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INFLUENCE OF THE NUMBER OF VEHICLES IN THE EMERGENCE OF SOUND EVENTS ON THE ANNOYANCE EXPRESSED
Experimental Study

~~M. Vallet~~
G. LABIALE

Translation of "Influence du nombre de vehicules et de l'emergence des evenements sonores sur la gene exprimee - Etude experimentale," Final report, Mar. 1981, Institut de Recherche des Transports; Centre d'Evaluation et de Recherche des Nuisances et de l'Energie, Bron Cadex, France, Report AER no. IV.2 (7306), 57 pp.

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION
WASHINGTON, D.C. 20546 MARCH 1982

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Please make this correction - See attached letter by Dr. Vallet

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INSTITUT DE RECHERCHE DES TRANSPORTS
CENTRE D'ÉVALUATION ET DE RECHERCHE
DES NUISANCES ET DE L'ÉNERGIE

Dr J. FIELDS
NASA
Langley Research Center
HAMPTON
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BRON, le -4. SEP. 1984

Dear Dr J.FIELDS,

Many thanks for your translations.

There is an error in the n° N 151 935 : the author is G.LABIALE.

Enclosed a copy of the article published in the J.S.V.

Yours sincerely,

M.VALLET

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établissement public de caractère scientifique et technique créé par décret n° 70.269 du 20 mars 1970

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16. Abstract A great number of studies have shown that the acoustical index L_{eq} was the most representative of the annoyance expressed by populations subjected to traffic noise. Yet, in some situations, it seems as if the L_{eq} lacked precision. Therefore it was necessary to verify this point. Because of this we tested the annoyance expressed in experimental situations where the frequency of the number of heavy vehicles varied from 3 to 30 HV/30 min for different classes of the L_{eq} level at 50, 55, 60 dB(A) of traffic noise. The results showed that: (1) for a constant L_{eq} level the annoyance increases as a function of the number of HV up to a certain threshold at which the annoyance is stabilized; (2) for a constant frequency of passage of HV, the annoyance increases with the L_{eq} level; (3) composite indexes of the type L_{eq} + Log NHV, L1 + EMER or L1 + L10 give a predictive value greater than that of the L_{eq} pr Log nHV taken alone.

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INFLUENCE OF THE NUMBER OF VEHICLES IN THE EMERGENCE OF SOUND EVENTS ON THE ANNOYANCE EXPRESSED

M. Vallet

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SYNTHESIS /2*

I. Purpose

The goal pursued by this research was to study the development of the psychological annoyance as a function of the global noise and of the various frequencies of passages of heavy vehicles (H.V.) emerging from continuous traffic noise.

In fact, if a great number of studies have shown that the Leq was the most predictive acoustical index to give an account of the annoyance expressed by those populations subjected to traffic noise, one can only conclude that for certain particular situations it seems that this index lacked precision.

In order to verify this point and possibly improve the predictive value of the Leq by the addition of an index which takes into account the number of vehicles, this research has been undertaken.

II. Experimental Procedure

77 Subjects were tested in a laboratory in 10 traffic noise situations of 30 min, composed of linking 3 acoustical Leq levels with 4 frequency levels of H.V. passages (Table I). Thus, each situation was composed of background traffic noise from which the noises of H.V. passage emerged.

After listening in each situation, the subjects indicated the annoyance and noise level on a nine point scale; moreover, notice was also taken of the imagined annoyance and of the annoyance specifically due to noise from passage of H.V. or to background noise. /3

*Numbers in the margin indicate pagination in the foreign text.

TABLE I. EXPERIMENTAL PLAN: NUMBER OF H.V. X LEQ; THE BARRED BASES HAVE NOT BEEN TESTED; THE LEQ OF ONE H.V. WAS 36DB(A) (30 MIN).

Number of H.V./30 mn — Leq/30 mn	3	5	15	30
50		\		\
55				
60				

III. Results

Among the numerous results which we have analyzed we conclude that:

- the annoyance expressed is influenced in a statistically significant way both by the Leq level as well as by the frequency of passage of H.V., but there is no interaction between these 2 variables,

- more precisely (Fig. 1),

. the expressed annoyance increases strongly from 3 to 5 H.V., and then more weakly from 5 to 30 H.V., for the Leqs of 50 and 55 dB(A),

. the expressed annoyance increases strongly from 3 to 5 H.V. and then becomes saturated from 5 to 30 H.V., for an Leq of 60 dB(A).

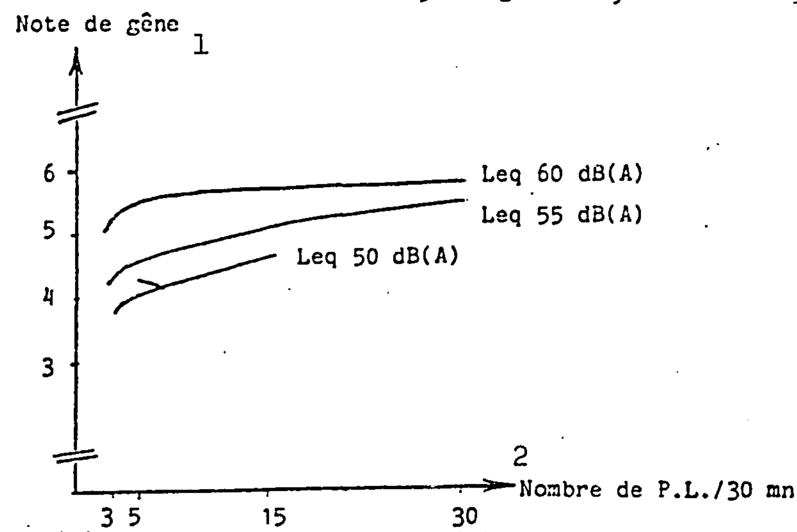

Figure 1. Development of the psychological annoyance as a function of the Leq and of the number of H.V.

Key: (1) Annoyance notation; (2) Number of H.V./30 mn

- the predictive value of Leq on the level of expressed annoyance can be improved clearly by using a composite index of the type: /4

G (notice of annoyance) = 0.12 Leq + 0.75 Log n H.V. - 2.82

(average annoyance correlation - with Leq, r = 0.84, - with Log n H.V. r = 0.58, - with composite index, r = 0.97); moreover, other composite indexes of the type (L1 + EMER + cte) or (L1 + L10 + cte) appeared also among the better predictors of the individual annoyance or of the average annoyance.

The curve of development of the annoyance as a function of the number of H.V. compares with the logarithmic relation found by Rasmussen, but does not confirm the inverse U relation proposed by Rylander. These 2 earlier studies had serious deficiencies, and all the interest of our study consists of having isolated an experimental area where the variations in Leq level and the frequency of H.V. are independent of each other, and of showing in these conditions that Leq and the number of H.V. each have effects on the psychological annoyance. As we have seen the Leq levels were between 50 and 60 dB(A) and we can consider that the results which we have obtained are applicable to local roads.

IV. Prospects for Further Research

In order to draw more general conclusions from the actual results it appears to be necessary to extend our study to noise levels higher than Leq 65, 70 and 75 dB(A).

This study opens the door to a series of researches on the composite indexes which in certain particular situations of traffic noise could be more predictive of the expressed annoyance than the Leq index alone.

I. Purpose of the Research /5

The purpose of our research is the study of the psychological annoyance (also called expressed annoyance) as a function of the number of Heavy Vehicles; it is part of a research program which has as its goal the acoustical analysis of events determining the annoyance in a state of alertness and which specifies a study of annoyance provoked by road vehicles as a function of their number and their emergence. It should be underlined that until now researchers have especially studied the relationship between levels of annoyance and levels of noise measured by various acoustical indexes such as Leq, L10, LNP, LDN,... Moreover, the majority of the member countries of the OCDE have chosen to use the index Leq (equivalent acoustical level).

Yet, in spite of the great predictive value of the Leq, some researches (cf. bibliographical review, Labiale [1]) have shown that this index somewhat lacked precision in giving an account of the expressed annoyance at certain sites exposed to traffic noise. Because of this, in order to try to improve the predictive precision of the Leq, we have prepared the present study: through situations controlled in the laboratory it develops and tests the hypothesis of the influence of the number of H.V. (those vehicles which produce a considerable expressed annoyance) as a possible prediction of the annoyance either complementing or combining with the Leq level.

II. Bibliographical Survey and Concern of the Study /6

A certain number of studies by research as well as in the laboratory have shown the importance of a nonacoustical parameter: the number of vehicles or the percentage of the number of Heavy Vehicles or the Log of the number of Heavy Vehicles in traffic as the indicator of the annoyance.

We will examine the results obtained concerning traffic:

A) Research

One of the most exhaustive studies is that of Langdon (2) in England. He has done a study of 2,933 residents located at 53 different sites in London and its surrounding areas. The noise level, the type of flowing or obstructed traffic, the number of H.W. and H.V. have been determined.

Concerning the research there were several questions and a scale of psychological annoyance of 7 points. Langdon analyzes the results as a function of 2 types of traffic.

- free flowing traffic, with a flow of 250 to 5,000 vehicles/hour and a noise level of L10* varying between 69 and 80 dB(A). He establishes a strong correlation between the annoyance and 2 acoustical indexes, the L10 (24, 18 or 12 hours), ($r = 0.84$) and the Leq (24 hours), ($r = 0.84$), but

*L10 = sound level reached or surpassed during 10% of the period of measurement.

also between the logarithm of the number of vehicles/hour, ($r = 0.80$).

- non-free flowing traffic (by traffic jams, pedestrian crossings, fires etc.); in this situation annoyance due to noise is not evaluated correctly by the L10 or Leq indexes. On the contrary, the Log of the percentage of heavy vehicles (including trucks, buses, but also all vehicles with a diesel engine) between 8 a.m. and 8 p.m. represents the most valid index ($r = 0.74$).

It should be emphasized that for free flowing traffic the Log of the number of vehicles is most closely related to the annoyance, while for non-free flowing traffic it is the Log of the percentage of heavy vehicles (Table I).

TABLE I. CORRELATION OF VARIED TRAFFIC CONDITIONS WITH FOUR MEASURES OF THE COMPOSITION OF THESE TRAFFIC CONDITIONS. /7

Traffic variable	Free-flow		Non-free flow		All traffic	
	Group	Individual	Group	Individual	Group	Individual
No. heavy vehicles	0·795	0·201	0·514	0·203	0·578	0·197
log (No. heavy vehicles)	0·78[illegible]	0·205	0·573	0·228	0·613	0·214
% Heavy vehicles	0·535	0·158	0·70	0·281	0·646	0·233
log (% heavy vehicles)	0·515	0·156	0·74	0·298	0·657	0·293
n	24	1359	29	1574	53	2933

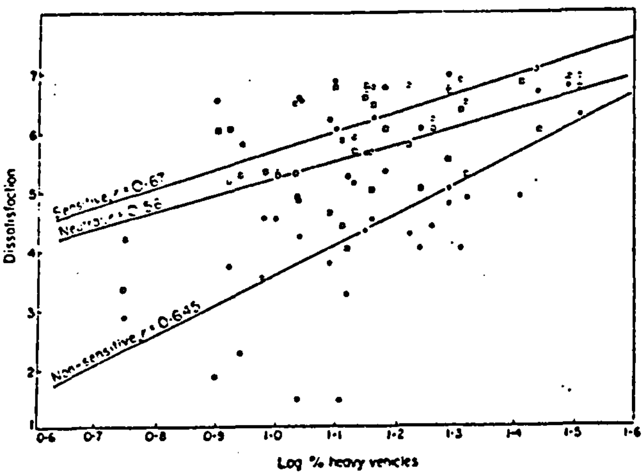

Fig. 1. Average notation of dissatisfaction for three sub-populations.

1 -- o sensitive; 2 -- ▫ neutral; 3 -- • nonsensitive to noise

The fact of whether the subjects are sensitive to noise in daily life can modify the strength of interrelation between the annoyance and the number of vehicles and therefore it seems important to distinguish these 3 groups (Fig. 1).

