Validation of a new procedure for rating shooting sounds with the help of field survey data

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Introduction

It is well-known that the community response to environmental sounds not only depends on sound level but also on source type. At least at moderate and relatively high sound levels, aircraft sounds are more, and railway sounds are less annoying than those produced by road traffic (e.g., see [1]). To enhance the comparability between the community responses, and to facilitate equal treatment of different transportation sources with respect to the degree of annoyance that may be considered being acceptable, adjustments relative to the dose-response relation for road traffic have been recommended in ISO 1996-1 [2]. For shooting sounds, there is ample evidence that at comparable sound levels, the annoyance is higher than that caused by road-traffic sounds [3, 4]. In the present study, a new procedure for rating shooting sounds is made suitable in such a way that overall, the procedure directly yields a rating level that numerically corresponds to the sound level of equally annoying road-traffic sounds. The advantage is that, dependent on various acoustic features, penalties can be applied to single events. We will see below that especially for artillery fire, it would actually be wrong to apply penalties in a global way afterwards.

In previous laboratory studies on the annoyance caused by shooting sounds produced by small, medium-large and large firearms [5, 6], it was shown that an accurate prediction of the annoyance was obtained on the basis of the outdoor A-weighted and C-weighted sound exposure levels (ASEL and CSEL; L_{AE} and L_{CE}). For a single event, the rating sound level, L_r in decibel, as determined on the basis of the laboratory results, is given by $L_r = L_{AE} + 12 + \beta(L_{CE} - L_{AE})(L_{AE} - \alpha)$. The third term $\beta(L_{CE} - L_{AE})(L_{AE} - \alpha)$ implies (1) that the annoyance is dependent also on the spectral content of the sound (characterized by $L_{CE} - L_{AE}$), and (2) that the additional annoyance ($\beta > 0$; $L_{CE} > L_{AE}$) due to the spectral distribution of the sound increases with ASEL for $L_{AE} > \alpha$ dB, and decreases with ASEL for $L_{AE} < \alpha$ dB. With the formula given above, it is in principle possible to express L_r in such a way that, overall, it numerically corresponds to the A-weighted day-evening-night level (L_{den}) of equally annoying road-traffic sound. As a result, the present procedure supersedes application of the adjustments for highly and high-energy impulsive sounds advised in ISO 1996-1 [2]. On the basis of the laboratory results the parameter values α = 47 dB and β = 0.015 were recommended. The annoyance ratings obtained in the laboratory, however, may not fully represent the annoyance experienced by the residents around shooting ranges. Moreover, in field surveys, respondents are asked for an overall annoyance rating, taking into account the annoyance experienced in the day-, evening- and night-time, and integrating the annoyance experienced in indoor and outdoor conditions. In the laboratory studies such comprehensive final judgements had not been provoked.

As a result, the Dutch Ministry of Defence contracted TNO Human Factors to validate the pertinent parameter values in the rating procedure. To enable the validation of the parameter values α and β, the community response to both shooting and road-traffic sounds is needed. For an optimal comparison between the responses to these two different sound sources to occur, the subjective effects of these sounds were determined for the same respondents, and with a uniform questionnaire. With the present design, unwanted influences of climatic, cultural, personal, physical, and methodological factors, as well as various possible interactions of these factors on the comparison are reduced as much as possible [7, 8].

Brief description of the field survey

Method

Subjective reactions to shooting and (local) road-traffic sounds were determined for 400 respondents divided among 15 different residential areas located around an infantry shooting range (ISR) and an artillery shooting range (ASR). In general, the number of personal (face-to-face) interviews in each area ranged between 20 and 30. The questionnaire consisted of more than 200 questions. Both for the road-traffic and the shooting sounds, the annoyance was rated for indoor and outdoor conditions, and separately for the day-, evening-, and night-time. The respondents also had to give an overall rating, taking into account the annoyance experienced in the various conditions just described. For the annoyance questions, the response alternatives were “not at all” (1), “a little” (2), “moderately” (3), “very” (4), and “very much” (5).

