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ANNOYANCE CAUSED BY IMPULSE SOUNDS PRODUCED BY SMALL, MEDIUM-LARGE, AND LARGE FIREARMS

J Vos

Department of Perception, TNO Human Factors Research Institute, PO Box 23, 3769 ZG Soesterberg, The Netherlands

1. INTRODUCTION

Determination of the rating sound level for shooting sounds produced at fire ranges is complicated by the fact that, in general, the sounds may have been produced by a variety of firearms. From the results obtained in various field and laboratory studies, it can be concluded that the sounds produced by small and large firearms cannot be rated in the same way. For impulse sounds produced by small firearms it has been shown that, overall, a penalty of 12 dB has to be added to the (outdoor) A-weighted sound exposure level (ASEL) to obtain ASEL of equally annoying vehicle sounds [1]. For heavy bangs, such as those produced by artillery weapons and supersonic aircraft, the penalty to ASEL may extend to 20—25 dB [2,3]. For impulse sounds produced by the category of medium-large weapons (calibers between 20 mm and 100—110 mm), the information about appropriate penalties is very limited. For firearms with calibers of 20—35 mm, penalties between 13 and 16 dB have been found [4,5]. Other results [6], however, suggest that at equal (outdoor) ASEL, the indoor rated annoyance caused by the sounds from an anti-tank missile and a rifle was not significantly different, implying that in both cases a 12 dB penalty would suffice.

For lack of detailed information about the annoyance caused by medium-large weapon sounds, a new laboratory study was designed in which the annoyance was investigated for 14 different impulse sound types produced by various firearms ranging in caliber from 7.62 mm to 155 mm. In addition to an overall effect of sound level, it was expected that the annoyance would increase with firearm caliber. A possible predictor for the 'heaviness' of the impulse sounds might be the difference (ΔL) between CSEL and ASEL. In the experiment the various firearms were selected in such a way that for the entire ΔL-range (from

-1 to about 30 dB) a balanced distribution of the number of events was obtained. Sixteen subjects rated the annoyance indoors with (1) the windows wide open, and (2) the windows closed.

2. METHODS

For each impulse type, a digital recording was made at a distance ranging from 100—200 m for the small firearms to 800—900 m for the large firearms. On the basis of each recording various versions of the impulse sound were prepared. For the windows-open condition there were four such versions per impulse type. In the experiment, the (outdoor) ASELs ranged from 40 to 70 dB; CSELs ranged from 43 to 96 dB. The corresponding distances between source and receiver were simulated by broadband attenuation (geometric spreading) and additional attenuation of the high frequency components (air absorption). To simulate a representative outdoor-to-indoor noise reduction in the windows-closed condition, the additional spectral reduction of the impulses ranged between 13 dB for the 16 Hz and 31.5 Hz octave bands up to 35 dB for the 8 kHz octave band. Since the CSELs of the impulses were relatively low (96 dB at the maximum), this additional reduction is also valid for the heavier bangs included. The number of impulses in the latter condition was reduced to 35: 21 of the 56 impulses (14 types x 4 levels) presented in the windows-open condition were hardly audible after application of the outdoor-to-indoor noise reduction.

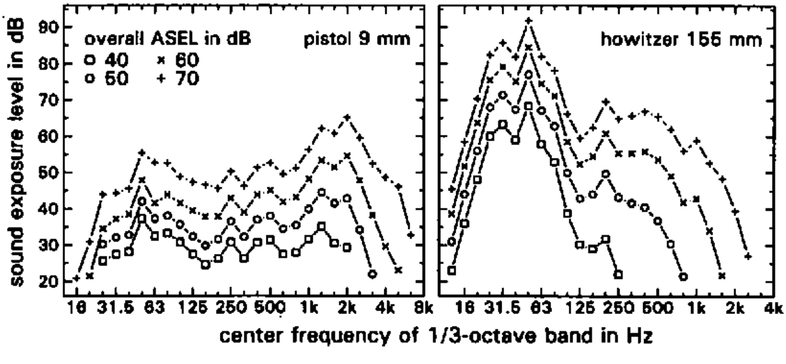

Fig. 1. Spectra of pistol and howitzer sounds

Fig. 1 shows the linear SEL in the various 1/3-octave bands for the four versions of a pistol 9 mm, and for the four versions of a howitzer 155 mm muzzle bang, as determined near the ears of the subjects in the windows-open condition. Especially for the pistol bangs presented at relatively high overall levels (L_{AE} equal to 60 and 70 dB), the spectral content is dominated by the energy in the frequency bands between about 800 Hz and 2500 Hz, whereas for all howitzer bangs, the spectral content is dominated by the energy in frequency bands between about 20 Hz and 100 Hz. For both impulse types, Fig. 1 also shows that due to air absorption, the relative contribution of the higher frequency components decreases with overall level. Eight subjects started with the windows-open condition and the other eight started with the windows-closed condition. After each stimulus presentation they responded to the question "How annoying would you find the sound if you heard it at home with windows closed (or opened) on a regular basis?" They were encouraged to use the whole range of the rating scale with values from 1 ("not annoying at all") to 10 ("extremely annoying"). Remote-traffic sound served as continuously present background noise. This sound was presented at an A-weighted average level of 35 dB and 40 dB in the windows-closed and windows-open conditions, respectively.