In a comparable study, conducted at various sites in Antwerp and Brussels, Myncke and Cops (3) arrive at the conclusion that the number of vehicles gives an indication of the foreseeable daily annoyance (activity disturbance scale) as good as the Leq, L10 and L50 ($r = 0.83$).

The study of Yeowart et al. (4) is also very interesting because it researches the relationships of various acoustical indexes with the expressed annoyance (measured by a 7 point scale) in different traffic conditions in the area of Manchester (27 locations with 30 people). Concerning the annoyance during the day it appears at first sight that no acoustical index (Leq, TNI, LNP, L10, L50, L90) is sufficiently general to predict the response of annoyance for broad traffic conditions; for instance for Leq (24 hours), r = 0.56 for freeways, and r = 0.92 for free flowing traffic. The influence of the number of vehicles, unfortunately, is not determined for the annoyance during the day. /8

For the annoyance expressed at night there is practically no significant correlation with the acoustical indexes; the authors propose a new composite index which takes into consideration the acoustical level and the number of heavy vehicles (>1525 kgs): this is the Extended Noise Index (E x L10) calculated by the formula: E x L10 = L10 (18 h) + 0.13 (number of H.V. between midnight and 6 a.m.). The correlations of the annoyance with this index E x L10 are relatively homogeneous, being r = 0.88 for freeway, r = 0.90 for free flowing traffic, r = 0.75 for obstructed traffic.

Finally, there appeared a clear correlation (r = 0.73) between the percentage of subjects who declared that night rest was disturbed by the noise and the average number of H.V./h between midnight and 6 a.m. The authors conclude that the number of H.V. at night is an important parameter to predict the annoyance and they foresee other studies.

In Australia, Brown (5) has done research on 818 residents at 19 locations in the cities of Brisbane, Sydney and Melbourne. Traffic, according to the locations, was 4,000 to 5,700 vehicles/day with 1 to 12 percent H.V. and the exterior L10 index varied from 62 to 76 dB(A). In these conditions, the number of H.V. is the parameter which is most closely linked to the expressed annoyance (measured by a global scale with 7 points or by a composite scale defined as the sum of the standardized scores of the notation of each variable studied: interference with conversation, sleep disturbance, closing of windows etc.).

We note that the correlations are stronger with the composite scale of annoyance than with the global scale.., which seems to indicate a better precision of the composite scale (Table II). /9

Brown notes that, as the distribution of the number of H.V. is not uniform, this increases the corresponding correlation artificially; therefore, he selects the Log of the number of H.V. (Log n H.V.) as a better predictor of the annoyance as it thus shows a uniform distribution.

Contrary to other studies, tests of indexes which combined Log (n H.V.) + 1 acoustical index (L10 or Leq or LNP, etc...) do not allow predicting the expressed annoyance in a satisfactory manner. Brown emphasizes that the negative result seems to be explained by the samples chosen where there appears to be a high correlation between acoustical indexes and measures of traffic density.

TABLE II. CORRELATIONS OF THE ANNOYANCE WITH THE NUMBER OF VEHICLES AND WITH THE ACOUSTICAL INDEXES.

Number of vehicles and acoustical indexes	Global scale, 7 points	Composite scale
Q/24h	r = 0.50	r = 0.63
Log Q/24h	r = 0.41	r = 0.56
% P.L/24h	r = 0.66	r = 0.70
n P.L/24h	r = 0.72	r = 0.79
Log (n.P.L.)	r = 0.52	r = 0.66
Leq (24h)	r = 0.25 N.S.	r = 0.41
L10 (24h)	r = 0.33 N.S.	r = 0.43

Finally, the author proposes a hypothesis which takes into account 2 traffic situations:

- intense traffic with background noise composed of mixed car noise over which emerge sound peaks of certain noisy vehicles such as those of H.V.

- light traffic where the sound of each car is individualized and constitutes peaks relating to surrounding noise. /10

In the 2 cases, the number of noisy vehicles (motorcycles, H.V., cars, ...) where the number of noise peaks allowed a better prediction of annoyance than the number of vehicles or of H.V. (Fig. 2) [sic].

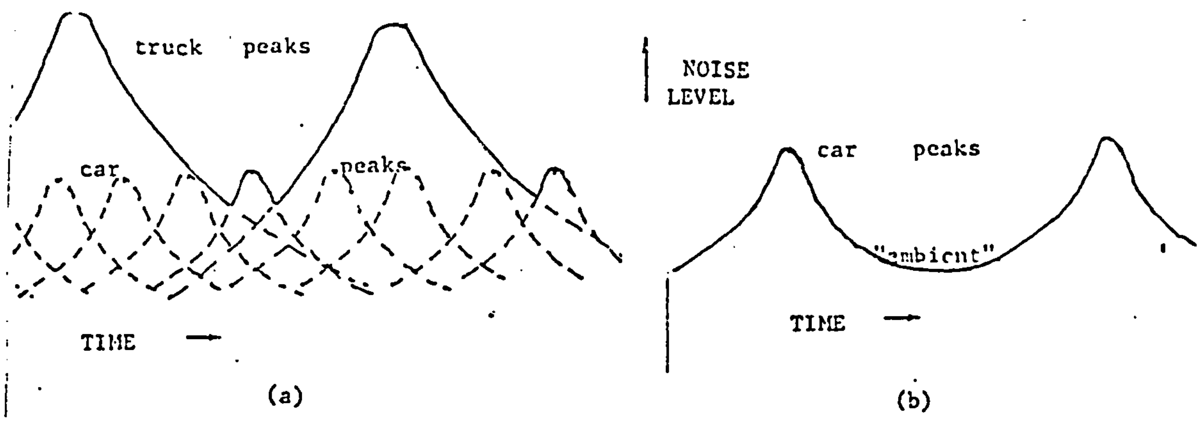

Fig. 2. Occurrence of level peaks according to 2 situations of (a) heavy or (b) reduced traffic.

Suede, Rylander et al (6) in the cities of Stockholm and Visby (city centers and suburbs) have studied the influence of the density of traffic and the noise level on the expressed annoyance. Research was done on 11 groups of 85 subjects (between the ages of 18 and 75). The percentage of people who termed themselves "very annoyed" by the noise has been retained as the measure of annoyance.

The results were as follows:

- whatever the noise level, there is a clear correlation between the annoyance and the total number of vehicles (r = 0.70) as well as between the annoyance and the Log of the number of H.V. (r = 0.75). The strength of these interrelations is comparable to those obtained between the annoyance and the Leq and L1 indexes (respectively r = 0.78 and r = 0.69).

- for a peak level of 80 dB(A) for the H.V. and 70 dB(A) for road vehicles /11
the correlation between the annoyance and the total number of vehicles (r = 0.82) and between the annoyance and the number of H.V./24 h (r = 0.98) is even more important.

- yet this saturation phenomenon did not appear when the noise exposure level is calculated by an index composed as follows: A = L1 + 10 log n H.V.

In a situation of more limited urban traffic, Rylander (7) studied the annoyance provoked by the noise of streetcars and trucks in 6 locations (80 subjects/site, ages 18 to 75). The study was done using masked questionnaires which researched annoyance due to the environment and to vehicle noises. The questions in particular pertained to the interference of noise related to various specific activities: conversation, TV-watching, sleep...; there was also a 3-point global scale of annoyance. The level of traffic varied, for the number of H.V. (trucks and buses) from 50 to 700/24 h, for the number of cars from 65 to 13,500/24 h, for the number of streetcars from 210 to 832/24 h; the global Leq level varied from 53 to 70 dB(A); the peak noise level was 80 dB(A) for streetcars and from 76 to 83 dB(A) for trucks.

The results show that there is no relationship between the Leq level of streetcars and the percentage of very annoyed people while there does exist a slight relationship with the Leq level for motor vehicles.

On the contrary, we note a fairly clear relationship between the number of H.V. or the number of streetcars and the percentage of very annoyed people (Fig. 3).

The author emphasizes that the capability of people to distinguish /12
between the various traffic noises and those of streetcars in relation to annoyance leads him to reject the possibility of using a common acoustical index.

On the other hand, he thinks that for one given location we can have a more considerable level of annoyance for streetcars than for H.V., but that for another location this can be the opposite. These facts lead to having to be careful in drawing conclusions and they show that a number of variables are still not controlled.

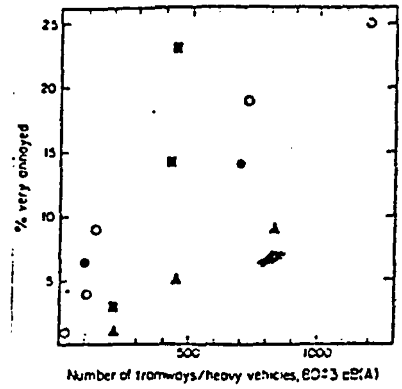

Fig. 3. Relationship of the annoyance with number of streetcars(■, ▲) and with the number of H.V. (o, ●).

The research done by Roumegoux and Valet (8) on the expressed annoyance due to city buses in 4 cities in France is more conclusive. First of all it appears that bus noise is recognized as such in the traffic flow. Moreover, if bus noise is well tolerated in the street, it is considered very annoying at home. The results (Fig. 4) show that the annoyance increases with the number of buses/h (r = 0.88) or, even more, with the percentage of buses in the traffic (r = 0.98).

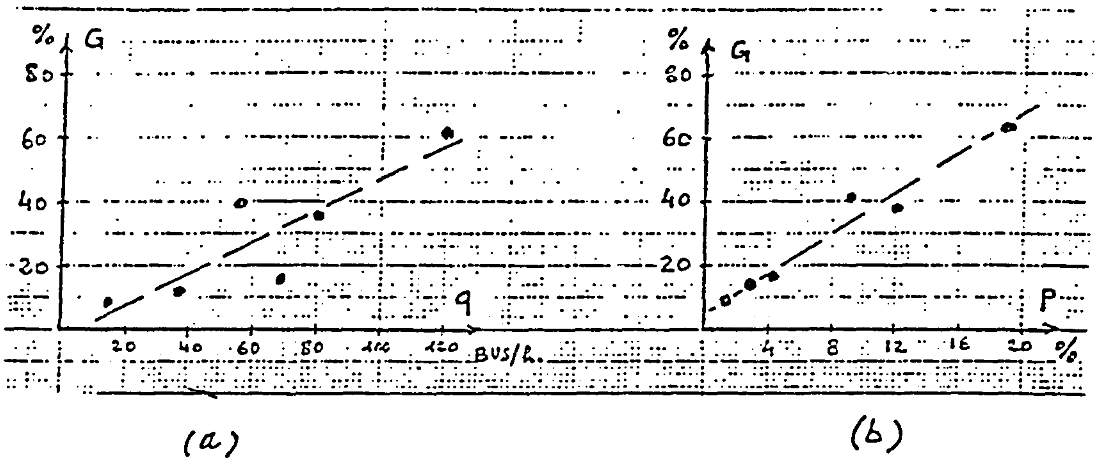

Fig. 4. Relationship between the annoyance caused by bus noise and the specific parameters q and p.

a. Relationship between annoyance at home and output q of the bus in the street.

b. Relationship between annoyance at home and percentage p of buses in the traffic.

B) Laboratory Studies

Besides these tests in the field, laboratory studies in experimentally controlled situations have tried to compare the predictive value on the annoyance of acoustical indexes and of the traffic output. /13

Rylander et al. (9) have had passage noises listened to in the laboratory of heavy trucks mixed with a background noise of other road vehicles (emergence of 10 dB(A) of truck noise/background noise, as in usual traffic conditions).

The experimental plan carried out on 150 students (between the ages of 19 and 35) consisted of 2 principal situations:

- an acoustical situation where the Leq could take on 3 values (57.5; 62.5 and 67.5 dB(A), with a constant number of vehicles (N = 20, with a peak at 70 dB(A)).

