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World Health Organization's guidelines for environmental noise revisited

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ABSTRACT

Recent data published after the presentation of the 2018 WHO Environmental Noise Guidelines for Europe do not support the recommended limits for transportation noise to prevent adverse health effects. Comprehensive studies from Switzerland, along with survey results from UK and US, indicate that noise exposure limits should be about 10 dB more lenient than those recommended by WHO. New data will be presented and discussed.

Keywords (3-6): Noise, Annoyance, Guidelines

INTRODUCTION

In 1999, the World Health Organization, WHO, published its first guidelines for community noise. In the foreword, WHO state~~s~~d that the *scope of the guidelines is to consolidate actual scientific knowledge on the health impact of community noise and to provide guidance to environmental health authorities and professionals trying to protect people from the harmful effects of noise in non-industrial environments* (1).

Exposure limits for critical health effects, so-called guideline values, were listed for various environments. However, the document gave no information on how these guideline values were determined.

The report listed recommended noise exposure limits for what was called *critical health effects.* For a general outdoor living area, the guideline value was L_{Aeq} = 55 dBA for the 16-hour daytime period. The rationale for choosing this limit was as follows: *During daytime, few people are highly annoyed at L_{Aeq} levels below 55 dB* with no further explanation or quantification. Considerations of political or economic consequences which are necessary inputs in a regulatory process were not part of the WHO document.

All guideline values were for environmental noise in general and they were not source specific.

In 2018, WHO published new environmental noise guidelines (2). In the foreword, the guidelines are presented as *the first of their kind globally* despite the fact that the full title of the report is *Environmental noise guidelines for the European Region.* The new guidelines were said to be the next evolutionary step following the 1999 Community noise guidelines and the 2009 Night noise guidelines for Europe (3). It was stated explicitly that the new 2018 WHO guidelines superseded and complemented the two previous documents.

The new guidelines were said to *offer robust public health advice* [and] *serve as a solid basis for future updates.* The guidelines also introduced the concept that ten percent absolute risk of prevalence of a highly annoyed population was the benchmark level for adverse health effects. No further explanation was offered for this choice of limit value. New exposure-response curves for transportation noise were established on the basis of a relatively small number of observations and surveys conducted after 2000. In combination with the 10 % risk criterium WHO recommended new limit values for general noise exposure and nighttime exposure which were drastically lowered compared with the 1999 guidelines. The 2018 document used the expression ***strongly*** *recommends* (in bold !) yet in the same paragraph the evidence for these recommendations was considered being of *moderate quality.*

The exposure-response curves developed by Guski et al. (4) which were the basis for the new WHO guidelines are shown in Figure 1, and the corresponding recommended limits are listed in Table 1.

