Predicting aircraft noise annoyance: Exploring noise metrics other than Lden

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ABSTRACT

Residents living around a military airbase are concerned about the long-term health effects of their exposure to high peak noise levels of AWACS aircraft using old and noisy engines. They argue that their exposure to high peak levels is not adequately taken into account by using Lden. We investigated the relation between reported annoyance and yearly averaged noise metrics with different characteristics in a questionnaire survey with 9365 respondents. Noise metrics were based on the highest sound level (such as LA_{max}), the duration of the noise events (TAx: Time Above level x), and the number of noise events (NAx: Number Above level x). We also adapted the calculation of L_{den} by introducing a factor alpha that could place more emphasis on noise levels or aircraft numbers. Within the set of 28 indicators, no noise metric was identified that could improve upon L_{den} for describing the relation between aircraft noise and annoyance.

INTRODUCTION

In 1982, the NATO E-3A Component became operational at the Geilenkirchen airbase in Germany. Currently, fourteen AWACS (previously seventeen) and several supporting aircraft use the airbase for training purposes and as a starting point for NATO missions. The AWACS aircraft are remodeled Boeing 707s equipped with a radar dome that can monitor the airspace within a radius of 400 km. The number of flight movements over the Netherlands varies over time but was limited to a maximum of 3600 per year at the time of this study (recently a limit of 2600 is applied), with only occasional flights during the nighttime and in the weekend.

The airbase is situated close to the Dutch border near the towns of Schinveld (2 km) and Brunssum (8 km). The whole period since the start of NATO operations is marked by strong protests of the nearby population and municipalities. Complaints range from noise annoyance and air pollution to the occurrence of adverse health effects. Residents demand the replacement of the old and noisy aircraft engines by modern and more silent engines.

Since the nineties, a number of studies have been performed around the airbase looking into the effects of noise and air pollution on annoyance and health. Most of these studies have only been published in Dutch [1-5], with the exception of [6].

When looking into the relation between aircraft noise exposure and annoyance, these studies have either used the dose-response curve described in EC/WG2 [7], or connected the address location of survey respondents to the outcome of noise models. Both methods use the L_{den} and L_{night} as the noise metrics of choice, as described in the European Environmental Noise Directive 2002/49/EC [8]. However, residents claim that Lden does not adequately describe their exposure to noise and the annoyance that they experience. The EU dose-response curve gives a general impression of the annoyance situation based on studies that were mainly carried out around large civilian airports. The current situation around these airports can be characterized by a large number of overflights with relatively low noise levels per overflight. The situation around the Air Base in Geilenkirchen is the opposite, with few overflights with peak levels of up to 110 dB(A) at ground level. This results in L_{den} levels that are comparable with large civilian airports, but are based on a different underlying soundscape.

This is possible because the calculation of the L_{den} is an integrated yearly averaged summary of three factors: the number of overflights, the duration of the overflights and the noise level of the overflights. In the calculation of the L_{den} the importance of each factor relative to the others is assumed to be fixed. We wanted to find out what would be the influence of varying these factors systematically on the relation between noise exposure and annoyance around the Geilenkirchen Air Base.

Based on the 2012 flight tracks, an array of noise indicators was calculated for the address locations of survey respondents that participated in a questionnaire survey in 2012. Using logistic regression, the best model fit between the annoyance score and noise exposure was evaluated.

METHODS

Noise metrics

We characterized the yearly averaged noise metrics based on three properties of the aircraft noise exposure.

- The (highest) noise level of an overflight in one year (maximum level; LA_{max})
- The number of overflights in one year (Number Above; NA)
- The duration of exceeding a certain sound level during one year (Time Above; TA)

Furthermore, we looked at integrated noise metrics that constitute a combination of noise level, number and duration.