- an acoustical situation with a constant Leq (60 dB(A)) but with a number of passages which could vary from 1 to 70/45 min (duration of one presentation).

The results clearly indicate that with a constant number of H.V., there exists a good relationship between the Leq level and the expressed annoyance (measured by a 4 point scale); with a constant Leq level, there exists a curvilinear relationship between the number of H.V. and the annoyance; to be more exact, the percentage of annoyed people increases from 1 to 12 H.V./45 min, then decreases to 70 H.V./45 min (Fig. 5a).

Rylander insists on the fact that, since the number of H.V. is no longer constant, the interrelationship annoyance-Leq level deteriorates, which limits the validity of usage of the Leq.

In an experiment making use of weak noises to simulate traffic noises, Rasmussen (10) set himself the task of defining the influence of the traffic density as well as that of some acoustical indexes on the expressed annoyance. The Leq level varied from 40 to 70 dB(A) with peak levels of 80 dB(A) for the trucks and 65 dB(A) for the vehicles. Under these conditions with a constant background noise of 40 dB(A) the number of passages of H.V. and V.L. varied at 1, 3, 10, 30, 60 passages/30 min. Ten students did the experiment and a relatively linear relationship was brought out between an annoyance scale with 7 points and the log of the number of passages of vehicles (Fig. 5b). /14

Thus, we think that there are clear differences between the Rylander- /15
and Rasmussen results; while Rasmussen finds a linear relationship between the number of H.V. (1 to 60 H.V./30 min) and the annoyance, Rylander poses an inverted U relationship (the expressed annoyance increasing from 1 to 4 H.V./45 min, then diminishing from 4 H.V. to 70 H.V./45 min).

In order to try to understand these discrepancies, it appears to be necessary to resume another laboratory study, the object of the present work, on the relationship expressed annoyance-number of H.V., for several classes of an Leq level which is held constant.

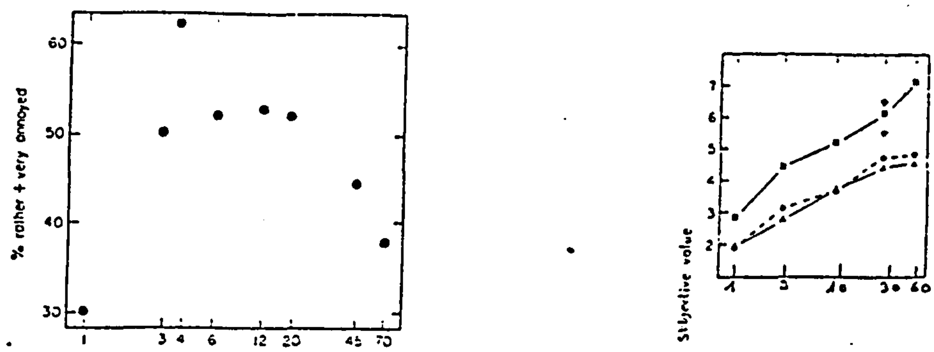

Fig. 5a and 5b. Relationship between the expressed annoyance and the number of passages of H.V. accordingly to Rylander (a) and Rasmussen (b).

(a) Rylander Experiment

- constant global Leq = 60 dB(A)
- variable background noise Leq = 60→ 57.8 dB(A)
- H.V. peak noise = 70 dB(A)
- H.V. passage duration = not specified
- H.V. noise slope = not specified
- interval between H.V. = not specified
- window attenuation of 5 dB(A) per octave
- scale of psychological annoyance, 4 points
- the percentage of annoyed people is taken into account on the ordinate

(b) Rasmussen Experiment

- variable global Leq = 40→70 dB(A)
- constant background noise Leq = 40 dB(A)
- H.V. peak noise = 80 dB(A)
- passage duration = 20s
- H.V. noise slope = 4.3 dB(A)/s
- interval between H.V. = equidistant
- no window attenuation
- scale of psychological annoyance, 2 points, later reduced to 7 points
- the average annoyance notation is taken into account on the ordinate
- ▫ trucks, • vehicles, ▵ trucks with a light noise level; ⁘ mixed traffic

III. Experimental Methodology /16

A) Subjects Tested

77 Subjects (40 males and 37 females between the ages of 19 and 50, residing in Lyon and surrounding area) were tested in this experiment; they were remunerated for their participation.

B) Road Traffic Noise

The road traffic noise used in this experiment consists of a background noise and noises coming from H.V. recorded on 2 separate magnetic tape tracks.

1. The background noise was recorded in 2 stages:

- one stage with "on site" recording with a microphone placed at approximately 100 m distance and at 30 m height from an intersection of 6 roads issuing a constant traffic noise (B. and K. microphone, 1/2", Nagra

SIVJ magnetophone, microphone attenuation 80 lin dB).

- one stage in the laboratory: two mixed versions of the same "on site" recording, displaced by 1 min in time, were recorded simultaneously on track 2 of a magnetic tape; this method made it possible to obtain a continuous background noise (extreme level variations: ± 2 dB(A)).

2. Truck passage noises were recorded at 25 m from a road with light traffic; two types of truck noises were isolated on the tape and recorded on separate tapes (truck noises: Leq (30 min) of 46 and 45 dB(A), peak level: 69 dB(A), duration 17.7 and 19.6s).

3. Recording and reading of magnetic tapes: four magnetic tapes were recorded consisting of the background noise on track 2 and the 4 passage frequencies on track 1, different for each tape (3, 5, 15 and 30 H.V. per 30 min; the H.V. passages are equidistant in time with ± 20% variation).

Fig. 6 shows the acoustical signatures of the H.V. noises and the background noise for 2 acoustical situations. /17

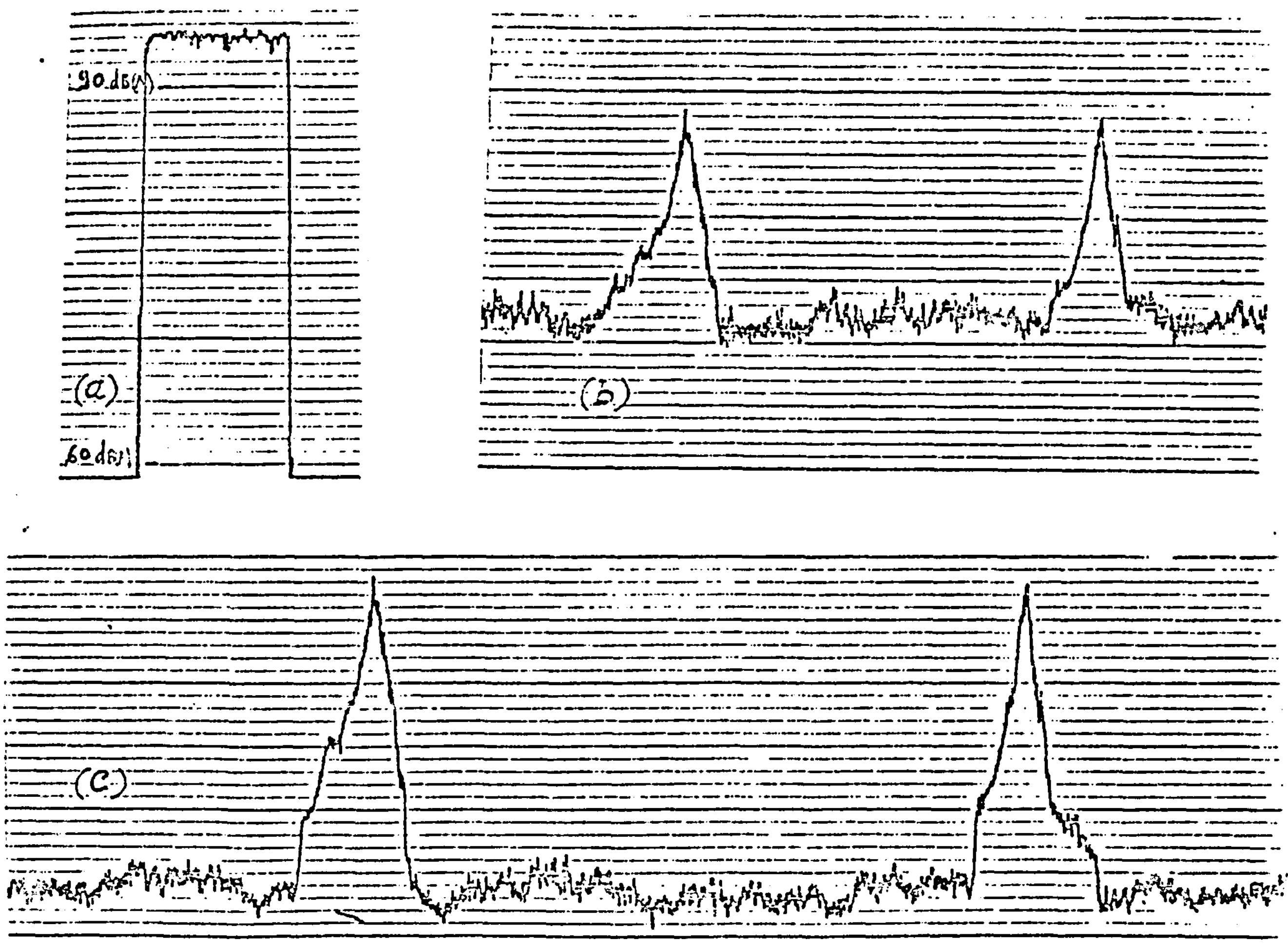

Fig. 6. (a) Standard signal; (b, c) Acoustical signature of 2 H.V. emerging from 2 different background levels.

Reading of the magnetic tapes is done using a two-track Nagra SIVJ magnetophone, which permits regulating the sound level of each of the 2 types of noise (particularly the background noise level). At the output of the Nagra, an analysis was done of the frequency spectrum of the background noise and the H.V. noise (fig. 7 and 8). /18

The background noise and the H.V. noise were mixed at the input by a series of filters regulated to attain the sound level (Kerno System 737) of 10 dB by octave thirds (approximately corresponding to an attenuation of a half-open window), and the resulting signal was amplified by an attenuated two-track amplifier (Sony 1140) and transmitted on 2 acoustical rings (JBL model 4311).

C) Laboratory Description

1. The listening room: the subjects are placed in a large room (4 x 6m) furnished as a waiting room, where the traffic noise is diffused thanks to 2 acoustical rings.

The principal characteristics of this listening room consist of:

- insulation with the exterior of 60 dB(A)
- insulation with the control room of 50 dB
- reverberation time is 0.63 on all audible frequencies
- background noise of 33 dB(A) due to the air conditioner
- constant temperature of 19 ± 1°C.

2. The control room: next to the listening room, it contains the following devices: the Nagra SIVJ magnetophone, the electronic filters and the Sony amplifier connected to the acoustical rings; an ambient microphone, B + K model 41-65, 1/2" placed 1 m from the ground in the center of the listening room and connected to a sonometer B + K type 2607, and to an acoustical index analyzer B + K model 44-26 which permit continued visual control of the noise level in dB(A) and of the acoustical indexes.

A video camera hidden in a piece of furniture in the listening room makes it possible for the researcher to observe the subjects using a television screen placed in the control room (Fig. 9).

D) Experimental Plan /22

The experimental plan consists of crossing the Leq variable of the traffic noise (3 levels of 50, 55 and 60 dB(A) per 30 min) with the number of H.V. variable (4 frequencies 3, 5, 15 and 30 H.V. per 30 min); of these 12 situations, only 10 situations were tested on the subjects (Table III).

The background noise above which different frequencies of H.V. emerge takes on the average values of 46.1 ± 2 dB(A) for an Leq of 50 dB(A), 53 ± 1.4 for an Leq of 55 dB(A) and 58 dB(A) ∓ 1 for an Leq of 60 dB(A); the Leq (over 30 min) of the passage of a H.V. is 36 or 35 dB(A). It should be noted that from a general point of view the global Leq of an acoustical situation is not independent of the noise caused by passages of H.V.; yet, our experiment is voluntarily set in an area of values where there is practically independence between the global Leq and the number of H.V. (Table IV).