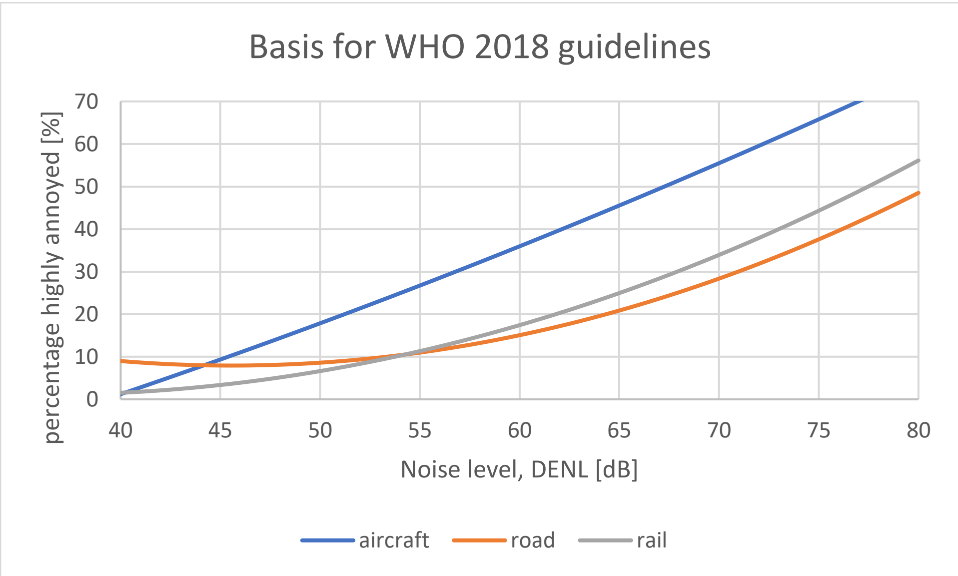

Figure 1. Exposure-response curves for transportation noise developed by Guski et al. (4)

The new noise limits proposed by WHO have been endorsed by the European Union (5), but to these authors' knowledge, no national regulatory authorities have yet adopted the new WHO recommendations. Since their publication, however, new survey results and studies have been presented that in no way support the proposed WHO environmental noise limits.

Swiss environmental noise report

~~The~~ Eidgenössische Kommission für Lärmbekämpfung, EKLB, in Switzerland (Federal Noise Abatement Commission), has presented new limit values for road, rail and aircraft noise (6) (English translation (7)).

This EKLB report is particularly interesting ~~as~~ because there is a large mismatch between the Swiss limit values and the 2018 WHO recommendations. The main reason for this is that the Swiss commission defines 25 % highly annoyed as the maximum permissible nuisance as opposed to the 10 % limit recommended by WHO. Both parties, however, claim to have set limit values for transportation noise to avoid adverse health effects.

The proposed Swiss limits have not yet been implemented in new noise regulations as they are still pending in the legislative system. The new Swiss generic limit values are shown in Table 1.

ALTERNATIVE SURVEYS

UK Aircraft noise survey

In the summer 2014, UK authorities conducted a survey on aircraft noise annoyance referred to as SoNA – Survey of Noise Attitudes. Face-to-face interviews were conducted at 9 large airports in England, addressing 2000 residents exposed to aircraft noise levels above $L_{Aeq,16h}$ = 51 dB. An exposure-response function showing the prevalence of highly annoyed residents as a function of the chosen noise index was derived by conventional regression techniques (8). The sixteen-hour day equivalent level can be converted to DENL using the conversion tables proposed by Brink et al. (9). The SoNA exposure-response curve indicates a slightly smaller prevalence of annoyance than the curve derived by Miedema & Vos as shown in Figure 2. In other words, for a given noise exposure in 2014 people in the UK seem to be less annoyed by aircraft noise than what was predicted by the exposure-response curve presented by Miedema & Vos in 1998.

The SoNA curve can be used to calculate the noise level corresponding to 10 % highly annoyed as proposed by WHO. The result is presented in Table 1.