Maximum level

The LA_{max} describes the highest noise level in a one-year period. Because the LAmax is based on a single noise event during a whole year only, we investigated whether related noise metrics – based on the LA_{max} – could describe the relation between noise exposure and annoyance in a better way. To that effect the LA_{max_3}, LA_{max_5} and LA_{max_10} were calculated, representing the noise level of the 3rd, 5th and 10th noisiest overflight in the year. In a similar fashion, we determined the noise level that was exceeded by 1, 5 and 10% of the overflights, called LA_{max_p1}, LA_{max_p5} and LA_{max_p10}. Finally, we considered the average LA_{max} of those overflights that exceeded a certain noise level. The noise metric M_LA_{max60}, M_LA_{max65},

M_LA_{max70} and M_LA_{max75} describe the arithmetic mean of all overflights that exceeded an LA_{max} of x dB(A).

Number above

To indicate the number of overflights that exceed a certain noise level we use the NAx (Number Above x dB(A)). This indicates the number of overflights of which the maximum noise peak level LAmax exceeds x dB(A). We counted the number of events above 60, 65, 70, 75 and 80 dB(A).

Time above

To indicate the duration that the combined overflights exceed a certain noise level we use TAx (Time Above x db(A)). TAx is measured in seconds for the noise levels 60, 65, 70, 75 and 80 dB(A). In addition, the noise level to which respondents were exposed during a time period was determined. If, for example, the L_4h is 70 dB(A) this means that the respondent is exposed to noise levels of 70 dB(A) or higher during 4 hours in a year. Time periods of 15 minutes (L_15m) up to 24 hours (L_24u) were considered.

Integrated noise metrics

The L_{den} unites two aspects of aircraft noise (level and number) in a yearly averaged noise metric. The metric also takes into account the time of day using penalties for overflights during the evening and night-time, under the assumption that these flights are more annoying than daytime flights. As there are a small number of evening and hardly any night-time flights around the Geilenkirchen Airbase, these penalties were not taken into account. Underlying the calculation of L_{den} is the equal-energy principle. This implies that one overflight can be replaced by 10 overflights that have sound exposure levels (SEL) of 10 db(A) less. Both situations result in the same L_{den} value. By using the L_{den} an (implicit) trade-off is made between the number of overflights and the sound level of the individual overflights. We will call this the ‘trade-off factor’. The question is whether this trade-off is valid for the situation around Geilenkirchen Air Base with few overflights and very high noise peak levels. We investigated the trade-off assumption by introducing a parameter alfa (α) in the calculation of the L_{den}, as described in [9]. This can be represented with the following formula

$$L_{den,\alpha} = 10lg\frac{1}{24}(12 * \frac{L_{Aeq,\alpha,day}}{10} + 4 * \frac{L_{Aeq,\alpha,evening}+5}{10} + 8 * \frac{L_{Aeq,\alpha,night}+10}{10} \qquad (1)$$

With

$$L_{Aeq,\alpha,T} = 10\lg\left(\sum N\left(10^{\frac{SEL}{10}}\right)^{\alpha}\right) - 10\lg(T) \qquad (2)$$

If α=1, the $L_{den(\alpha)}$ is equal to the regular L_{den}. In the case where α>1 events with the highest SEL have a larger effect on $L_{den(\alpha)}$ and a smaller effect if α<1. In other words, when α<1 the number of flights carries a greater weight in the calculation and when α>1 the SEL (and thus the noise level and duration) of the flights carries a greater weight.

The Netherlands Aerospace Centre (NLR) used the statutory noise model for airports in the Netherlands to compute the different noise metrics. The calculations are based on the actual flight paths in 2012 over an area on 35x32 km2 with a grid size of 250 m2. We combined the home address location of the survey respondents with the grid cells.