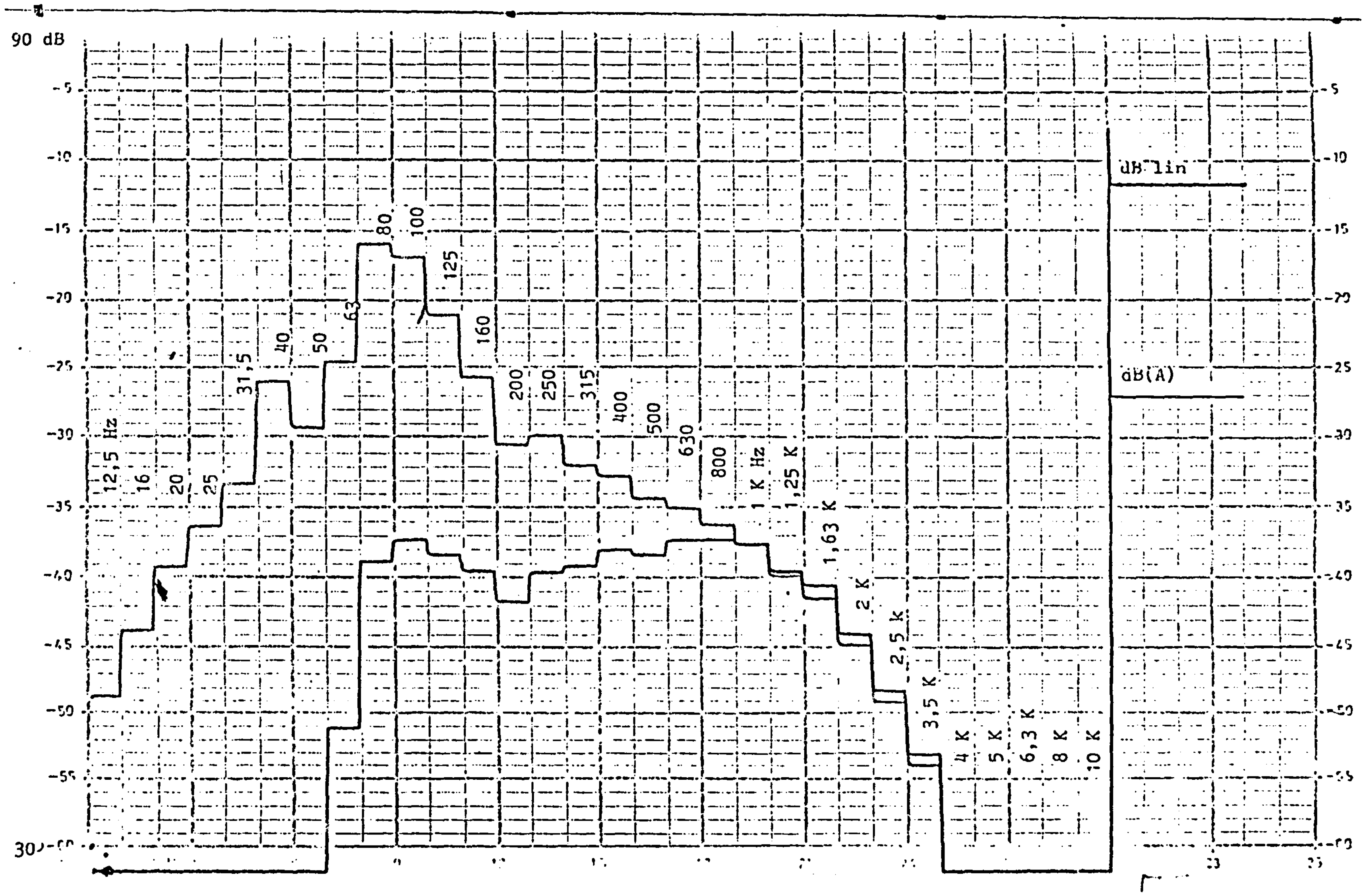

Fig. 7 Spectral analysis in octave thirds of the background noise frequencies.

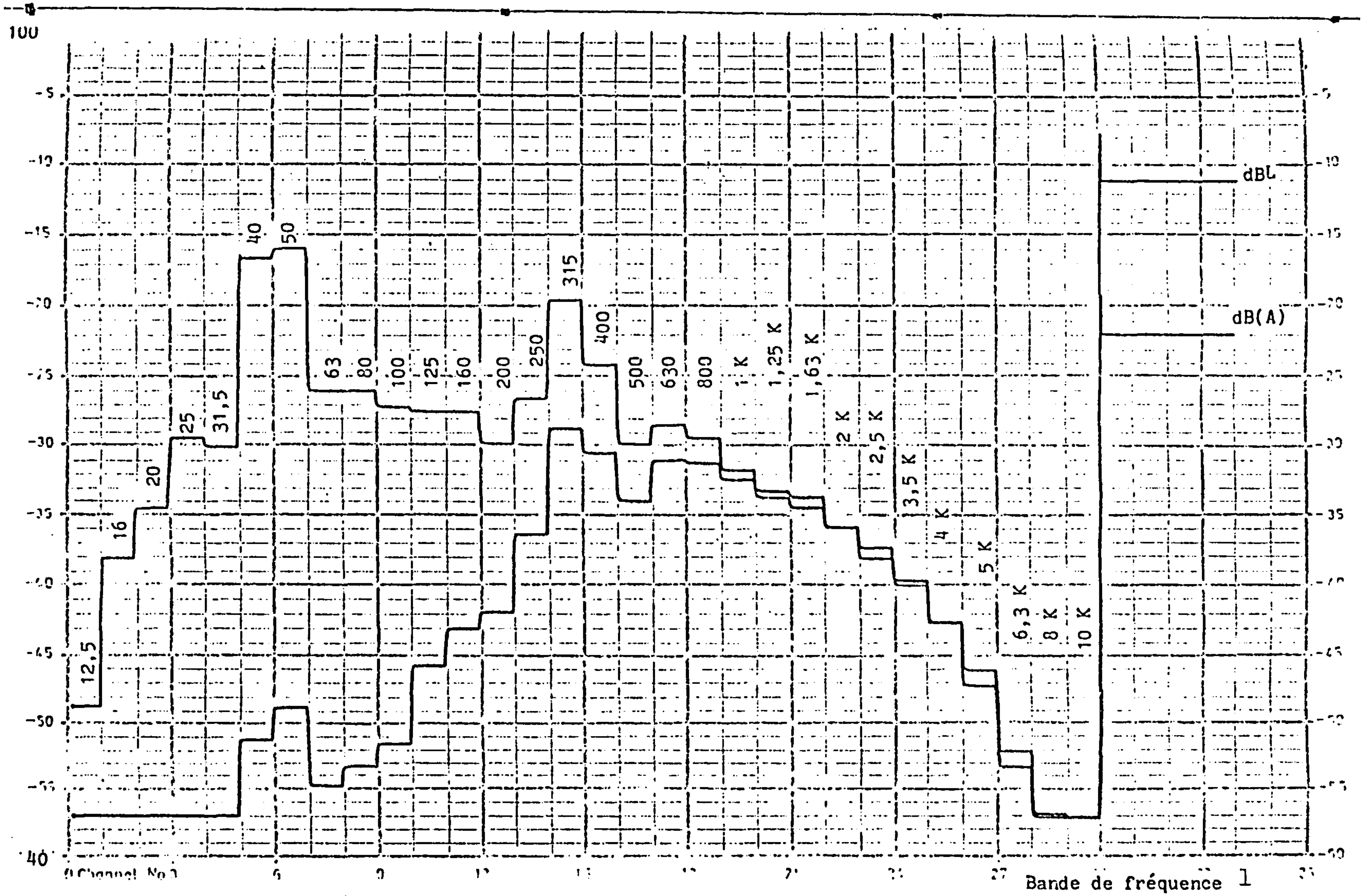

Fig. 8. Spectral analysis in octave thirds of the frequencies of the noise of an H.V.

1 — Frequency band

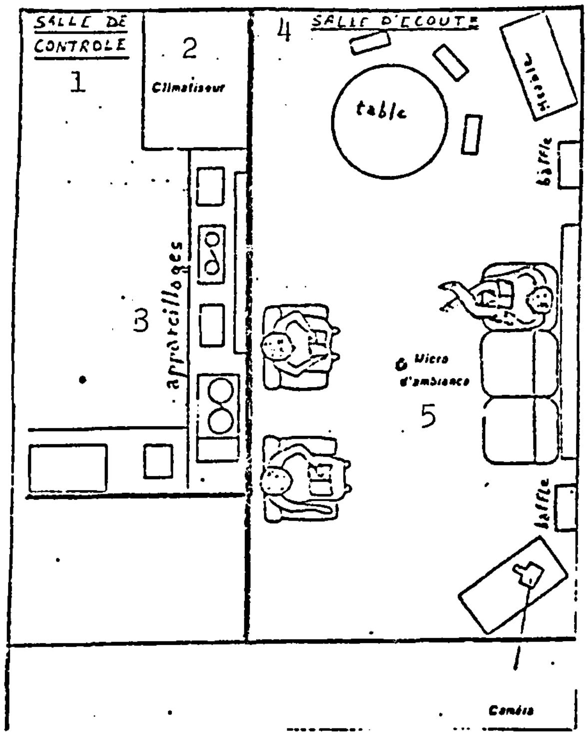

Fig. 9. Sketch of the listening room and the control room (as seen from above).

1 -- Control room; 2 -- Air conditioner; 3 -- Equipment; 4 -- Listening room; 5 -- ambient microphone

TABLE III. PLAN OF EXPERIMENT LEQ x nHV; THE BOXES MARKED BY A SLANTED LINE HAVE NOT BEEN TESTED

		Number of H.V.			
		3	5	15	30
Leq in dB(A) (30mn)	50		/		/
	55				
	60				

Thus, we have chosen the global Leq values of the traffic noise, the Leq value of the passage of a truck, the limits of variations of the frequency of passage of the H.V. such that the 2 Leq variables and the number of H.V. vary independently, while always keeping to a background noise level which is perceptively constant for each global Leq value (the average of the maximum and minimum differences of the background noise is 2.5 ± 0.5 dB(A); this variation is not noticed by the subjects, as a control experiment showed.

TABLE IV. AVERAGES OF THE ACOUSTICAL LEVELS MEASURED IN THE LISTENING ROOM FOR EACH THEORETICAL EXPERIMENTAL SITUATION

Number of H.V./30mn / Leq in dB(A)	3	5	15	30
50	Leq = 50.7 L01 = 58.5 L05 = 51.5 L10 = 51 L50 = 49.8 L90 = 47.7		Leq = 51.7 L01 = 65.8 L05 = 58.3 L10 = 51.3 L50 = 45.5 L90 = 44.5	
55	Leq = 55.7 L01 = 59.8 L05 = 57.3 L10 = 57.0 L50 = 55.5 L90 = 54	Leq = 55.9 L01 = 62.0 L05 = 57.5 L10 = 57 L50 = 55.5 L90 = 54.3	Leq = 55.6 L01 = 65.8 L05 = 59.5 L10 = 56.3 L50 = 54 L90 = 52.5	Leq = 56.1 L01 = 66.8 L05 = 62.5 L10 = 59.3 L50 = 52.5 L90 = 51.2
60	Leq = 60.7 L01 = 64.0 L05 = 62.8 L10 = 62.5 L50 = 61 L90 = 59.5	Leq = 60.5 L01 = 65 L05 = 62.2 L10 = 62.3 L50 = 61 L90 = 59.2	Leq = 59.8 L01 = 66.5 L05 = 62.8 L10 = 60.8 L50 = 59.0 L90 = 57.5	Leq = 59.9 L01 = 67.3 L05 = 64 L10 = 61.8 L50 = 59 L90 = 57.7

E) Experimental Procedure

After they had their hearing ability verified by an audiogram, the subjects (averaging 4 per session) were placed in the "listening room." A notice was read to them and commented upon in order to explain to them the nature of the task they had to carry out (Fig. 10).