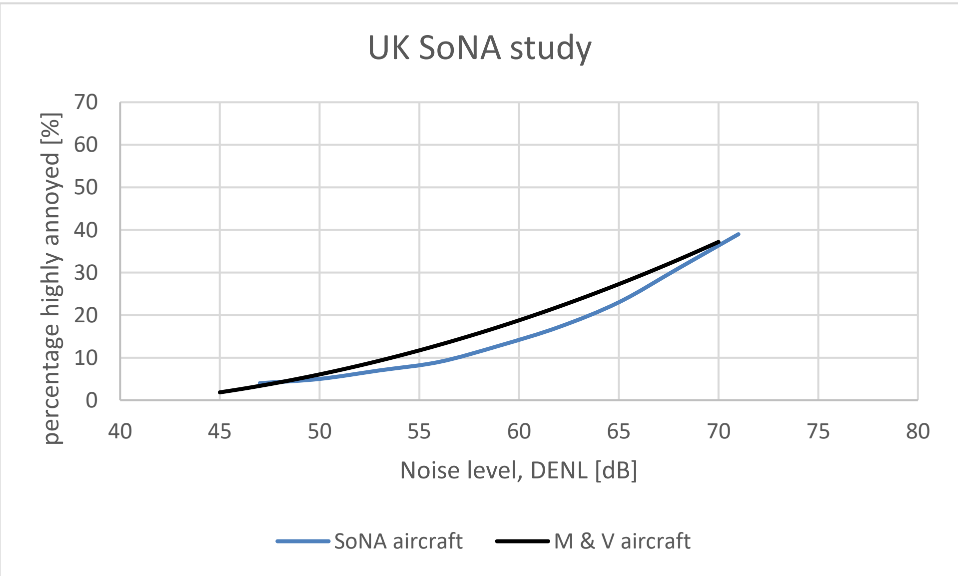

Figure 3. Exposure-response curve derived from the UK SoNA study (8)

US Aircraft noise survey

The US Federal Aviation Administration has recently sponsored a large-scale aircraft noise survey. The consultancy firm HMMH, Inc. was commissioned to carry out the Neighborhood Environmental Survey, NES, which comprised interviews of about 10 000 residents at 20 representative US airports. The field work was completed 2015-16 and the final report was published in 2021 (10).

HMMH conducted a conventional regression analysis to develop a *US national average exposure-response function*. They concluded that the prevalence of highly annoyed residents was much higher than predicted by the previous 1992 FICON exposure-response function, see Figure 3.

At first glance the NES exposure-response function established by Miller et al. also seems to predict a much higher prevalence of annoyance than the Miedema & Vos curve, but a closer analysis yields a different result.

Most social and socio-acoustic surveys have previously been conducted as live-agent interviews either in the respondent's residence or via telephone. Miller et al., however, decided to carry out the NES study as a postal survey. A limited number of residents (about 2 300) in the selected study areas, however, were interviewed via telephone. The analysis showed that people are more likely to express high annoyance when answering a written questionnaire than when being interviewed by a live agent. Miller et al. found that the difference was equivalent to about a 5 dB shift in the noise exposure (Figure D-2 in (10)).

By convention people that respond to the upper 27-29 % of the annoyance scale are characterized as *highly annoyed.* This corresponds to the three upper response categories of an 11-point numerical scale. In the NES study the annoyance was assessed on a 5-point verbal scale and a person responding to either of the two upper categories (very annoyed or extremely annoyed) was considered *highly annoyed.*

The standard ISO 15666:2021 (11) describes a method to convert a 5-point verbal scale response to a response that is comparable with an 11-point numerical scale response. A CTL analysis was carried out for both sets of the NES response data, postal and telephone, and the difference was ΔL_{ct} = 4.8 dB.

The Miedema & Vos exposure-response curves are based on surveys conducted as telephone or face-to-face interviews and the scoring of *highly annoyed* for these surveys closely resembles using the upper 27-29 % of the annoyance scale. So, in order to compare the NES results with the Miedema & Vos curve, the NES data should be adjusted 1) by 5 dB to compensate for postal vs. live agent interview, and 2) by 5 dB to compensate for verbal vs. numerical response scale. The original NES curve and the adjusted one are shown in Figure 3. The adjusted curve is quite similar to the Miedema & Vos curve for exposure levels below about L_{dn} = 60 dB. This is the primary range of regulatory interest.