Questionnaire survey

The study population consists of the 9365 adult participants of the 2009 regional health monitor of South-Limburg in the age range 17-65 years old. The participants were living in the whole service area of the regional health authority, not only close to the military Airbase. The area also encloses the Maastricht-Aachen civilian airport, which was included in the noise calculations. This airport handled approximately 13.700 flights in 2009. The whole study population of the health monitor was included to cover a wide range of noise exposures and not focus solely on the municipalities close to the military airbase. The participants were selected using a stratified study design, taking into account the distribution of the population by age and sex over the municipalities in the study area. The size of the sample was increased and further stratified by postal code in the municipalities surrounding the military airbase to ensure sufficient participants and coverage of the noise annoyance situation due to the airbase.

The questionnaire included the standardized annoyance question as described in ISO/TS 15666 [10]. The answering scale ranged from 0 (not annoyed) to 10 (extremely annoyed). A person was considered severely annoyed when he/she gave a score of 8-10 on the eleven point scale.

Statistical analyses

The relation between the noise metrics and severe noise annoyance was determined using logistic regression, while considering the stratified study design using the SUDAAN software package within the SAS software environment. The following statistical model was used

$$\log\left(\frac{p}{1-p}\right) = \beta_0 + \beta_1 * noise\ metric + \beta_i * covariate_i \tag{3}$$

Where p is the percentage of the population with severe annoyance, β_1 denotes the association between the noise metric and severe annoyance while taking into account possible confounding factors. The exponential e^{β} gives the odds ratio of the influence of aircraft noise on the percentage of the population severely annoyed. Age, gender, migrant origin, education level and socio-economic status were included as categorical confounding factors in the model. Noise exposure due to other traffic related sources was included as a confounding factor.

The noise annoyance outcome and confounding factors were kept constant in all models, and only the noise metric was changed. We compared the relative quality of the statistical models using the AIC (Aikaike Information Criterion). The AIC is a means for model selection that gives a relative estimate of the information lost when a given model is used to represent the process that generates the data. It deals with the trade-off between the goodness of fit of the model and the complexity of the model. Furthermore, we used the ROC (Receiver Operating Characteristic) curve to determine the Area Under the Curve (AUC). The ROC curve is a graphical plot that illustrates the performance of a binary classifier system as its discrimination threshold is varied. On the x-axis, the true positive rate (sensitivity) is plotted against the false positive rate (1-specificity) at various threshold settings. The AUC is a summary measure of this curve and gives an indication whether a noise metric can discriminate well between those who are annoyed due to aircraft noise and those who are not.

RESULTS

9386 respondents filled out the general health questionnaire in 2009 with average aircraft noise levels of postal codes ranging from 29 to 54 dB L_{den} and severe annoyance levels ranging from 1 to 72%. In 2008, LA_{max} levels of over 100 dB were measured while the total number of overflights approaching or leaving the military airbase was approximately 2800.