Each of the 10 experimental situations lasted 30 min with a break of 10 min between them where the subjects could leave the room; moreover, after the presentation of 5 situations the subjects were permitted to take a break of 2 hours in order to go out to eat. During the experiments the subjects were free to relax or to read.

The 10 situations were presented in a different order for each group of subjects (Table V).

At the end of 30 min of traffic noise in each experimental situation, the subjects had to fill out the annoyance questionnaire (Fig. 11) and turn it in to the researcher.

The estimate of the annoyance and of the noise is done by a 9-point scale.

Seven questions were posed:

- on the expressed annoyance,

- on the expressed noise,

- on the annoyance imagined by the subjects, as if they were in their own apartment,
  . during the day,
  . during the evening,
  . at bedtime,

- on annoyance caused specifically by background noise,

- on annoyance caused specifically by the passing by of trucks.

Even though we have only a few indications as to the structure of the scale of expressed annoyance and noise, we have, in a plan which is comparable to almost all the studies in this area, treated our results while considering that the scale of annoyance was to be assimilated to an interval scale, that is to say that the elementary arithmetic operations (adding, subtracting, multiplication) and from there, statistical calculations (averaging, correlations, etc....) were used for the annoyance notations.

GENERAL INSTRUCTIONS

The experiment in which you are participating has as its goal to study the reactions of people to various road traffic noises.

You will be presented with various periods of 30 min each of traffic noise.

At the end of each 30 min period of traffic noise we will ask you for your personal judgment on the annoyance you have been exposed to.

You will express your judgment on a graduated scale of annoyance of 1 ("not at all annoyed") to 9 ("extremely annoyed"), circling the number which corresponds with your level of personal feeling toward this traffic noise.

Answer naturally, without too much reflection; what counts is what you personally feel, it is your own personal judgment; there is no right or wrong judgment.

We ask you not to indicate your personal judgment to other people in the session (by words, gestures, emotions, etc...).

During each 30 min period of noise you are free to relax or even to read.

Thank you for your valuable help in this study.

Fig. 10. Explanation presented to the subjects.

F) Computerized and Statistical Treatments

The data:

- noise levels: Leq, L1, L5, L10, L50, L90
- relative emergence: $EMER = \frac{\text{Peak noise H.V.} - \text{background noise}}{\text{background noise}}$
- number of H.V.
- notations of annoyances

were entered in the memory in the form of a file (Iris 80 CII-HB computer).

Various statistical treatments were established:

- calculation of the means and the standard deviations, comparison of the means (Student T) and of the variances (Snedecor F) on a Hewlett Packard 9825 computer.

- complex statistical treatments, using the BMDP computer library (University of California, 1979) on the Iris 80 CII-HB computer: Analysis of variance (P2V), Correlation matrix (P1M), Simple regressions (P1R), Multiple regressions (P3R), Algorithm of choice of the best multiple regressions (P9R), Discriminating analysis (P7M). Finally, the segmentation test of Walter Fisher in "optimal" k classes was used (DEVISU: CIR Arcueil program).

PERSONAL ESTIMATION SHEET	Name: Day: Hour: Situat. exp.

This traffic noise which you will hear is to you:

NOT AT ALL ANNOYING	1	2	3	4	5	6	7	8	9	EXTREMELY ANNOYING
NOT AT ALL NOISY	1	2	3	4	5	6	7	8	9	EXTREMELY NOISY

If you would hear this road traffic noise at home in your apartment, would it be:

- during the day:

NOT AT ALL ANNOYING	1	2	3	4	5	6	7	8	9	EXTREMELY ANNOYING

- during the evening, in your living room:

NOT AT ALL ANNOYING	1	2	3	4	5	6	7	8	9	EXTREMELY ANNOYING

- during the evening, when you are ready to go to bed:

NOT AT ALL ANNOYING	1	2	3	4	5	6	7	8	9	EXTREMELY ANNOYING

Do you think that this traffic noise represents

- continued background noise of traffic:

NOT AT ALL ANNOYING	1	2	3	4	5	6	7	8	9	EXTREMELY ANNOYING

- noises of passages of trucks:

NOT AT ALL ANNOYING	1	2	3	4	5	6	7	8	9	EXTREMELY ANNOYING

Fig. 11. Questionnaire given to the subjects.

TABLE V. EQUILIBRATED ORDER OF PRESENTATION OF THE EXPERIMENTAL SITUATIONS (10 SITUATIONS x 20)

1	2	3	4	5	6	7	8	9	10
2	4	6	8	10	1	3	5	7	9
3	6	9	1	4	7	10	2	5	8
4	8	1	5	9	2	6	10	3	7
5	10	4	9	3	8	2	7	1	6
6	1	7	2	8	3	9	4	10	5
7	3	10	6	2	9	5	1	8	4
8	5	2	10	7	4	1	9	6	3
9	7	5	3	1	10	8	6	4	2
10	9	8	7	6	5	4	3	2	1
5	4	3	2	1	10	9	8	7	6
10	8	6	4	2	9	7	5	3	1
4	1	9	6	3	8	5	2	10	7
9	5	1	8	4	7	3	10	6	2
3	9	4	10	5	6	1	7	2	8
8	2	7	1	6	5	10	4	9	3
2	6	10	3	7	4	8	1	5	9
7	10	2	5	8	3	6	9	1	4
1	3	5	7	9	2	4	6	8	10
6	7	8	9	10	1	2	3	4	5

IV. Results

First, we will analyze the results of the annoyance levels obtained as a function of the experimental situations.

Secondly, we will investigate this analysis deeply by statistical studies which have closely examined relationships of the expressed annoyance with the acoustical indexes and the number of H.V.

A) Global Analysis of the Annoyance and of the Expressed Noise.

1. The Psychological Annoyance

- For each experimental situation, defined by an Leq level and a number of passages of H.V., the histograms show a frequency distribution of the annoyance notations which "approximate" a normal law (Fig. 12).

- The variance analysis (Table VI) shows that the Leq level and the number of H.V. are 2 variables each of which has a statistically significant effect ($p<0.02$) on the expressed annoyance; the interaction of these 2 variables, on the contrary, does not show a significant effect ($p>0.05$).

TABLE VI. SUMMARY OF THE VARIANCE ANALYSIS SHOWING THE INFLUENCE OF THE VARIABLES LEQ H.V. AND LEQ x H.V. INTERACTION.

ANALYSIS OF VARIANCE FOR 1-ST
DEPENDENT VARIABLE -- GENE

	SOURCE	SUM OF SQUARES	DEGREES OF FREEDOM	MEAN SQUARE	F	TAIL PROBABILITY
	MEAN	1640.85398	1	1640.85398	536.21	.0000
	LEQ	82.98027	2	41.49014	13.56	.0000
	PL	45.23392	3	15.07797	4.93	.0021
	LEQ X PL	11.60317	6	1.93386	.63	.7048
1	ERROR	2325.68831	760	3.06012		

To be more exact, if we analyze the development of the annoyance (average notations, Fig. 13) as a function of the number of H.V. and of the Leq, we see that:

- for a Leq of 50 dB(A) the annoyance increases in a significant fashion from 3 to 15 H.V. (paired Student t-test, $p<0.05$),

- for an Leq of 55 dB(A), the annoyance increases linearly from 3 to 30 H.V. ($p<0.05$),

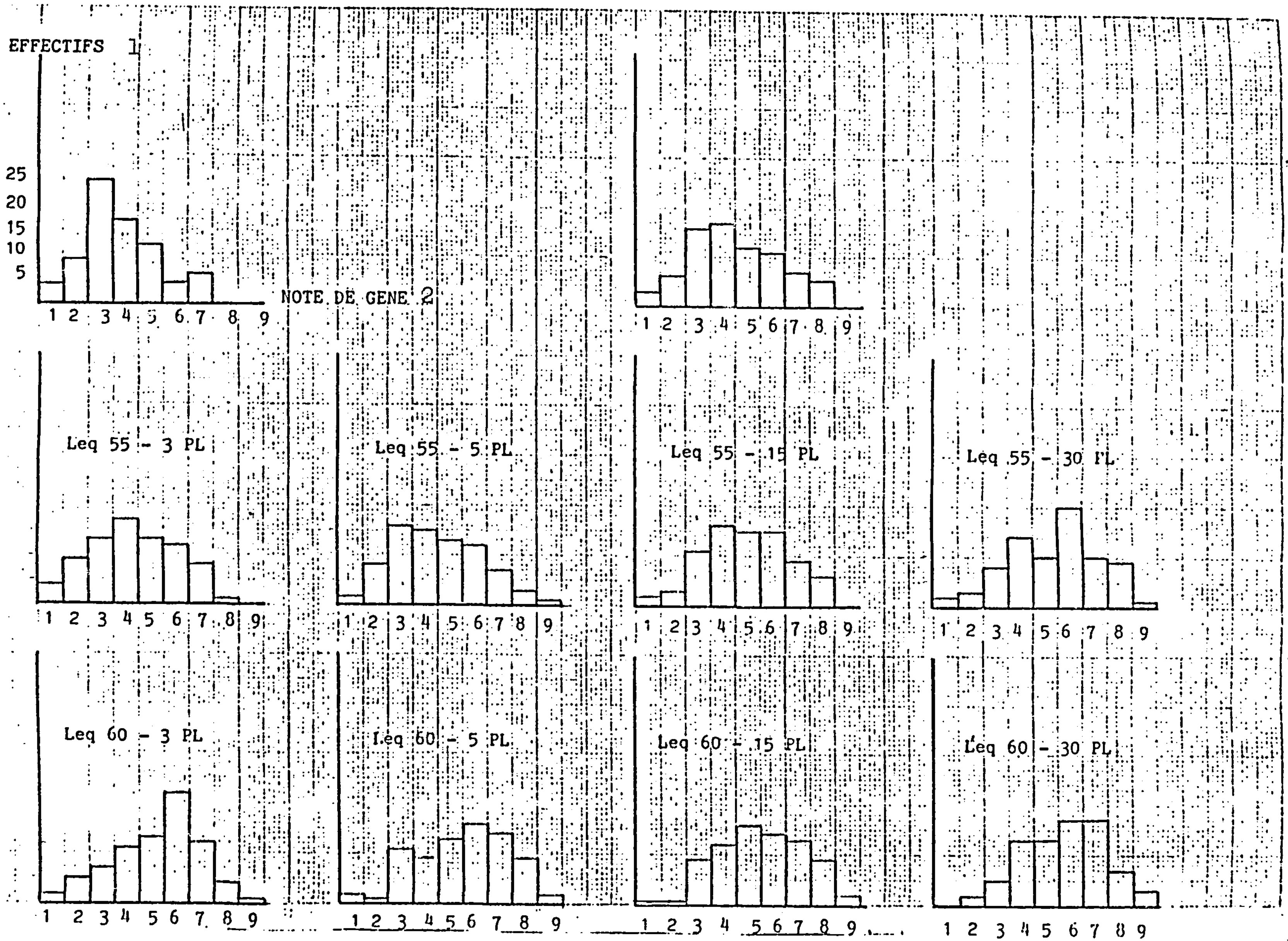

Fig. 12. Histogram of the frequencies of annoyance notations as a function of each experimental situation.

1 -- Effects; 2 -- Annoyance notation

- for an Leq of 60 dB(A), the annoyance increases in a significant way from 3 to 5 H.V. ($p<0.05$), then to stabilize at from 5 to 30 H.V. (N.S., $p>0.05$).

We have arbitrarily regrouped the annoyance notations in 3 classes in order to facilitate our later analysis:

- one class termed weak annoyance comprising the notations 1, 2, 3,
- one class termed medium annoyance comprising the notations 4, 5, 6,
- one class termed strong annoyance comprising the notations 7, 8, 9.