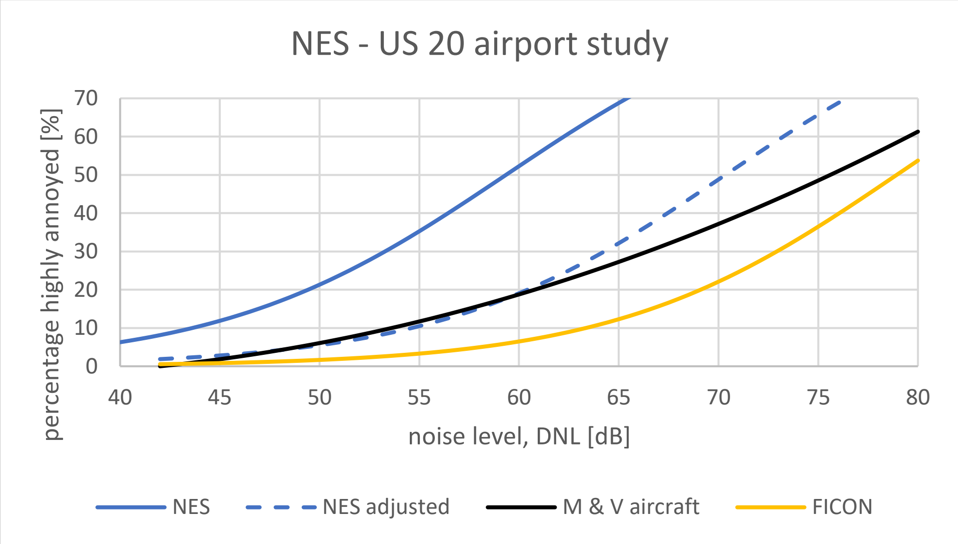

Figure 3. Exposure-response curves derived from the US NES study. Original ERF (blue) and an ERF adjusted 10 dB according to the response scale and mode of presentation (blue dashed) (10).

The new "US National Dose-Response Curve" developed by Miller et al. can be used to calculate the noise level corresponding to 10 % *highly annoyed.* This is the limit for adverse health effects according to WHO. A noise exposure level of L_{dn} = 44 dB corresponds to 10 % *highly annoyed.* The exposure-response curves established by Guski et al. (4) are based on face-to-face or telephone surveys and the annoyance was assessed using a numerical response scale. The limit for 10 % *highly annoyed* according to the NES study should therefore be adjusted by (5 + 5 = 10) dB as explained above for a direct comparison with the WHO recommendation and the Miedema & Vos curve.

Analyses of post-2000 annoyance surveys

Gjestland has analyzed 18 aircraft noise surveys conducted after 2000 comprising more than 16 000 individual responses (12). He used the CTL method (13) and found that the average CTL value for these surveys was L_{CT} = 70.7 dB and the noise level associated with 10 % *highly annoyed* was L_{den} = 53 dB.

Gjestland has also analyzed 18 surveys on road traffic noise conduced after 2000 comprising more than 28 000 individual responses (14). The average CTL value for these surveys was L_{CT} = 80.3 dB and the noise level associated with 10 % *highly annoyed* was L_{den} = 63 dB.

Japanese studies

Yokoshima et al. have presented an analysis of 34 Japanese surveys on annoyance due to transportation noise (15). They divided the sources in road traffic, conventional railroad, high-speed railroad (Shinkansen), civil aircraft and military aircraft.

A majority of the Japanese surveys have been conducted using self-administered questionnaires that were either delivered directly to the respondent or distributed by mail. The completed questionnaires were either picked up by a survey representative or returned by mail. The remaining surveys were conducted as face-to-face interviews.

Miller et al. (10) have shown that a survey based on self-administered questionnaires yields a higher prevalence of annoyance than a face-to-face interview. They found a difference equivalent to a 5 dB shift in the exposure level. A comparison reported by Fidell et al. (16) of 10 mail surveys on aircraft noise (32 airports) and 35 surveys (47 airports) using face-to-face interviews showed an average difference in the prevalence of annoyance equivalent to a 10 dB shift. This higher value, however, may be partly due to differences in other non-acoustic factors. A conservative conclusion is that the difference between the two modes of surveys is *at least* equivalent to a 5 dB shift. It is likely that a similar shift can also be found for surveys on rail and road traffic noise.

CTL calculations have been carried out according to ISO 1996 (13) for all the Japanese studies reported by Yokoshima et al. (16), and the CTL values for the mail surveys have been adjusted by 5 dB.

