposure window among the events (case and control) for night-time deaths, years 2000–2014. The central line represents the median value, the squares the interquartile range (IQR), and the whiskers the lower and upper limits (lower IQR value -1.5*IQR / upper IQR value + 1.5*IQR).

4. SUMMARY

This paper presents a method to provide individual aircraft noise exposures with a high temporal resolution, using a list of movements and previously calculated aircraft noise footprints for different aircraft types and air routes at various points in time. The choice of the exposure events is very flexible and precise, which makes it an attractive approach for conducting case-crossover studies investigating short-term or transient effects of noise on health.

We illustrate examples of exposure estimates for specific time windows within a selected population around Zürich Airport. As the follow up in the epidemiological analyses will be extended to 2016, slightly different exposure levels can be expected in future estimations.

Finally, some refinement on the strategy to replace missing footprints may be made in the future, potentially improving the precision of the final exposure estimates.

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6. LIST OF ABBREVIATIONS

ZRH: Zürich Airport
SNC: Swiss National Cohort
Leq: equivalent continuous sound presser level over a defined period of time
LAE: Total energy of an event condensed on one second[dB]
LMAX: Maximum reached energy level of an event [dB]
NAT_{55}: Number above threshold of 55dB

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