inter.noise 2000
The 29th International Congress and Exhibition on Noise Control Engineering
27-30 August 2000, Nice, FRANCE

I-INCE Classification: 6.1

BINAURAL LOUDNESS EQUALISATION OF A SET OF REAL CAR SOUNDS

N. Chouard

HEAD acoustics, Ebertstrasse 30a, 52134, Herzogenrath-Kohlscheid, Germany

Tel.: +49 (0) 24 07 57 734 / Fax: +49 (0) 24 07 57 799 / Email: nicolas.chouard@head-acoustics.de

Keywords:
SOUND QUALITY, LOUDNESS EQUALIZATION, BINAURAL LOUDNESS, JURY TEST

ABSTRACT
When carrying out listening test, there is sometimes the need to get rid of the loudness dimension, because it is one side already known as being the main dimension, and on the other side because it acts as a masking dimension on other second-order dimensions of the perceptual space. Some previously work carried out by the author showed that, at least for usual stationary car sounds, the interaural average of calculated loudnesses describes in a satisfactory way the overall perceived loudness. For car sounds presenting more peculiar characteristics (like e.g. slow intensity fluctuations, strong booming noise,...) it is however unclear if this remains valid. Car sounds of different types and classes ranging from small to luxury were thus matched to the same loudness by subjects in a listening experiment featuring an adaptive forced choice procedure. These subjective results will be compared to predictions based on different model-proposals. This work was carried out within the frame of the BRITE EURAM Project BE-96-3727 OBELICS.

1 - INTRODUCTION
When carrying out jury tests, there is sometimes the need to reduce the influence of the loudness dimension in order to get more information on others dimensions acting on the perceived sound quality: due to its main importance on sound perception, the loudness may act as a "masking dimension" on others perceptive dimensions: It is thus necessary to cancel this influence in order to be able to examine other dimensions. A possibility to do this is to equalise all noises to be presented to the same perceived loudness. The aim of this contribution is to propose a logical way to do this, and to test its validity on a set of car sounds.

2 - PROPOSAL FOR LOUDNESS EQUALIZATION
There are two possibilities to equalize a set of sounds to the same perceived loudness. The first one is to let subjects adjust the level of the sounds so that they become equal in perceived loudness. This might be seen as the best way to equalise loudness values. It is however a quite time consuming work. The other possibility is to use directly loudness computation models. This implies however that a model exists, which can describe in an adequate way the magnitude of the perceived overall loudness.

2.1 - Loudness model
Different models are provided for computing loudness. The ISO532b standardized loudness model for steady-state noises has been tested in many situations and with different types of noises, and despite some known limitations appears to be a good computation model for estimating the loudness of continuous sounds [1], for synthetics as well as real sounds: in the following proposal, we will use this model but other models might be used depending on the sounds considered.

2.2 - Timbre
Altering the loudness can have the consequence to change the timbre of the sound as well. This is particularly true for such real noises, which have a rich spectral content. In order to minimize such timbre modifications, it appears then reasonable to act on a "as small as possible" loudness range. This way, the difference in timbre modifications, between the weakly changed noise and the strongly one,

will not be crucial: no supplementary variable will be introduced if the eventual changes in timbre are comparable for each noise. Clearly: loudness equalization must not be done on a too big loudness interval. As a consequence, the use of the median loudness N_{med}=medianN1;N2;....;N14 seems to be best appropriated for such a loudness equalization procedure.

2.3 - Interaural differences and interaural loudness summation

In automobiles, quite strong interaural differences can frequently be recorded [2]. The loudness model however was originally developed for signals presented without interaural differences. For what concerns the question as wether to know how it is possible to summarise the two recorded information in order to describe the overall perceived loudness, the author found [2] that for synthetic (car indoor similar noises) as well as for real car sounds (dummy head indoor recordings) the interaural loudness summation hypothesis holds. As a consequence, it is adequate to consider the average $N_M=(N_L+N_R)/2$ of both calculated loudness on each ear N_L and N_R in order to get a sufficient good estimation of the perceived overall loudness of such binaural signals (however for "weak loudnesses" i.e. about N_M<1sone, this summation hypothesis underestimates the perceived loudness, when using ISO532b).

2.4 - Loudness fluctuations

Usually stationary indoor car sounds exhibit loudness fluctuations instead of one constant loudness over time. This leads to the question of the settings to be chosen for loudness computation: should the loudness be calculated on the whole duration, or regularly in time and averaged, or should a percentile value be chosen,...? Fastl [3] showed that the perceived average loudness of road traffic noise is strongly influenced by the louder events within the noise and can be estimated by the percentile loudness $N_{4\%}$, which describes the loudness exceeded 4% of the time measured in accordance with ISO532b. Some later experiment confirmed this for other sounds and when considering either $N_{4\%}$ [4], [5] or $N_{5\%}$ [6], [7] values.