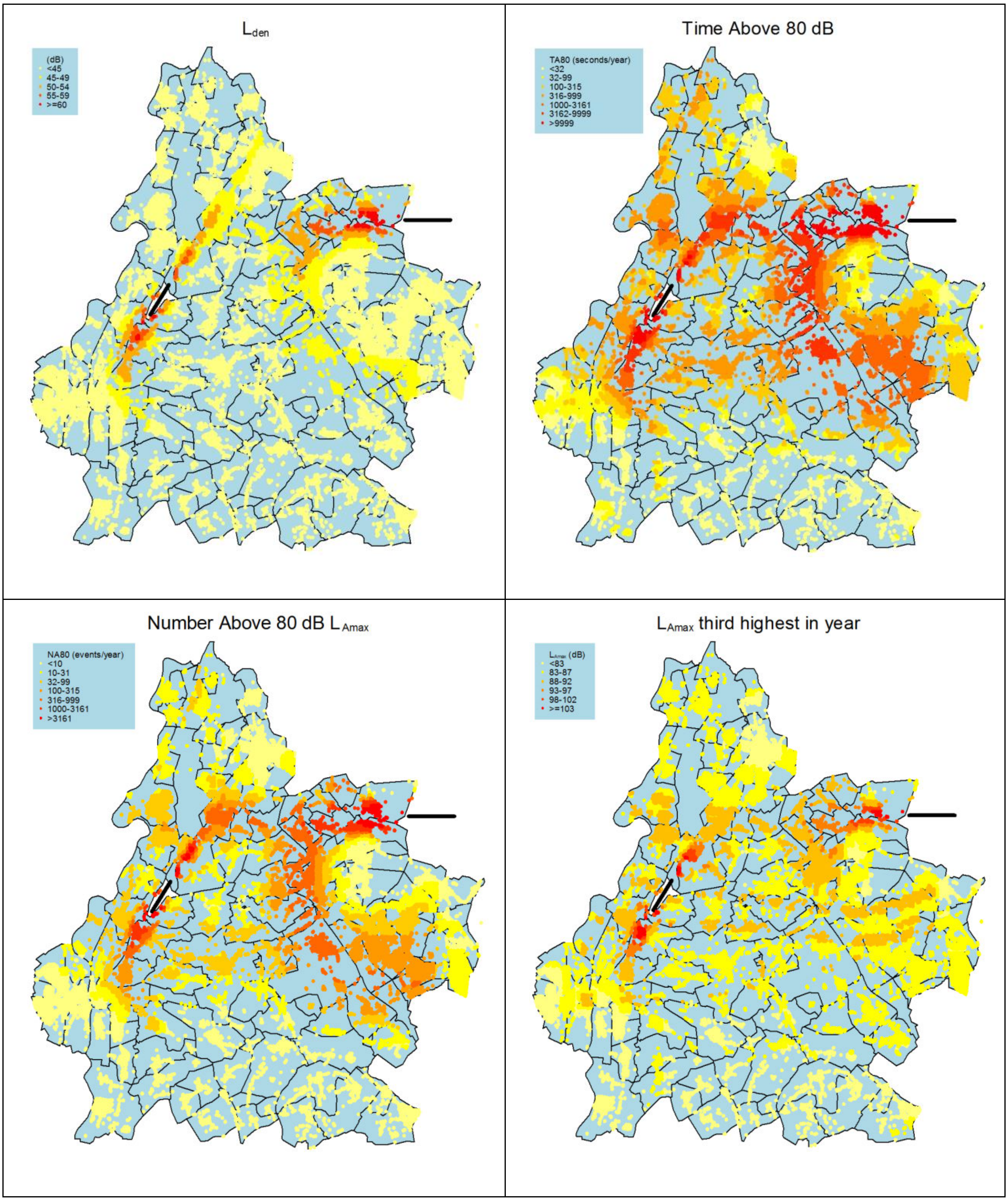

Figure 1: Noise exposure at the address locations of the population in South-Limburg using the L_{den}, L_{Amax} level exceeded 5% of the time, NA_{80} and the third highest L_{Amax} overflight in the year

The L_{den} noise exposure levels at the home addresses of the population of South Limburg is visible in the top left corner of figure 1. The elevated noise levels in the north east due to the Geilenkirchen airbase are clearly visible, while Maastricht Aachen Airport is located in the west of the province.

The other insets show the noise exposure at the home addresses using a noise indicator based on duration of exposure (TA80), number of overflights (NA80) and peak exposure level (third highest LA_{max}). Other areas of the province now start showing that would normally not have been picked up when only considering L_{den} values of 50 dB(A) and higher. Of course, this also depends on the noise categories that are chosen for display. However, the flight patterns around both airports become more clearly visible. This is also supported by the prevalence of noise annoyance in the municipalities which are not only elevated near the airports, but also in the areas under the most used flight paths.

The correlation between the postulated noise indicators is moderate to high. The indicators based on time exposed show the lowest correlations, especially with the indicators based on the maximum noise levels. The L_{den} is highly correlated with most noise indicators. This is to be expected, because the L_{den} takes into account both noise and numbers.