Ammunition spent at the shooting range

Since the respondents had been asked to base the annoyance ratings on their experiences in the last 12 months, the ammunition spent at the ranges was determined for that time period as well. For each source (i.e., a specific combination of firearm, ammunition type and firing location) the total number of rounds was collected for each of the three relevant periods of the 24 hours’day. Similar information was obtained for the detonations, and the relevant features of sound mitigating measures (fences, shields, etc.) were specified.

Noise dose for road traffic

For 274 respondents, L_{den} for local road traffic in front of the façade nearest to the pertinent road was determined with the help of a Dutch standard calculation procedure. To enable these calculations, specific acoustically relevant information (e.g., distance between the road and the façade of the dwelling, degree of absorption and reflection) had to be determined for each of the 274 dwellings, and for 18 streets detailed information about traffic intensity had to be collected.

Annoyance caused by shooting sounds

Both for the group of respondents who lived around ISR and for those who lived around ASR, the percentages of "very" or "very much annoyed" respondents did not exceed 5% in any of the rated periods of the 24 hours' day. Since here, only respondents are considered to be annoyed who gave responses that exceeded a cut-off point at 60% of the scale, an implicit annoyance criterion A_{60} was applied (cf. [1]). With this criterion the percentage "overall annoyed" would be 0% in nine of the 15 areas. In the interest of a more sensitive effect measure, the annoyance was expressed as the percentage "annoyed" with a cut-off at 50 on the same scale of 0-100. With this criterion (denoted as A_{50}) 12 of the 15 areas yielded percentages "overall annoyed" higher than 0%.

Annoyance caused by local road-traffic sounds

Almost 260 of the 274 respondents for whom L_{den} for road traffic had been determined could be assigned to one of five class intervals with boundaries ranging from 48 to 68 dB in steps of 4 dB. All respondents with an overall annoyance score in the upper half of the annoyance scale (A_{50}) were considered as being "annoyed."

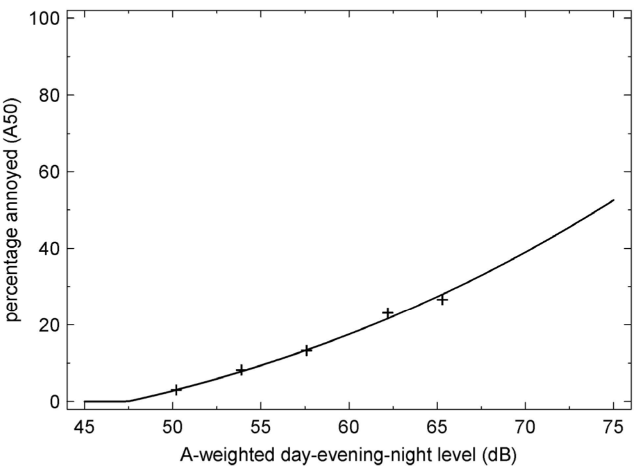

Figure 1: Community response to road-traffic sounds as a function of L_{den}.

Figure 1 shows the resulting percentages as a function of mean L_{den} in the various class intervals. The solid line nicely fits the data. The shape of the function is identical to the corresponding function obtained in [1]. For the present fit, however, the intercept had to be decreased by 8.1 percent points.

Calculation procedure

For a given combination of α and β, the contribution $L_{C(sm)}$ of source *s* in meteorological condition *m* to the rating level $B_{s,period}$ in a specific juridical period (day, evening, night) was determined with the help of $L_{C(sm)} = L_{AE(sm)} + 12 + \beta(L_{CE(sm)} - L_{AE(sm)})(L_{AE(sm)} - \alpha)$.