Yokoshima et al. reported ten surveys on road traffic noise conducted between 1994 and 2011 (15). Nine of the Japanese surveys have similar results having adjusted CTL values between L_{ct} = 76 dB and L_{ct} = 86 dB, (average 80 dB ± 4 dB) whereas one survey from Kanagawa (SASDA reference JPN010RT1999) reported by Yokoshima and Tamura (17) is a typical outlier with adjusted L_{ct} = 59.6 dB. This study was excluded from the analysis by Yokoshima et al. The resulting *average exposure-response curve for road traffic noise in Japan* is a little below the Miedema & Vos curve at intermediate exposure levels as shown in Figure 4. The limit value for 10 % HA is L_{den} = 63 dB.

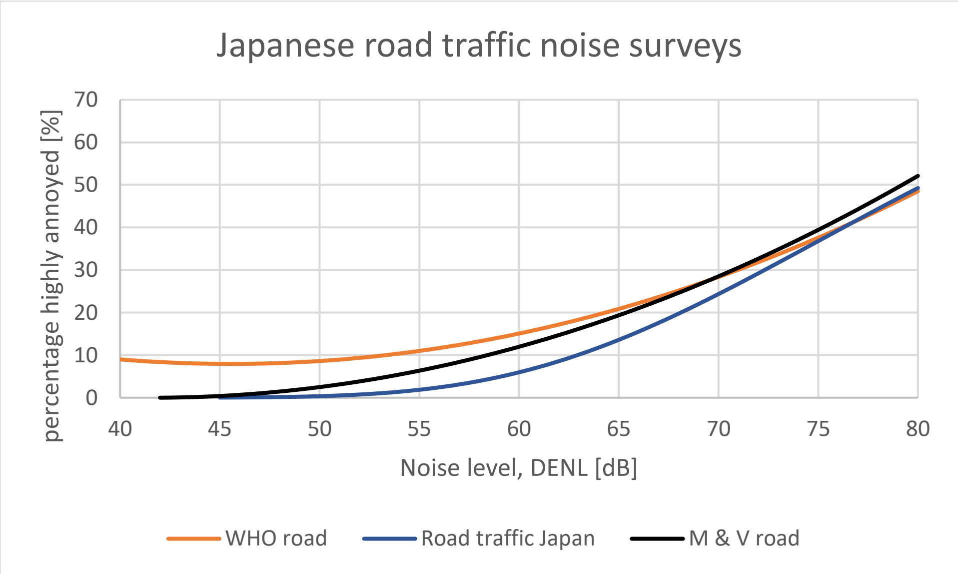

Figure 4. Exposure-response curves derived from nine post-2000 Japanese surveys on road traffic noise compared with similar curves presented by Miedema & Vos (2) and WHO (3). The Japanese exposure-response curve has been adjusted for direct comparison with the two other curves.

Yokoshima et al. have presented a similar analysis of annoyance due to noise from Japanese railroads (15). Eight surveys of conventional railroads conducted between 2001 and 2016 were included. These surveys have adjusted CTL values in the range L_{ct} = 72 dB and L_{ct} = 78 dB (average 74 dB ± 3 dB).

Surveys of high-speed railroads were analyzed separately. Eight surveys conducted between 2001 and 2016 were included. Their adjusted CTL values vary quite a bit from L_{ct} = 61 dB to L_{ct} = 89 dB (average 71 dB ± 8 dB). The difference between the two types of train is about ΔL_{ct} = 2.5 dB The resulting *average exposure-response curves for noise from conventional railroad and high-speed railroad in Japan* are shown in Figure 5. The limit value for 10 % HA is L_{den} = 56 dB and L_{den} = 54 dB respectively.