Table 1: Spearman correlation coefficients between a selected set of noise metrics

	Lden	**NA75**	**TA75**	**L_15min**	**L_4hrs**	**LAmax**	**LAmax_10**	**LAmax_p5**	**Lden, 0.9**
NA75	0.81	1							
TA75	0.74	0.95	1						
L_15min	0.96	0.74	0.67	1					
L_4hours	0.94	0.72	0.65	0.85	1				
LAmax	0.79	0.68	0.65	0.76	0.71	1			
LAmax_10	0.89	0.64	0.58	0.93	0.73	0.79	1		
LAmax_p5	0.63	0.63	0.59	0.75	0.56	0.61	0.74	1	
Lden, 0.9	0.99	0.79	0.72	0.93	0.94	0.75	0.85	0.54	1
Lden, 1.1	0.99	0.80	0.75	0.97	0.91	0.84	0.92	0.70	0.97

In Table 2, the goodness-of-fit (AIC) of only a few logistic regression models was better when using a different noise metric than L_{den} to describe the relation between noise exposure and severe annoyance. Table 2 indicates that only the model with the noise level exceeded during 4 hours in a year and and the L_{den} alpha of 1.05 and 1.1 perform slightly better in fitting the model. An alpha higher than 1 indicates that the emphasis in the calculation of the metric is on the noise level rather than on the number of overflights. However, this is not supported by any of the noise metrics based on the peak noise levels that invariably show worse model fit. Only the number above 75 dB(A) performs close to the L_{den} in the model fit and in discriminating between those severely annoyed and not annoyed. Time above 70 and 75 dB(A) has almost equal fit and discrimination power as the L_{den}, indicating that duration of the noise exposure remains an important factor. The AUC of the noise metrics ranges from fair (0.7 – 0.8) to good (0.8 – 0.9) and follows the same pattern as the AIC results.

Table 2: Relative comparison of the logistic regression models for severe annoyance due to aircraft noise (adjusted for confounding) using the AIC and AUC criterion

	AIC	AUC		AIC	AUC		AIC	AUC
LAmax of x^{th} loudest noise event			**Mean noise level of overflights exceeding x LAmax**			**Noise level exceeded during time period**		
LAmax_1	187344	0.796	**M_Lmax60**	177071	0.823	**L_15m**	178843	0.820
LAmax_3	186244	0.804	**M_Lmax65**	185901	0.784	**L_1h**	177584	0.826
LAmax_5	184983	0.808	**M_Lmax70**	193998	0.730	**L_4h**	173241	0.831
Lamax_10	184558	0.802	**M_Lmax75**	204246	0.596	**L_24h**	177403	0.802
Time Above			**Number Above**			**Loudest x percentile of noise events**		
TA60	182270	0.828	**NA60**	187208	0.801	**Lamax_p1**	197631	0.726
TA65	178545	0.836	**NA65**	182286	0.820	**Lamax_p5**	191933	0.757
TA70	176212	0.838	**NA70**	179979	0.828	**Lamax_p10**	187189	0.781
TA75	175548	0.833	**NA75**	177810	0.829			
TA80	182413	0.820	**NA80**	182505	0.815			
Lden			**Lden, alpha**			**Lden, alpha**		
Lden	175276	0.835	**Lden, 0.90**	177292	0.831	**Lden, 1.10**	174723	0.835
			Lden, 0.95	176111	0.833	**Lden, 1.20**	175858	0.833
			Lden, 1.05	174803	0.836	**Lden, 1.30**	178512	0.829

DISCUSSION

The search for noise metrics that relate well to the annoyance reactions of the population exposed is not new. The introduction of the L_{den} and L_{night}, which are based on the LA_{eq}, only took place after long and extensive discussions. However, in the debates around airports residents frequently complain that their exposure to noise is still not well captured by the noise metrics that are used within the policy discourse. For example, in the ANASE study around the London airports researchers investigated whether the LA_{eq} is the appropriate measure to relate to reported annoyance. They introduced the noise metrics Lav and Nav that focused on the sound level and the number of events respectively. They concluded that the relative importance of the number of aircraft has increased over time [11]. In the NORAH study around four German airports, it was found that the percentage of persons highly annoyed by air traffic noise at comparable noise levels was larger than would be expected from the generalized dose response curves introduced by Miedema and Oudshoorn [12]. Therefore, other noise metrics based on number of events and noise level were also taken into account [13].