We have been able to verify that this division corresponded well enough with the "exact optimal" division in k classes (Table VII) determined by the Walter Fisher algorithm (1958).

TABLE VII. SEGMENTATION IN OPTIMAL K CLASSES ACCORDINGLY TO WALTER FISHER.

Note: maximum of classes = 3.

division of 9 observations in 3 classes

3 division sum of cars = 379.20

class	number of obs.	mean	stand.deviation	boundaries		highest val.	lowest val.
3	309.000	6.773	.844	9	6	9.000	6.000
2	271.000	4.480	.500	5	4	5.000	4.000
1	190.000	2.521	.694	3	1	3.000	1.000

For each annoyance class, Fig. 14 (a, b, c) shows the development of the percentage of annoyed people in each experimental situation. We note that:

- for an Leq of 50 dB(A), the percentage of slightly annoyed people decreases from 3 to 15 H.V. while the percentage of moderately and very annoyed people increases in parallel.

- for an Leq of 55 dB(A), the percentage of slightly annoyed people stays constant from 3 to 5 H.V., then decreases strongly from 5 to 15 H.V., and weakly from 15 to 30 H.V.

, the percentage of very annoyed people increases linearly from 3 to 30 H.V.

- for an Leq of 60 dB(A), the percentage of slightly annoyed people is stable from 3 to 5 H.V., then decreases linearly from 5 to 30 H.V. /32

, the percentage of moderately annoyed people decreases from 3 to 5 H.V., then increases from 5 to 15 H.V. to stabilize at between 15 and 30 H.V.

, the percentage of very annoyed people increases from 3 to 5 H.V., stabilizes at from 5 to 15 H.V., and increases slightly from 15 to 30 H.V.

Summarizing, there appeared a clear tendency which shows that

- for an Leq of 50 dB(A) and an increase from 3 to 15 H.V., the percentage of slightly annoyed people decreases in favor of the percentage of the moderately and very annoyed people,

- for an Leq of 55 and 60 dB(A) and an increase from 3 to 30 H.V., the percentage of slightly and moderately annoyed people (to a lesser degree) decreases, resulting in an increase in the percentage of very annoyed people.

We also note that, if the percentages of slightly annoyed people vary between 9% and 50% and the percentages of very annoyed people between 8% and 35%, in contrast the percentage of moderately annoyed people is much higher and varies between 43 and 60%.

2. Noise

The mean noise levels, as a function of the number of H.V. and of the Leq level, are similar to the levels and to the development of the psychological annoyance (Fig. 13). For each of the experimental situations the paired Student tests show that the deviations between the notations of annoyance and the notations of noise are not statistically significant ($p>0.05$).

Fig. 14(d, e, f) shows that when we reduce the noise scale to 3 classes, the percentage of judgments "slightly noisy," "moderately noisy," "very noisy" develop globally in an identical fashion, respectively, into the judgments: "slightly annoyed," "moderately annoyed," and "very annoyed."

3. Imagined Annoyance in the Person's Apartment

a) Imagined annoyance during the day (Fig. 15a)

The corresponding annoyance levels and their development as a function of the number of H.V. and the Leq are identical to the estimated annoyance /35
in an experimental situation (paired Student t-test, $p>0.05$).

Thus, everyone thought as if the annoyance level which the subjects indicated in the experimental situations was referenced by the latter in the acoustical situation of their apartment.

b) Annoyance imagined in the evening

Fig. 15b shows that the development of the imagined annoyance in the evening runs parallel with the development of the psychological annoyance in the experimental situation; the levels of imagined annoyance in the evening are displaced upward by a 1.34 notation of moderate annoyance (paired Student t-test, $p<0.05$).

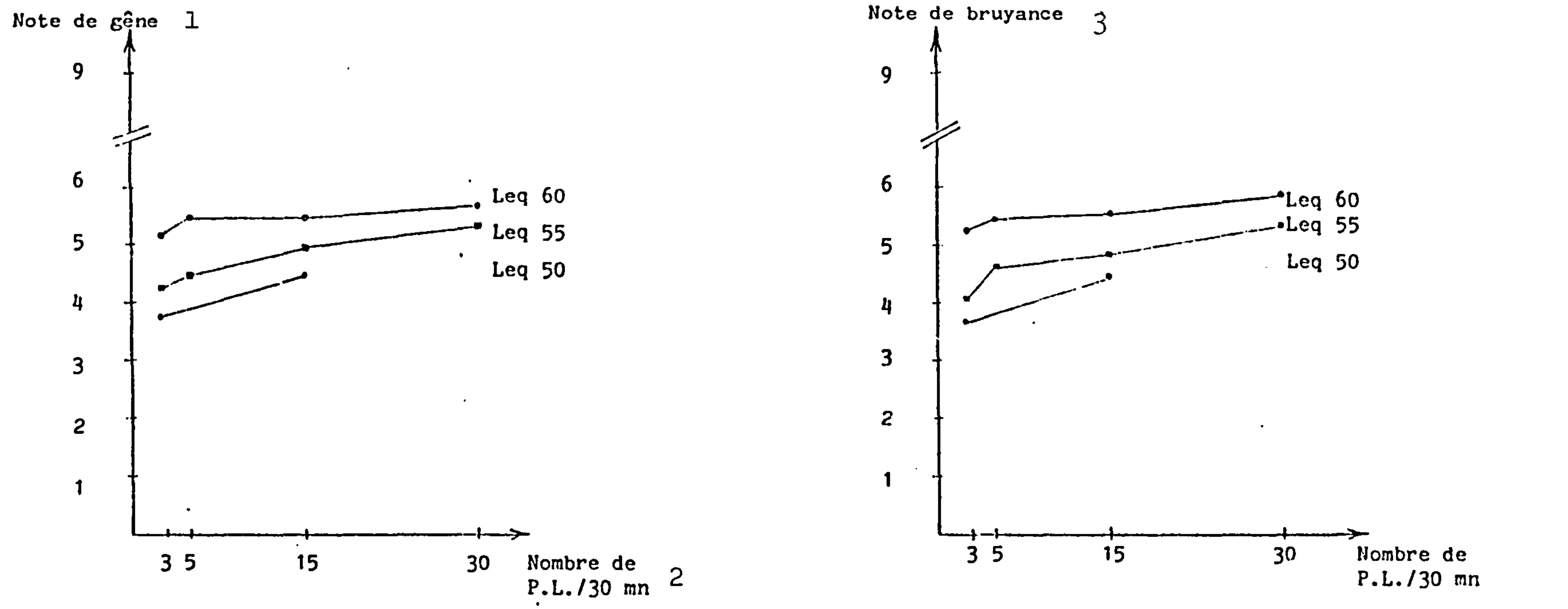

Fig. 13. Development of the expressed annoyance, (a) and noise (b) as a function of the number of H.V. and the Leq.

1 -- annoyance notation; 2 -- number of H.V./30 min; 3 -- noise notation

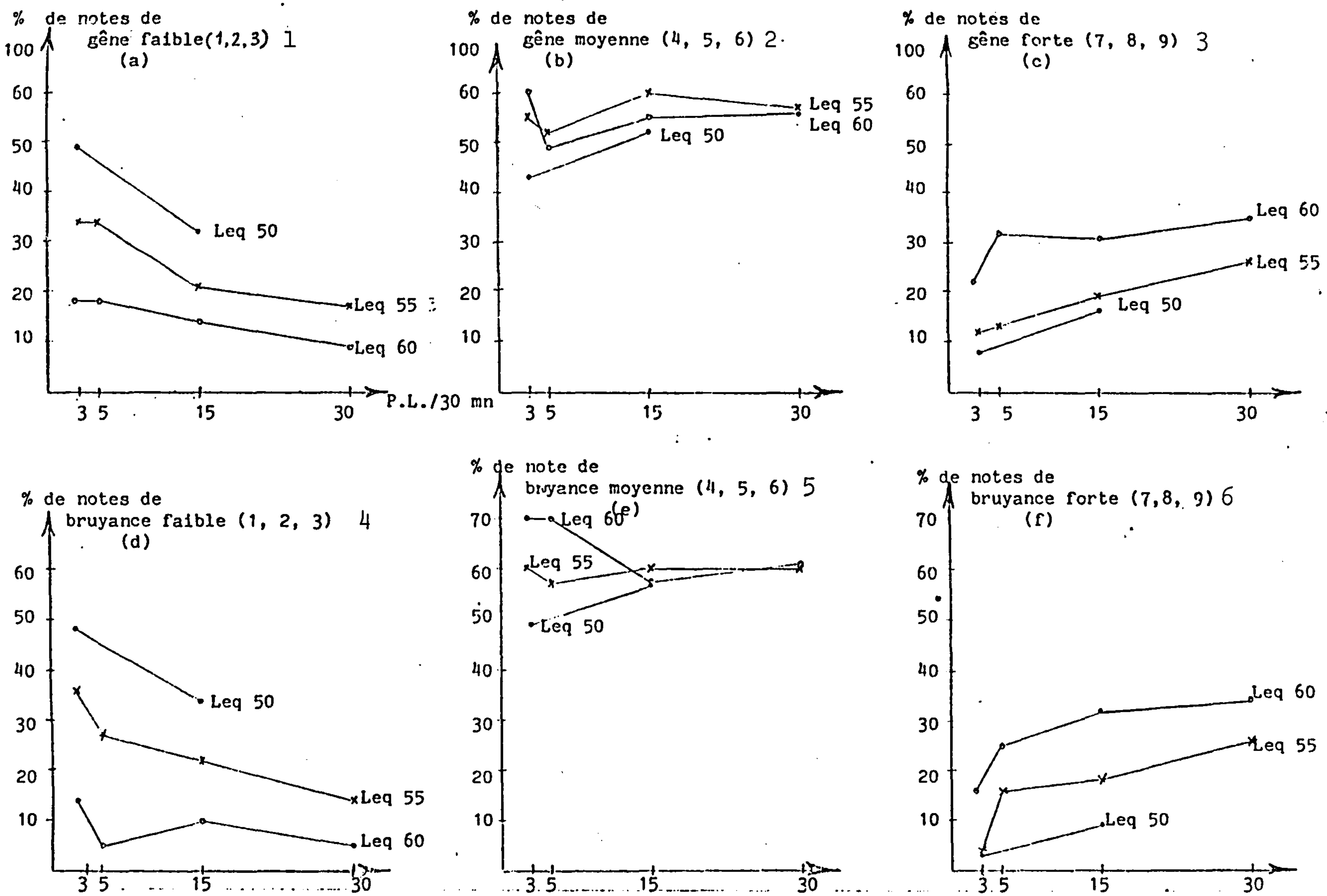

Fig. 14. Development of the percentage of judgments "slightly annoyed," "moderately annoyed," "very annoyed" and of the judgments "slightly noisy," "moderately noisy," "very noisy" as a function of the Leq and the number of H.V.

1 — % of notations of slight annoyance (1, 2, 3); 2 — % of notations of moderate annoyance (4, 5, 6); 3 — % of notations of strong annoyance (7, 8, 9); 4 — % of notations of slight noise (1, 2, 3); 5 — % of notations of moderate noise (4, 5, 6); 6 — % of notations of strong noise (7, 8, 9)

c) Imagined annoyance at bedtime

Fig. 15c shows that the development of the imagined annoyance at bedtime runs parallel with the development of the imagined annoyance during the day and in the evening; yet, the levels of imagined annoyance at bedtime are displaced upward by a 2.19 notation of moderate annoyance for the annoyance notation in an experimental situation (paired Student t-test, $p<0.05$).

4. The annoyance due to the level of background noise and the number of passages of H.V.

Let us remember that the questionnaire also contained 2 other types of evaluations: the annoyance which the subjects estimated was specifically caused by the background noise (marked as Gbf) and the annoyance which the subjects estimated was specifically caused by the repeated passages of H.V. (marked as Gpl), for each of the 10 experimental situations.