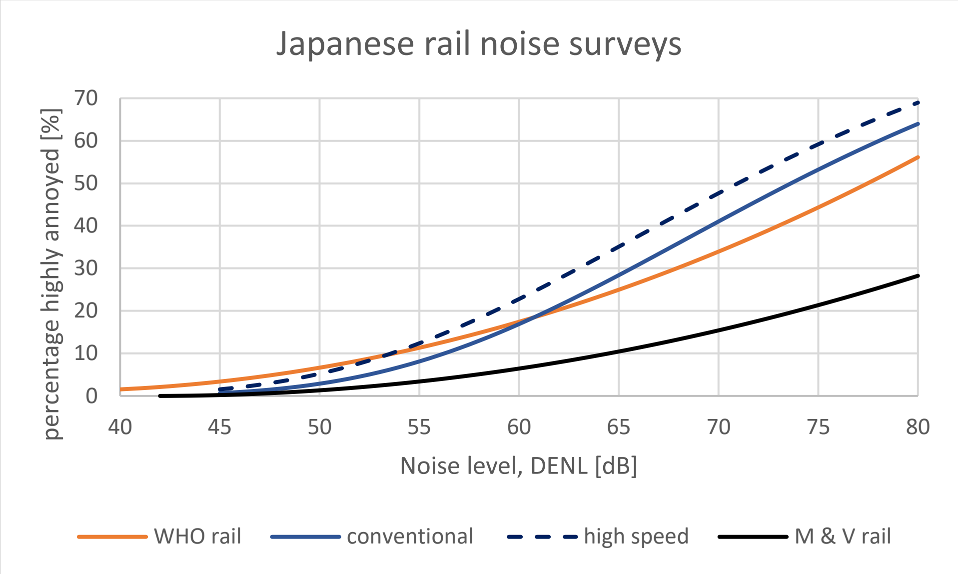

Figure 7. Exposure-response curves derived from recent Japanese surveys on railroad noise compared with similar curves presented by Miedema & Vos (2) and WHO (3). The Japanese exposure-response curves have been adjusted for direct comparison with the two other curves.

Yokoshima et al. (15)also presented surveys on civil and military aircraft noise, but the number of surveys was too small to present any meaningful average response curves.

Comparison of limit values

Table 1 lists limit values for noise exposure to avoid adverse health effects. These values have either been recommended by a relevant authority (WHO or EKLB) or they represent the level associated with 10 % *highly annoyed* from derived exposure-response functions.

According to WHO noise levels that yield a prevalence of high annoyance greater than 10 % of the exposed population are associated with adverse health effects (3).

Eight of the entries in Table 1 are limit values calculated from derived exposure-response functions using the WHO definition. These entries are marked with *). Data for these entries are based on surveys that have been carried out in accordance with the recommendations in ISO/TC 15 666 (11) or the reported survey results have been adjusted accordingly. The percentage of *highly annoyed* respondents have been based on the assumption of a live agent interview. The cut-off point for high annoyance has been 70-75 percent on the annoyance scale. The survey protocols have been sufficiently similar so that the survey results can be directly compared. Similar survey protocols were used for the surveys included in the 2018 WHO guidelines recommendations.

However, it should be noted that the survey protocol is not a part of the WHO recommendations. Surveys conducted in a different manner could give different noise limit values for ten percent prevalence of *high annoyance.* As an example, consider the results reported by Miller et al. (10). The US National Dose-Response curve based on a mail survey shows 10 % *highly annoyed* for L_{dn} = 44 dB (see Figure 3). Miller et al. also reported a dose-response curve based on telephone interviews. This curve was shifted about 5 dB and shows 10 % *highly annoyed* for L_{dn} = 49 dB. Finally, if the results were also adjusted for a numerical vs. verbal response scale 10 % *highly annoyed* would correspond to a noise level L_{dn} = 54 dB. So, which of these values should be used as a limit for adverse health effects? A definition of adverse health effects related to 10 % *high annoyance* is therefore ambiguous and must be further qualified.