In this study, we were confronted with residents around a military airbase that asserted that their exposure to noise could not be compared to civilian airports. Instead of the number of aircraft increasing over the years and the noise level per event decreasing, the opposite is occurring around the airbase: few numbers and very high noise levels. This gave us the opportunity to check how the noise versus numbers trade-off would hold in this situation. In an attempt to capture all relevant aspects of aircraft noise exposure, we defined noise metrics for “level”, “number”, “duration” and “integrated exposure”. These metrics were related to reported severe annoyance by respondents of a survey that investigated the general health of the population in the South of Limburg. In this study we could not look at the influence of time of day because flights at Geilenkirchen mostly take place during daytime on working days.

The results do not clearly point in the direction of a noise metric based on peak levels, number above or time above that would perform better than L_{den} in describing the relation between aircraft noise and annoyance. The spearman correlation between the metrics is moderate to high, indicating that despite the different ways of deriving the metrics they describe a similar noise pattern over the study area. Interestingly, the models including noise metrics based on the duration of the exposure (time above) did seem to fit the data equally well as the L_{den}, despite having the lowest correlation with the L_{den}. Especially the models with the time above 70 dB(A) and 75 dB(A) and the noise level exceeded for 4 hours during the year. The models based on the highest LA_{max} events and the highest percentiles did perform poorly compared to L_{den}. Possibly because only very few events are used to describe the yearlong exposure of the residents. As we are looking at the exposure at the home address, residents might even have missed these events completely. Metrics based on the number of events above a certain noise level did show better model fit than models based on noise levels, but did not improve upon the L_{den}.

Based on their data analyses Miedema and Vos [9] argued for a trade-off factor of 10 between noise and numbers in the calculation of the L_{den}. In the ANASE study the case is made that the trade-off has increased in recent decades and more emphasis should be given to the number of noise evens [11]. In this study, we used a similar approach as suggested by Miedema and Vos by calculating an L_{den} alpha. The results around the military airbase suggest that placing more emphasis on the number of noise events by using an alpha of 1.05 or 1.10 might improve the model fit, but the difference with the regular L_{den} metric is small.

We do appreciate that the circumstances around the military airbase are distinct from the situation around most larger civilian airports, with relatively few overflights and very high noise levels per event. However, the noise exposure was not only due to the military airbase, but also to the Maastricht Aachen Airport. This is a civilian airport with a small number of aircraft movements, but its presence ensures that our results regarding the noise metrics are not only based on the situation around the military airbase. Due to the differences in fleet composition, the correlation between the noise indicators “behaves” differently for the two airports. This made it possible to study the noise indicators under different noise exposure conditions.

Although the number of respondents to the health survey is large, the group of highly noise exposed is relatively small. In total, 218 respondents were exposed to L_{den} levels > 55 dB(A). This might hamper the comparison of the logistic regression models because the exposure distribution is skewed to the lower end.

One factor is kept constant in studies looking into alternative noise metrics. Most metrics are based on a one year period of noise exposure. From a policy point of view this is a logic standpoint. It is difficult to base norms and regulations on single events or short periods of time. In line with these regulations and the accompanying noise metrics, in survey research respondents are asked to reflect on their annoyance level during the past 12 months. The period of one year is a construct that might not agree with the way residents perceive and react to the aircraft noise events. While looking at the best noise metric to describe the annoyance experienced by the population is a useful exercise, it should be kept in mind that solutions to the annoyance itself must also be found outside the discussion about noise exposure alone.

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