For the areas around ISR and ASR, there were 368 and 132 sources, respectively. To cover a wide range of possible meteorological situations, from strong downwind to strong upwind conditions, TNO Science and Industry determined the ASELs and CSELs received in the various residential areas for 27 different sound speed profiles. To enable the computation of the long-term average rating level, the statistical weights of the profiles were determined both for the meteorological day and the meteorological night. Since, due to prevailing south-west winds, the wind rose is asymmetrical, these statistical weights were actually determined for all sources separately. Additional information may be found in [9]. In the juridical day-time, the yearly-average noise dose $B_{s,day}$ is determined by the weightings for the meteorological day and night in 80% and 20% of the cases. In the juridical evening-time, these percentages were 15% and 85%, respectively. After applying the statistical weights and, dependent on both the absolute ASELs and CSELs and the juridical period of the 24 hours' day, weighting the total yearly number of rounds per source for audibility [10], $B_{s,period}$ was obtained by energetic summation of the contributions. For obtaining the day-evening-night rating level for the shooting sounds ($B_{s,den}$), penalties of 5 and 10 dB were applied to the levels in the evening and nighttime, respectively.

Results

Calculations for combinations of α and β

Here, due to limited space, we directly focus on the data from the more relevant residential areas, excluding two distant areas with very low noise doses. For the remaining 13 areas, the percentages of respondents who were "annoyed" by the shooting sounds, were converted into L_{den} of equally annoying (local) road-traffic sounds. The conversion was carried out with the help of the function shown in Figure 1. German field data suggest that the difference between dose-response relations for shooting and road-traffic sounds depends on the annoyance criterion, i.e., the adjustment is smaller with the annoyance expressed as A_{60} than as A_{50} [11]. Since, initially, it was intended to predict the percentage „highly annoyed," the levels of equally annoying road-traffic sounds were decreased by 1.5 dB. With the parameter values recommended on the basis of the laboratory results, the mean difference (M) between $B_{s,den}$ and the level of equally annoying road-traffic sound was equal to about -4 dB, implying that with these parameter values, $B_{s,den}$ was underestimated.

Next, for α between 25 and 65 dB, those β-values were sought (iterative method) that yielded unbiased predictions of the rating level (M = 0 dB). The appropriate estimated β varied from about 0.012 to 0.133. Especially for α >50 dB, the standard deviation (s.d.) of the differences was unacceptably high. However, even for combinations with α around 45 dB, s.d.-values of about 7 dB were obtained. This is explained by the absence of a significant correlation between the annoyance and $B_{s,den}$ for the areas around ISR.

Area (1)	$B_{s,day}$ (2)	$B_{s,evening}$ (3)	$B_{s,den}$ (4)	$L_{den,traf}$ (5)	d (6)
1	48.4	55.2	49.5	47.8	1.8
2	48.3	55.0	49.4	53.2	-3.8
3	59.1	66.4	60.5	60.9	-0.4
4	61.9	69.0	63.2	55.8	7.4
5	45.5	54.0	47.7	52.5	-4.8
6	49.4	57.6	51.5	51.1	0.4
7	44.2	51.3	45.5	46.0	-0.5
				M	0.0
				s.d.	3.7

Table 1: Areas around the artillery shooting range ASR and calculations of the adjusted noise dose ($B_{s,period}$ in decibel) for shooting sounds in the day and evening time with α = 45 dB and β = 0.0299. At ASR, there are no shooting activities during the night. The adjusted day-evening-night level ($B_{s,den}$) is given in column 4, and the level ($L_{den,traf}$) of road-traffic sounds that yield the same annoyance as the shooting sounds is given in column 5. The difference (d in decibel) between predictions (column 4) and observations (column 5) is given in the last column. M and s.d. represent the mean and standard deviation of the differences.

On the basis of the data from the residential areas around ASR only (see Table 1), the estimated β in combination with α = 45 dB was equal to 0.030, and the s.d. of the differences was equal to 3.7 dB, much smaller than for the larger data set. For the areas around ASR, Figure 2 shows the percentage of "annoyed" respondents as a function of $B_{s,den}$ of the shooting sounds. The regression line fitted to the data explains 65% of the variance in the percentages (r = 0.81).

Consequently, unbiased predictions of the rating level were obtained for various combinations of α and β. Both for the larger and the smaller data sets, the range of $B_{s,den}$-values is slightly decreased with decreasing α. For example, relative to the results obtained with α = 45 dB, the calculations with α = 25 dB yield $B_{s,den}$-values that are about 1-1.5 dB higher for distant, and 1.5-2 dB lower for nearby residential areas.