2.5 - Recommendations for the loudness equalisation procedure

- The loudness equalization should only apply to sounds with "not too different" characters (e.g. a given driving condition)
- The loudness parameter used for the equalization should be the loudness value that is reached or exceeded in x% of the time $N_{x\%}$: based on studies at disposal, we propose the use of $N_{4\%}$.
- The instantaneous loudness of the binaurally recorded noise signal can be estimated by the average of the loudness from the left and right channel $N_{M,4\%}=(N_{L,4\%}+N_{R,4\%})/2$
- The target loudness for all noises within one noise set should thus be the median $N_{med,M,4\%}$ of the $N_{M,4\%}$ loudness values from the individual noises. After equalisation all noises should then reach a $N_{M,4\%}$ value equal to this $N_{med,M,4\%}$ median.

3 - TEST OF THE PROPOSAL ON THE BASIS OF REAL CAR SOUNDS

The sounds considered were binaural recordings of indoor car sounds when driving on a motorway at 130 km/h. Nine different cars covering the whole range of classes and types (from big to small cars and from luxury to economic) were recorded. These sounds present quite different characters with some extreme peculiarities: this is particularly clear per example for car 3, which has a very strong booming noise component so that the sound of this car depends quite exclusively of the engine noise and is perceived as a very tonal sound, or also for car 6, which contains quite only wind noise, i.e. a broad-band type sound with a strong low-frequency character.

3.1 - Loudness equalization using the proposal

The computation data according to the previous proposal as well as necessary level changes in dB in order to equalise all the sounds to the loudness of the car 7 are given in Table 1. For comparison, we consider both loudness equalisation models based on $N_{4\%}$ (4% loudness percentile) and on N_{AV} (average loudness value computed on the whole signal duration).

CAR	1 (sedan)		2 (luxury)		3 (economy)		4 (compact)		5 (sedan)	
Channel	L	R	L	R	L	R	L	R	L	R
$N_{4\%}$ [soneGD]	31,8	28,0	31,5	27,0	72,5	69,9	45,3	41,2	37,1	32,5
$N_{M,4\%}$ [soneGD]	29,9		29,25		71,2		43,25		34,8	
Amplification[dB] based on $N_{med,M,4\%}$	+5,2		+5,8		-8,3		-0,5		+2,9	
N_{AV} [soneGD]	30,12	26,1	29,4	25,1	64,6	62,1	42,6	39,4	35,1	30,8
$N_{M,AV}$ [soneGD]	28,1		27,2		63,35		41,0		32,95	
Amplification[dB] based on $N_{med,M,AV}$	+5,3		+5,9		-7,3		-0,4		+2,9	

CAR	6 (luxury)		7 (compact)		8 (van)		9 (economy)		
Channel	L	R	L	R	L	R	L	R	
$N_{4\%}$ [soneGD]	32,5	28,8	44,4	39,0	44,5	39,8	45,2	40,9	
$N_{M,4\%}$ [soneGD]	30,65		41,7=$N_{med,M,4\%}$		42,15		43,6		
Amplification[dB] based on $N_{med,M,4\%}$	+5		-0,1		-0,4				
N_{AV} [soneGD]	30,3	26,4	42,0	37,0	42,4	37,4	43,1	38,6	
$N_{M,AV}$ [soneGD]	28,35		39,5=$N_{med,M,AV}$		39,9		40,85		
Amplification[dB] based on $N_{med,M,AV}$	+5,2		-0,1		-0,5				

Table 1: Model-based computations and subsequent level-modifications.

3.2 - Loudness matching experiments

Our aim here was to let subjectively adjust the level of all the sound of the sound set to a same reference level (car 7). The chosen experiment-setting featured an adaptive "2AFC" (two alternatives forced-choice) 1up-1down procedure [8]: the two sounds are presented successively, and the task of the subject is to indicate which of the two sounds is the loudest one. The reference sound is the sound of car 7. The level of the test-sound is then modified in dependency of the subject's answer, so that at the end of a series of successive comparisons, the point of subjective equality (PSE) is attained between the loudness of the two sounds. The level changes steps are decreased during the course of the procedure, so that a greater precision can be attained in the vicinity of the PSE: steps are at the beginning 4dB and at the end of the procedure 1 dB. The duration of the sounds is of 1.5 s. The sounds are presented in a random order. When the loudness of the two sounds are similar, the subject's answer oscillate around the PSE. The PSE is then estimated from the median of the last 10 judgement oscillations. 12 normal hearing subjects took part to the test. Results are plotted in Fig. 1.

Fig. 1 shows that even if in general no great differences are obtained when using the N_{MAV} or $N_{M4\%}$ models, better amplification estimations are obtained from the model based on $N_{M4\%}$ values. This is particularly clear for the car 3, which presents a strong booming noise component. In this case, it is better to consider values based on $N_{M4\%}$. Moreover, the sounds for which the deviations between objective amplifications and subjective amplifications are the greatest, are the cars which present extreme characteristics (car 3=quite only booming noise, car 6=quite only low-frequency wind noise and car 8=strong rough motor noise).

4 - CONCLUSION

The loudness equalization method proposed here is based on the median of the interaural average of the ISO532b-based $N_{4\%}$ loudness values. The level of the signal present on each channel has thus to be modified, in the same manner for each channel so that the interaural differences proportions can be conserved, and so that the desired calculated average loudness values can be obtained. Subjective tests carried out showed that, this proposal is a first good approximation for estimating the level change to be applied to the sounds.