3. RESULTS

The annoyance ratings will first be related to ASEL and, for the sake of comparison, to CSEL of the impulses. Secondly, with the help of multiple linear regression analysis it will be determined to which extent the annoyance can be predicted from 1) the (linear) SELs in the nine octave bands between 16 Hz and 4 kHz, and 2) combinations of acoustic predictors such as ASEL, CSEL, and ΔL. In noise zoning the noise dose is usually expressed as levels measured outdoors. In the windows-open condition, the outdoor levels in front of the dwelling façade are, except for a small constant, close to the levels measured near the ears of the subjects. In the windows-closed condition, the annoyance will be related to the estimated outdoor levels as well.

Annoyance as a function of overall ASEL and CSEL

Windows-open condition. The ratings were significantly affected by ASEL and impulse type. Moreover, the effect of impulse type depended on ASEL: at low ASELs the impulses produced by small firearms were more annoying than those produced by medium-large and large firearms, whereas at high ASELs the impulses produced by the small firearms were less annoying than those produced by the large firearms.

This interaction effect is shown in Fig. 2a, where the ratings, averaged across subjects and replications, are plotted as a function of outdoor ASEL for eight of the 14 impulse types. For the total set of 56 impulses, 95% of the variance (r^2) in the mean ratings could be explained by ASEL. From the data shown in Fig. 2b, it can be concluded that, relative to ASEL, outdoor CSEL is an inadequate predictor of the annoyance. For the total set, r^2 was as small as 54%.

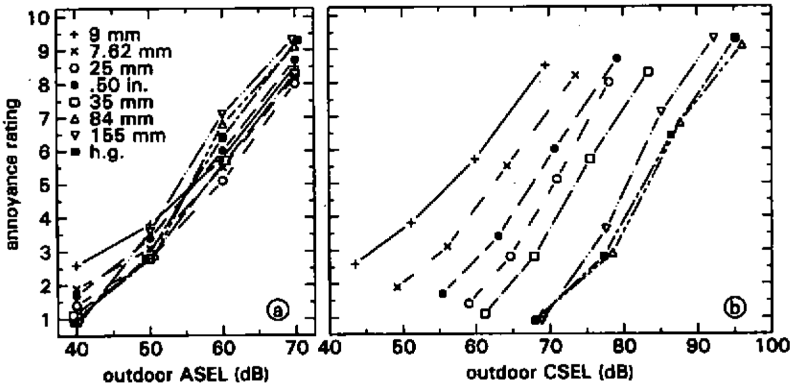

Fig. 2. Mean annoyance ratings in the windows-open condition, as a function of (a) outdoor ASEL and (b) outdoor CSEL, for various impulse sound types.

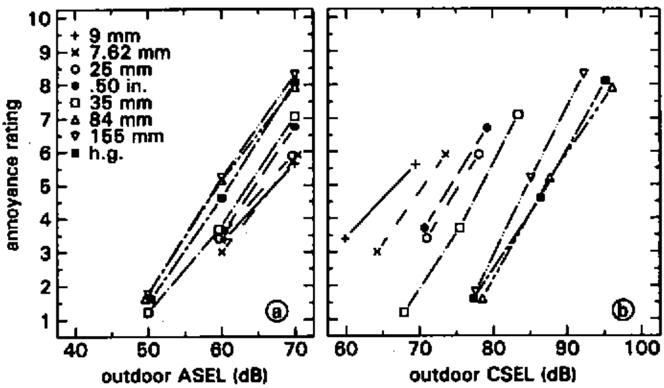

Fig. 3. Mean annoyance ratings in the windows-closed condition, as a function of (a) outdoor ASEL and (b) outdoor CSEL, for various impulse sound types.

Windows-closed condition. The annoyance ratings were significantly affected by ASEL and by impulse type. Again, the effect of impulse type depended on ASEL: the increase in the annoyance with ASEL was larger for the impulses produced by the large firearms than for those produced by the small firearms. The interaction effect is shown in Fig. 3a for eight of the 14 impulse types. For the total set of 35 impulses, 87% of the variance could be explained by (outdoor) ASEL. From the data shown in Fig. 3b, it must again be concluded that outdoor CSEL is less effective as a predictor of the annoyance. For the total set, r^2 was only 50%.

Annoyance as a function of specific spectral information

Windows-open condition. Fifty-six mean ratings (dependent variable) and 56 sets of the outdoor SELs in the nine octave bands (predictors) were subjected to a multiple linear regression analysis (stepwise procedure). With four predictors (SELs in the octave bands around 1 kHz, 63 Hz, 2 kHz, and 500 Hz), the total explained variance (multiple r^2) was equal to 0.95. With overall ASEL as the predictor, r^2 equaled 0.95 also. The predictive power of single measure ASEL is therefore equal to that of four octave-band levels. Neither addition of CSEL nor that of ΔL to ASEL resulted in a significant further increase in r^2.