Fig. 16a shows the developments of Gbf and of Gpl; we will consider:

- for Gbf, when the background noise increases, this annoyance increases
, when the number of H.V. increases, this annoyance increases globally as well.

In other words, it would seem that the estimation of the annoyance due to background noise is not independent of the number of H.V.,

- for Gpl, when the number of H.V. increases, this annoyance increases as well

, when the background noise increases, this annoyance is not affected (Fig. 16b); for each frequency of H.V., the Gpl notations are not /37
significantly distinct as a function of the Leq level (paired Student t-test, $p>0.05$).

Thus, the estimation of the annoyance as a result of the H.V. is here well ascribed by the subjects to the frequency of passage of the H.V. and it is not affected by the level of the background noise.

B) Statistical Analysis of the Relationship Psychological Annoyance-Acoustical Indexes and Number of H.V.

First, it is in order to study the intensity of the interrelationships of various acoustical indexes (Leq, L1 to L90, EMER) and of frequencies of H.V. (nHV and Log. nHV; the percentage of H.V. in the traffic has not been taken as an index since it was possible to calculate this; in fact, our background noise showed a very stable and continuous level where no single vehicle was identified in the traffic annoyance, and secondly, it is in order to study the index or the association of indexes (particularly with the Leq) which allow the best prediction of annoyance.

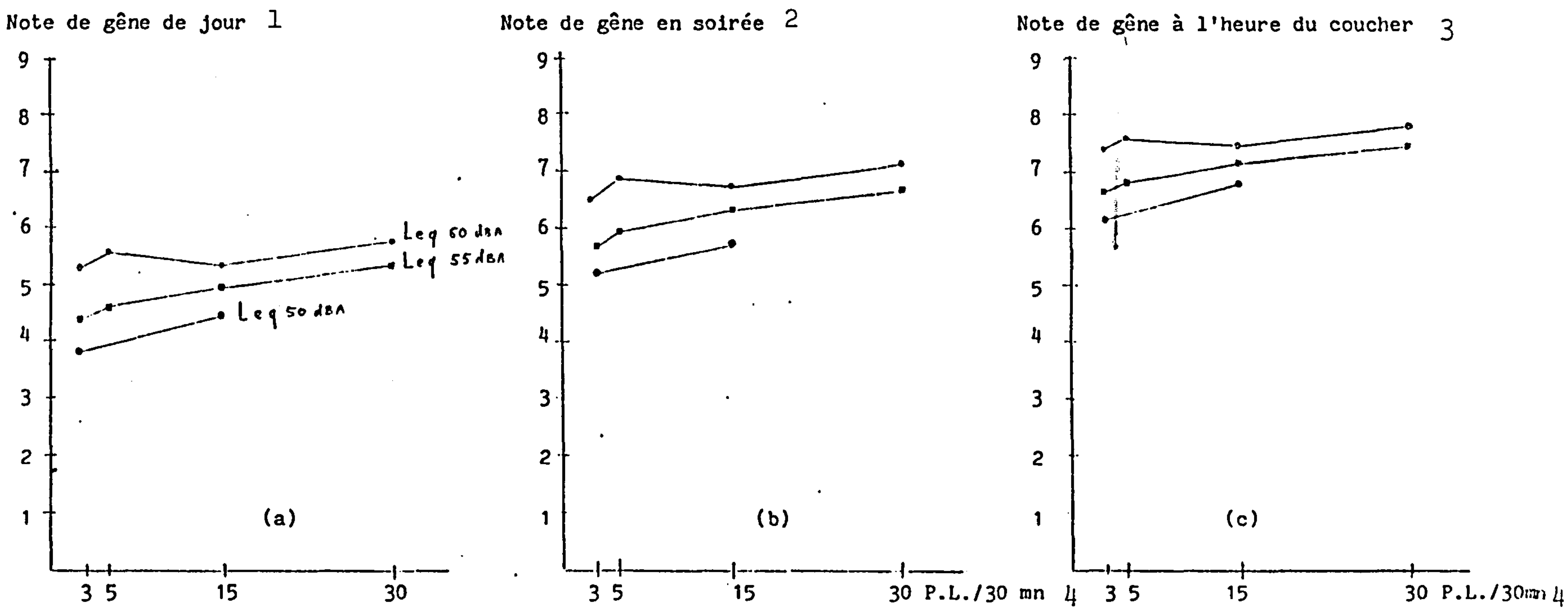

Fig. 15. Development of the imagined annoyance in the apartment as a function of Leq level and number of H.V.

1 -- Daytime annoyance; 2 -- evening annoyance; 3 -- annoyance at bedtime; 4 -- H.V./30 min.

Let us distinguish two aspects to take into account the expressed annoyance:

- either we relate each level of an acoustical index considered to the individual notations of corresponding annoyance; we speak, then, of the individual annoyance (marked as I.A.) since we take into account the dispersion of the individual notations of annoyance for a given acoustical level,

- or we relate each level of the acoustical index considered to the mean of the corresponding individual notations of annoyance; we speak, then, of the mean annoyance (marked as M.A.), since we have eliminated the dispersion of the individual notations in order to take into account the mean of those notations for a given acoustical level.

In our calculations we have taken these two types of annoyance into consideration.

1. Analysis of the correlation matrix /39

(Bravais-Pearson r) of the 2 types of annoyance with the various indexes (acoustical and frequency of H.V.) shows that the acoustical index L5 gives the strongest interrelationship with the mean annoyance (M.A.) and the individual annoyance (I.A.), followed by a second group of indexes: Leq, L1, L10 and EMER; the indexes nHV and Log nHV give the weakest interrelationship with the annoyance (Tables VIII and IX).

2. A discrimination analysis has been made, step by step, in order to study the index which best discriminates the groups of notations of individual annoyance from 1 to 9 (the moderate annoyance cannot be tested since it did not include enough data). /41

Program BMDP-7M chooses (step by step) the variables used in the treatment of the linear classification functions. A step forward/return selection is possible; at each stage or step, the variable which allows the greatest separation of the groups is entered (or the variable which allows the least separation is withdrawn) for a discriminating function.

The results (Table X) show that index L5 is the one which allows the best discrimination. Thus, the results between the Discriminating Analysis and Correlation Analysis are entirely in agreement.

3. Multiple regressions: the second part of this statistical analysis consisted of studying an improvement of the predictive value for annoyance of the Leq index by adding another variable such as the frequency of the H.V. (nHV and Log nHV). For this purpose, multiple linear regressions of the general form: $Z = \text{constant} + \alpha X + \beta X$ were calculated (where Z is a dependent variable, X, Y are independent variables, α and β are coefficients).

The results show that

- an index composed of the general form Leq α + nHVβ + cte has a predictive value which is slightly higher than the Leq index or nHV or Log nHV taken alone.

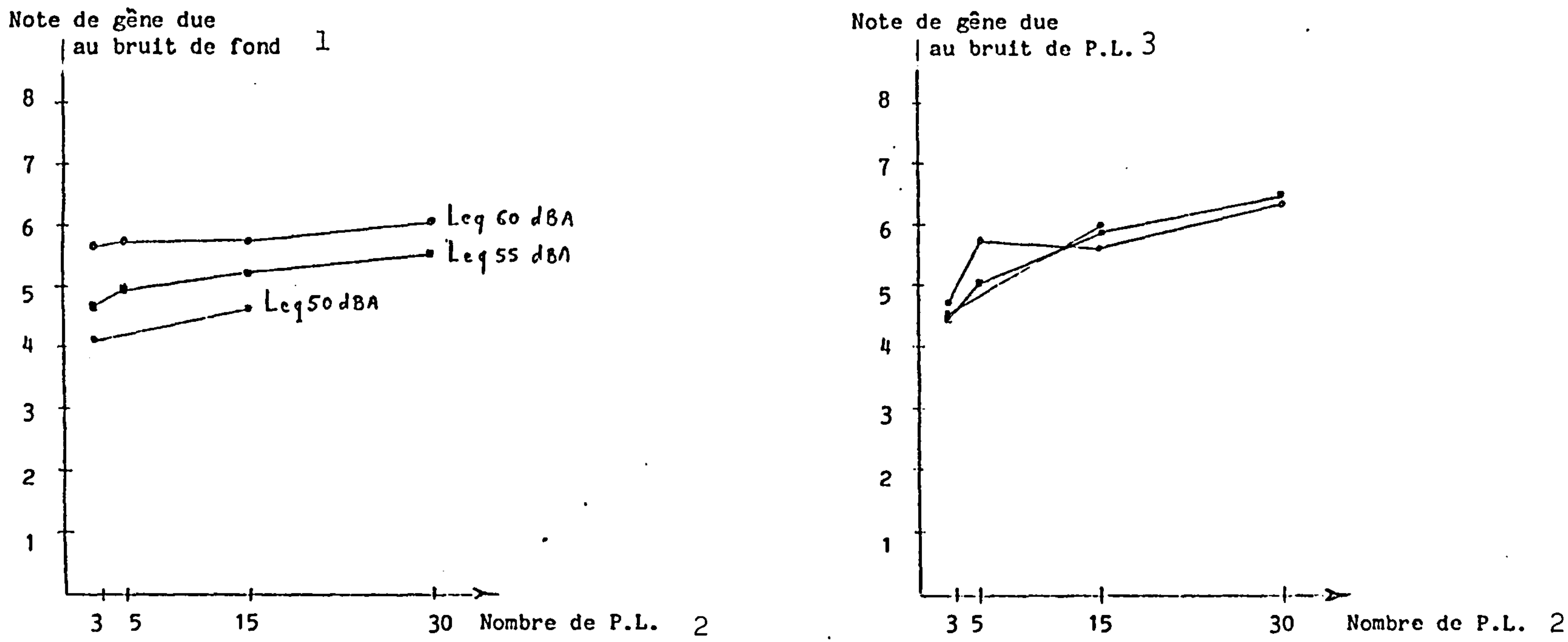

Fig. 16. Development of the estimated annoyance due to background noise and to the number of H.V. as a function of the number of H.V. and Leq.

1 -- annoyance due to background noise; 2 -- number of H.V.; 3 -- annoyance due to H.V. noise

TABLE VIII. CORRELATIONS BETWEEN THE ANNOYANCE AND THE INDEXES (THE LIMITS OF CONFIDENCE OF THE CORRELATION COEFFICIENTS ARE INDICATED BY:

xxx for $p<0.001$
xx for $p<0.01$
x for $p<0.5$)

Annoyance / Indexes	I.A.	M.A.
Leq	0.274xxx	0.842xx
L1	0.271xxx	0.835xx
L5	0.313xxx	0.964xxx
L10	0.278xxx	0.856xx
L50	0.210xxx	0.644x
L90	0.214xx	0.657x
EMER	0.274xxx	0.838xx
nP.L.	0.184xxx	0.575x
log nP.L.	0.187xxx	0.580x

- there are no statistically significant differences ($p>0.05$) between the index in the form Leq α + nHVβ + cte and the index in the form Leq α + log. nHVβ + cte.

- we note interrelationships of various intensities (R, multiple correlation coefficient) of the indexes which are composed with the annoyance, according to the fact that we consider the moderate annoyance (M.A.) and the individual annoyance (I.A.); the same goes for the coefficient of determination R^2 which expresses the variance percentage explained by the right multiple regression (for I.A., 10% of the variance is explained, for M.A., 95% of the variance is explained).