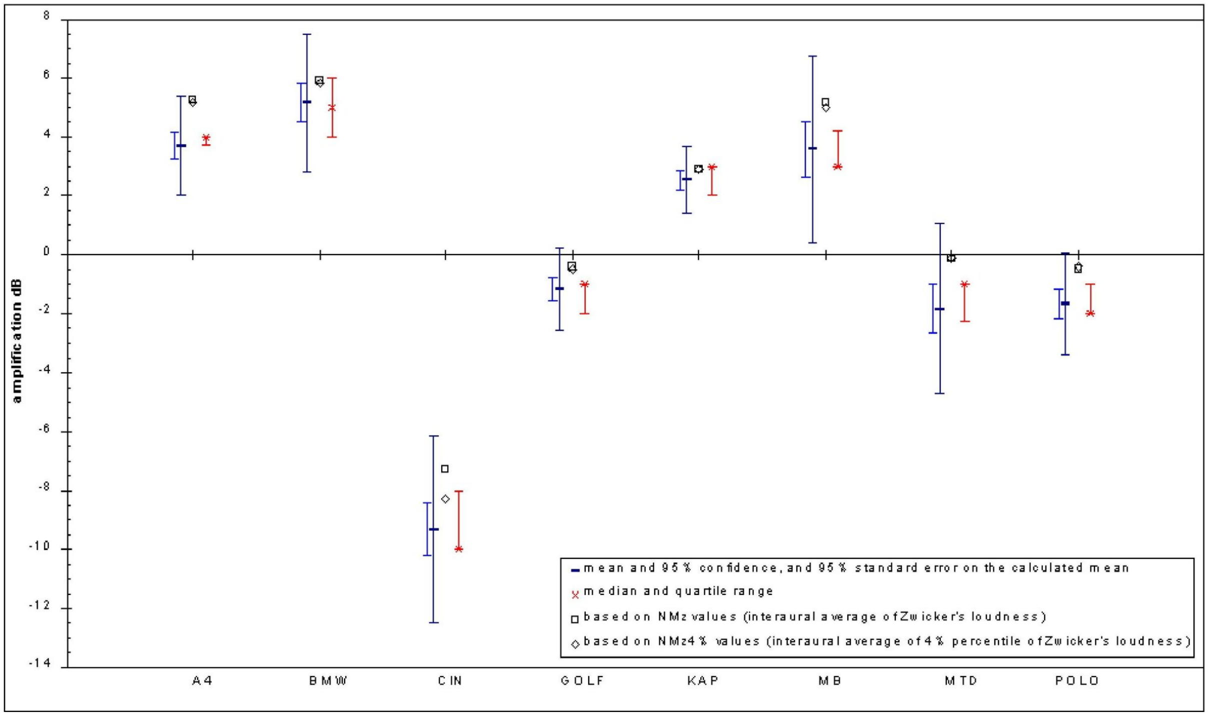

Figure 1: Amplifications [dB] obtained by subjective loudness equalisations tests: mean (+) and 95% confidence range on the data (great left vertical scatter lines) and 95% confidence range on the calculated mean (small left vertical scatter lines), as well as median (x) and quartile range (right vertical scatter lines); squares indicate the attenuation allowing to objectively equalise the sounds on the basis of the N_{MAV} values and lozenges indicate the attenuations allowing an objective equalisation on the basis of $N_{M4\%}$ values.

ACKNOWLEDGEMENTS
This work was carried out within the frame of the European BRITE-Euram Project OBELICS (Objective EvaLuation Of Interior Car Sounds - BE-96-3727).

REFERENCES

1. **Quinlan D. A.**, A comparative study of Zwicker's method for calculating the loudness of continuous sounds, *Noise Control Engineering Journal*, Vol. 42 (3), pp. 117-126, 1994

2. **Chouard N.**, *Loudness and unpleasantness perception in dichotic conditions*, Doctoral thesis of the University of Le-Mans, 1997

3. **Fastl H.**, *Evaluation and measurement of perceived average loudness*, in Contribution to psychological acoustics: results of the 5th Oldenburger symposium, 1991

4. **Stempliger I.**, Globale Lautheit von Industriegeräuschen, In *proceedings of the DAGA 96*, pp. 240-241, 1996

5. **Eichenlaub C.**, *Die Bedeutung psychoakustischer Parameter bei der Beurteilung von Windturbingeräuschen* , Diploma of the University of Oldenburg, 1999

6. **Widmann U.**, Evaluation of noise emissions of cars based on loudness, In *Proceedings of Internoise 96*, pp. 2205-2210, 1996

7. **Stempliger I.**, Beurteilung der Globalen Lautheit bei Kombination von Verkehrsgeräuschen mit simulierten Industriegeräuschen, In *proceedings of the DAGA 97*, pp. 353-357, 1997

8. **Gelfand K.**, *Hearing: an introduction to psychological and physiological acoustics*, Marcel Dekker Inc., pp. 284-312, 1990