Windows-closed condition. In the analysis (35 cases) three predictors (SELs in the 500 Hz, 63 Hz, and 2000 Hz octave bands) were selected, which together explained 93% of the variance. With overall ASEL, r^2 equaled 85%. In addition to ASEL, the product of ASEL and ΔL was selected as the best second predictor; r^2 increased from 85% to 97%.

4. DISCUSSION

The present data allow the determination of the extra penalty (P_e) that should be added to ASEL of the impulses produced by medium-large and large firearms to obtain ASEL of equally annoying impulses produced by small firearms. Here, maximum P_e will be first determined by comparing the annoyance caused by a) the various versions of the three impulse types with very high ΔL-values, typically between 25 and 29 dB (originating from hand grenade and weapon calibers 84 mm and 155 mm), to b) the 9 mm pistol shots (ΔL between −1 dB and 4 dB). For the heavy impulses rated in the windows-open condition, P_e ranged between about -8 dB at L_{AE} = 40 dB to 6 dB at L_{AE} = 70 dB (see Fig. 4). In the windows-closed condition, P_e ranged between about 3 dB at L_{AE} = 50 dB to 12 dB at L_{AE} = 70 dB (see Fig. 4), implying maximum $P_e \approx 0.5(L_{AE} - 45)$.

It is assumed here that for noise rating procedures the annoyance experienced indoors with windows closed is the decisive criterion. In this condition 97% of the variance in the total set of mean annoyance ratings (y) was explained by $y = c + \alpha L_{AE} + \beta \Delta L \cdot L_{AE}$. In terms of P_e for all impulses with ΔL between −1 and 29 dB, this result corresponds to $P_e = 0.017\Delta L(L_{AE} - 45)$. For impulses produced by small firearms ($\Delta L \sim 0$ dB) $L_{AE,vehicle} = L_{AE,impulse} + 12$ dB [1]. Combining the latter two functions results in $L_{AE,vehicle} = L_{AE,impulse} + 0.017\Delta L(L_{AE} - 45) + 12$ dB. The relevance of this equation is illustrated in Fig. 5, where for all 35 impulses the annoyance is plotted as a function of ASEL of equally annoying vehicle sounds. The correlation between the annoyance and ASEL was, as expected, very high ($r = 0.98$, $r^2 = 0.97$).

For (outdoor) $L_{AE} < 45$ dB, the impulses can only be heard indoors if the windows are open. In such a condition maximum P_e is about 5 dB lower than in the windows-closed condition (see Fig. 4). Since in normal practical conditions the rating sound level around artillery and rifle ranges is not determined by impulse sounds with outdoor ASELs lower than 45 dB, there is no real need to make the computation of equally annoying vehicle ASEL more complex.

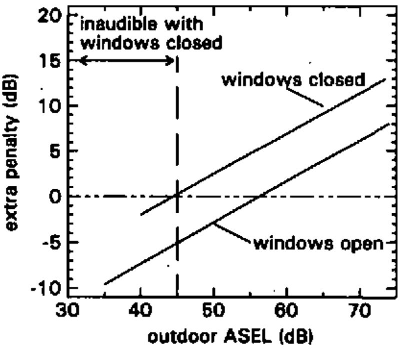

Fig. 4. Extra penalty to very heavy bangs as a function of ASEL, for two conditions

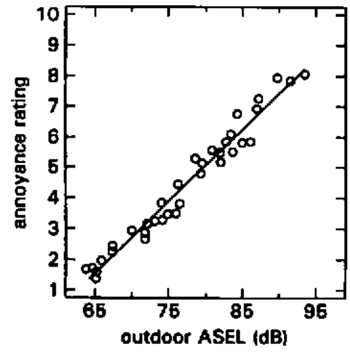

Fig. 5. Annoyance in the windows-closed condition, as a function of ASEL of equally annoying vehicle sounds

5. CONCLUSIONS

1) Outdoor ASEL of impulse sounds is a much better predictor of the annoyance than CSEL. 2) For a great variety of impulses produced by firearms ranging in caliber from 7.62 mm to 155 mm, an almost perfect prediction of the annoyance, as rated indoors with the windows closed, is obtained on the basis of the weighted sum of (outdoor) ASEL and the product of (CSEL-ASEL) and ASEL.

ACKNOWLEDGMENTS

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REFERENCES

[1] J. Vos, Proc. Internoise '95 (Newport Beach, CA) Vol. 2, 875-878 (1995).
[2] P.D. Schomer, Noise Control Eng. J. 42 (5), 179-191 (1995).
[3] P.D. Schomer, L.R. Wagner, L.J. Benson, E. Buchta, K.-W. Hirsch, and D. Krahé, Noise Control Eng. J. 42 (2), 71-84 (1994).
[4] E. Buchta, Belästigung durch Kanonen- und Straßenverkehrslärm (Institut für Lärmschutz, Düsseldorf, Germany, 1994)
[5] P.D. Schomer & L.R. Wagner, Noise Control Eng. J. 43 (1), 1-13 (1995).
[6] T. Meloni & A. Rosenheck, J. Acoust. Soc. Am. 97 (6), 1-6 (1995).