Confidence intervals

With the help of a bootstrap method, 95% confidence intervals of β were determined [12] for α-values of 35, 45, and 55 dB, and for two data sets (ISR+ASR and ASR). From each original set with *n* areas, a new random sample of *n* areas was drawn with replacement. Again with the iterative method a new β_{boot}–value was sought that yielded an unbiased solution (M = 0 dB). This procedure was repeated 100 times. Since in all six conditions, the frequency distribution of the β_{boot}–values did not differ from the standard normal distribution, the lower and upper limits of the confidence intervals are obtained by adding ±1.96 times the standard deviation of β_{boot} to the originally estimated β-values.

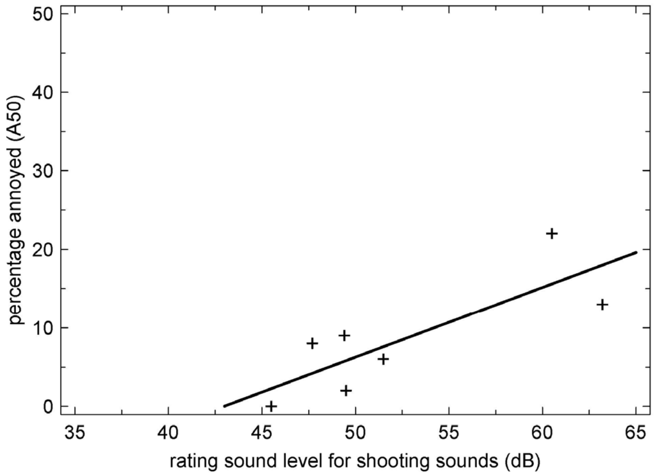

Figure 2: Annoyance in various residential areas around ASR as a function of $B_{s,den}$ as calculated with α = 45 dB and β = 0.030.

For the larger data set with 13 areas (ISR+ASR), the confidence intervals were relatively large: at the lower and upper limits of the interval, β (e.g. in combination with α = 45 dB) was equal to 0.013 and 0.037, respectively. These limits correspond to $B_{s,den}$–values that are 3.9 dB lower, and 4.6 dB higher than $B_{s,den}$ as calculated for the original β of 0.025. On the basis of the data from the seven areas of ASR only (see Table 1), the confidence intervals were much smaller: at the lower and upper limits of the interval, β (again in combination with α = 45 dB) was equal to 0.024 and 0.036, respectively, corresponding to $B_{s,den}$–values that are 2.7 dB lower, and 2.8 dB higher than $B_{s,den}$ as calculated for the original β of 0.030.

Discussion and Conclusion

The present rating procedure pretends to be widely applicable. Due to its features, there is no need to develop separate procedures for different categories of firearm calibers [5]. For an optimal test of the procedure, community responses are needed both for infantry and artillery ranges. If a field survey comprises the relevant acoustic and subjective data for only a restricted range of firearm calibers, a possible benefit of $B_{s,den}$ cannot be demonstrated because in such a case $B_{s,den}$ is highly correlated with most of the other acoustic measures. It is therefore unfortunate that in contrast with many other surveys around ranges with relatively small firearms (for a review, see [4]), for the areas around ISR there was no significant correlation between the annoyance and $B_{s,den}$.

For the areas around ASR the correlation between annoyance and $B_{s,den}$ (r = 0.81) was statistically significant. As expected, however, it was not significantly higher than that between annoyance and either the A-weighted (r = 0.79) or the C-weighted (r = 0.80) L_{den} of the shooting sounds. Since also for ISR and ASR together, the predictive power of the alternative measures is not greater than that of the present rating sound level, it is reasonable, awaiting a new opportunity for validation, to use the new model for noise zoning and land-use planning. There are several combinations of α- and β-values for which, on average, $B_{s,den}$ can be properly calculated. The range of $B_{s,den}$-values is slightly smaller for low than for higher values of α. For consistency with previous results [5, 6], we recommend to apply α = 45 dB together with an appropriate β-value. For various α-values and data sets, the 95% confidence intervals of β provide guidance in the selection of the value to be adopted in the rating procedure.

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