Similarly, Yokoshima et al. (15) have presented average dose-response curves for transportation noise in Japan. These curves have been compared with the recent WHO recommendations. However, most of the Japanese surveys have been using a self-administered questionnaire that the respondents completed themselves whereas the WHO data is based on face-to-face interviews. In order to make a meaningful comparison of the two sets of results it is necessary to adjust for the difference in survey mode.

The old WHO non-source specific daytime limit from 1999 has been converted to source specific DENL values using the conversion values provided by Brink et al. (9). The levels calculated from derived exposure-response functions have been rounded off to the nearest decibel, and no distinction has been made between DNL and DENL.

Table 1. Limit values to avoid adverse health effects

	General exposure L_{den} [dB]		
	Air	Road	Rail
WHO 2018 guidelines (3)	45	53	54
Swiss recommendations (7)	55	62	65
WHO 1999 (1)	57	57	61
*EU - Miedema & Vos (2)	54	58	65
*SoNA study (9)	57		
*NES study - adjusted (11)	54		
*18 post-2000 surveys (13)	53		
*18 post-2000 surveys (15)		63	
*9 Japanese road (16)		63	
*8 Japanese conventional rail (16)			56
*8 Japanese high speed rail (16)			54

Values marked with an asterisk represent 10 % highly annoyed

Discussion

Table 1 clearly indicates that the new 2018 limits from WHO are very different from most data presented by others. For aircraft noise in general WHO recommends a limit of L_{den} = 45 dB, whereas others suggest limits between 53 dB and 57 dB with a mean level L_{den} = 55 dB. The WHO limit is a full order of magnitude more stringent.

Studies on aircraft noise annoyance have recently been conducted in UK and USA with the specific objectives of updating the national noise regulations. The UK uses “average summer day noise exposure”, $L_{Aeq,16h}$, as the primary noise index. This index can be compared with DNL or DENL by means of the conversion tables provided by Brink et al. (9). The results from the UK SoNA study indicate a lower prevalence of annoyance than predicted by the Miedema & Vos curve from 1998. This finding contradicts the often-repeated assertion that annoyance due to aircraft noise has increased over the last few decades. Neither does the analysis of post-2000 aircraft surveys by Gjestland indicate any increase in the prevalence of *highly annoyed* residents.

At first glance the analysis of the US NES study by Miller et al. (10) indicates a much higher prevalence of annoyance than predicted by the FICON curve (see Figure 3). However, if the results are adjusted to make them comparable with other surveys, the NES results are very similar to the Miedema & Vos curve for exposure levels below about

L_{dn} = 65 dB. This is still a higher prevalence of annoyance than currently assumed by the US FAA, but the result confirms the long-term stability of annoyance with aircraft noise.

For road traffic noise the trend is the same. New findings do not confirm the low limit values recommended by WHO, but the difference between the WHO recommendation and the other limit values are a little smaller, with an average of 6 dB.

For annoyance caused by railroad noise the situation is different. The concept of *rail bonus and aircraft malus* has previously been considered a well-documented fact. In comparison with road traffic noise, people were generally more annoyed by aircraft noise and less annoyed by railroad noise at equal exposure levels. This is clearly illustrated by the Miedema & Vos. The recommendations by WHO and EKLB maintain the aircraft malus, but the annoyance from road and rail traffic appears to be more equal. There are few new railroad surveys from Europe, but the surveys from Japan indicate a high prevalence of annoyance similar to annoyance from aircraft noise.

Conclusions

In 2018 WHO published new environmental noise guidelines for Europe. It was recommended to keep exposure to various transportation noise sources below certain levels to avoid adverse health effects. These levels were chosen as the limit values for 10 % prevalence of high annoyance among the exposed residents. The 2018 recommended limits have so far only to a very little extent been implemented in regional or national noise regulations.

Since the publication of the WHO recommendations new survey results and new studies have been presented whose conclusions deviates substantially from the WHO exposure limits. This seems to support the allegation that the World Health Organization's guidelines have been based on a non-representative selection of survey results.

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