Let us note that the coefficients of correlation given in Table VIII and Table IX sufficiently resemble what the psychosociological tests furnished on the annoyance in connection with the Leq level of daytime traffic noises: for I.A., M = 0.31 Vallet [11], /43
r = 0.29 Langdon [2], r = 0.32 Aubree et al. [12]; for M.A.
r = 0.88 Langdon [2], r = 0.76 Yeowart et al. [4], r = 0.96 Lambert [13]

To finish this study, we have researched the best composite index in relation to the annoyance. The BMDP-P9R program ("All possible Subsets Regression") has allowed estimation of the best regression equations as a function of criteria such as:

TABLE IX. CORRELATION MATRIX: ACOUSTICAL INDEXES-
NUMBER OF H.V. - ANNOYANCE

CORRELATIONS

MATRICE DES CORRELATIONS

		GI 2	LEQ 3	NPL 4	L1 5	L5 6	L10 7	L50 8	L90 9	LOGNPL 10	EMER 11	GM 1
GI	2	1.000										
LEQ	3	.274	1.000									
NPL	4	.184	.135	1.000								
L1	5	.271	.444	.750	1.000							
L5	6	.313	.838	.517	.823	1.000						
L10	7	.278	.977	.217	.466	.860	1.000					
L50	8	.210	.943	-.111	.153	.621	.912	1.000				
L90	9	.214	.950	-.073	.169	.643	.929	.996	1.000			
LOGNPL	10	.187	.107	.957	.833	.515	.152	-.166	-.138	1.000		
EMER	11	.274	.990	.120	.440	.831	.953	.928	.929	.095	1.000	
GM	1	.325	.942	.575	.835	.964	.856	.644	.657	.580	.838	1.000

TABLE X. SUMMARY OF THE DISCRIMINATING ANALYSIS

VARIABLE	F TO REMOVE (DF= 8 762)	FORCE LEVEL	TOLERANCE	*	VARIABLE	F TO ENTER (DF= 8 761)	FORCE LEVEL	TOLERANCE
				*	3 LE0	8.328	1	1.000000
				*	4 NPL	3.669	1	1.000000
				*	5 L1	8.127	1	1.000000
				*	6 L5	11.113	1	1.000000
				*	7 L10	8.654	1	1.000000
				*	8 L50	4.939	1	1.000000
				*	9 L90	5.160	1	1.000000
				*	10 LOGNPL	3.848	1	1.000000
				*	11 EMER	8.234	1	1.000000

STEP NUMBER 1
VARIABLE ENTERED 6 L5

VARIABLE	F TO REMOVE (DF= 8 761)	FORCE LEVEL	TOLERANCE	*	VARIABLE	F TO ENTER (DF= 8 760)	FORCE LEVEL	TOLERANCE
6 L5	11.113	1	1.000000	*	3 LE0	.556	1	.321903
				*	4 NPL	.391	1	.757565
				*	5 L1	.771	1	.347053
				*	7 L10	.443	1	.283298
				*	8 L50	.498	1	.642568
				*	9 L90	.517	1	.615410
				*	10 LOGNPL	.605	1	.759870
				*	11 EMER	.712	1	.334077

U-STATISTIC OR WILKS' LAMBDA .8953968 DEGREES OF FREEDOM 1 8 761
APPROXIMATE F-STATISTIC 11.113 DEGREES OF FREEDOM 8.00 761.00

TABLE

VARIABLE ENTERED	VARIABLE REMOVED	F VALUE TO ENTER OR REMOVE	NUMBER OF VARIABLES INCLUDED	U-STATISTIC	APPROXIMATE F-STATISTIC	DEGREES OF FREEDOM	
6 L5		11.1127	1	.8954	11.113	8.00	761.00

TABLE XI. SUMMARY OF THE MULTIPLE LINEAR REGRESSIONS (WITH THE MULTIPLE CORRELATION COEFFICIENTS R AND THEIR COEFFICIENT OF DETERMINATION R^2) OF THE ANNOYANCE AS A FUNCTION OF THE LEQ AND THE FREQUENCY OF H.V.

Multiple regressions	R Multiple	R^2
I.A. = -2.36 + 0.12 Leq + 0.027 P.L.	0.31	0.097
M.A. = -2.37 + 0.12 Leq + 0.027 P.L.	0.96	0.92
I.A. = -2.86 + 0.12 Leq + 0.75 Log nP.L.	0.31	0.097
M.A. = -2.82 + 0.12 Leq + 0.76 Log nP.L.	0.97	0.95

- the Cp of Mallow
- the R^2
- the adjusted R^2

for indexes 1 to 9 (acoustical and number of H.V.).

It appeared that: /48

- there is no agreement between the individual annoyance and the moderate annoyance in the composite indexes which give the best multiple regression. For I.A. we will retain the expression: L1 + L10 (simpler than the last expression where the 8 variables are not independent of one another).

- the Leq associated with another index is not the most predictive one.

TABLE XII. SUMMARY OF THE MULTIPLE REGRESSION OF TYPE LEQ + LOG nHV + CTE FOR THE MODERATE ANNOYANCE

```
REGRESSION TITLE. . . . . . . . . . . . . . . .      Moderate annoyance
DEPENDENT VARIABLE. . . . . . . . . . . . . . .      1 MA
TOLERANCE . . . . . . . . . . . . . . . . . . .     .0100
ALL DATA CONSIDERED AS A SINGLE GROUP

MULTIPLE R              .9756          STD. ERROR OF EST..        .1313
MULTIPLE R-SQUARE       .9517

ANALYSIS OF VARIANCE
                    SUM OF SQUARES     DF    MEAN SQUARE      F RATIO    P(TAIL)
       REGRESSION        260.823        2       130.412      7562.438     .00000
       RESIDUAL           13.227      767          .017

                                                 STD. REG
   VARIABLE        COEFFICIENT   STD. ERROR       COEFF.        T    P(2 TAIL)  TOLERANCE

INTERCEPT           -2.82728
LEQ          3        .12570       .001            .789     98.844     .000      .988423
LOGNPL      10        .76200       .012            .496     62.115     .000      .988422
```

TABLE XIII. SUMMARY OF THE MULTIPLE REGRESSION OF TYPE LEQ + LOG nHV + CTE FOR THE INDIVIDUAL ANNOYANCE

```
REGRESSION TITLE. . . . . . . . . . . . . . . . . . Individual annoyance
DEPENDENT VARIABLE. . . . . . . . . . . . . . . .     2 IA
TOLERANCE . . . . . . . . . . . . . . . . . . . .   .0100
ALL DATA CONSIDERED AS A SINGLE GROUP

MULTIPLE R               .3172        STD. ERROR OF EST.        1.7462
MULTIPLE R-SQUARE        .1005
```

ANALYSIS OF VARIANCE

	SUM OF SQUARES	DF	MEAN SQUARE	F RATIO	P(TAIL)
REGRESSION	261.249	2	130.624	42.839	.00000
RESIDUAL	2339.748	767	3.049		

VARIABLE		COEFFICIENT	STD. ERROR	STD. REG COEFF	T	P(2 TAIL)	TOLERANCE
INTERCEPT		-2.96142					
LEQ	3	.12535	.017	.257	7.472	.000	.988423
LOGNPL	10	.75491	.163	.159	4.628	.000	.988422

TABLE XIV. SUMMARY OF THE MULTIPLE REGRESSION OF TYPE LEQ + nHV + CTE FOR THE MODERATE ANNOYANCE

REGRESSION TITLE. . . . . Moderate Annoyance
DEPENDENT VARIABLE. . . . . 1 MA
TOLERANCE 0100
ALL DATA CONSIDERED AS A SINGLE GROUP

MULTIPLE R .9617 STD. ERROR OF EST. .1638
MULTIPLE R-SQUARE .9249

ANALYSIS OF VARIANCE

	SUM OF SQUARES	DF	MEAN SQUARE	F RATIO	P(TAIL)
REGRESSION	253.476	2	126.738	4724.820	.00000
RESIDUAL	20.574	767	.027		

VARIABLE		COEFFICIENT	STD. ERROR	STD. REG COEFF.	T	P(2 TAIL)	TOLERANCE
INTERCEPT		-2.37651					
LEQ	3	.12407	.002	.778	77.958	.000	.981645
NPL	4	.02778	.001	.469	46.973	.000	.981645

TABLE XV. SUMMARY OF THE MULTIPLE REGRESSION OF TYPE LEQ + nHV + CTE FOR THE INDIVIDUAL ANNOYANCE

REGRESSION TITLE. . . . . .PIR

DEPENDENT VARIABLE. . . . . 2 Individual Annoyance

TOLERANCE 0100

ALL DATA CONSIDERED AS A SINGLE GROUP

MULTIPLE R	.3121	STD. ERROR OF EST.	1.7476
MULTIPLE R-SQUARE	.0974		

ANALYSIS OF VARIANCE

	SUM OF SQUARES	DF	MEAN SQUARE	F RATIO	P(TAIL)
REGRESSION	253.409	2	126.704	41.487	.00000
RESIDUAL	2348.604	769	3.054		

VARIABLE		COEFFICIENT	STD. ERROR	STD. REG COEFF	T	P(2 TAIL)	TOLERANCE
INTERCEPT		-2.35898					
LEQ	3	.12332	.017	.253	7.324	.000	.982411
NPL	4	.02767	.006	.152	4.397	.000	.982410

Tables XVI to XIX summarize the results. /48

TABLE XVI. SUMMARY OF THE BEST REGRESSIONS-ANNOYANCE-INDEXES-(THE AFFECTED COEFFICIENTS FOR EACH VARIABLE HAVE BEEN OMITTED IN ORDER TO SIMPLIFY THE PRESENTATION).

Annoyance / Choice of the better index	I.A.	M.A.
for 1 variable	L5	L5
for 2 variables	L1 + EMER	L1 + L10
After analysis of the 9 variables	L1 + EMER	L1+L5+L10+L50+L90 +EMER+nPL+LognPL

TABLE XVI. BETTER REGRESSIONS WITH ONE VARIABLE FOR THE INDIVIDUAL ANNOYANCE AND THE MODERATE ANNOYANCE.

FOR EACH SUBSET SELECTED BY YOUR CRITERION, THE R-SQUARED, ADJUSTED R-SQUARED, MALLOWS' CP, AND THE VARIABLE NAMES ARE PRINTED. THE REGRESSION COEFFICIENTS AND T-STATISTICS ARE PRINTED TO THE RIGHT OF THE VARIABLE NAMES.

MANY OTHER SUBSETS MAY ALSO BE REPORTED THAT ARE NOT ACCOMPANIED BY REGRESSION COEFFICIENTS AND T-STATISTICS. SOME OF THESE SUBSETS MAY BE QUITE GOOD ALTHOUGH THEY ARE NOT NECESSARILY BETTER THAN ANY SUBSET THAT HAS NOT BEEN PRINTED.

**** SUBSETS WITH 1 VARIABLES ****

Individual Annoyance

R-SQUARED	ADJUSTED R-SQUARED	CP	
.098095	.096970	.08	L5
.077202	.076001	17.83	L10
.075325	.074121	19.42	LEQ
.075023	.073819	19.68	EMEP
.073370	.072164	21.08	L1
.045914	.044672	44.41	L90
.044270	.043025	45.80	L50
.034999	.033743	53.68	LOGNPL
.033935	.032677	54.58	NPL

**** SUBSETS WITH 1 VARIABLES ****

Moderate Annoyance

R-SQUARED	ADJUSTED R-SQUARED	CP	
.929618	.929526	24462.90	L5
.733190	.732832	94877.24	L10
.708785	.708405	103621.51	LEQ
.703007	.702620	105692.75	EMEP
.697362	.696963	107716.31	L1
.431253	.430522	203101.01	L90
.414844	.414082	209986.42	L50
.336963	.336100	236903.22	LOGNPL
.330081	.329209	239369.97	NPL

TABLE XVII. BETTER REGRESSIONS WITH 2 VARIABLES FOR THE INDIVIDUAL ANNOYANCE AND THE MODERATE ANNOYANCE.

**** SUBSETS WITH 2 VARIABLES ****

Individual Annoyance

R-SQUARED	ADJUSTED R-SQUARED	CP	VARIABLE	COEFFICIENT	T-STATISTIC
.103061	.100722	-2.14	VARIABLE	COEFFICIENT	T-STATISTIC
			5 L1	.116228	4.90
			11 EMER	2.88777	5.04
			INTERCEPT	-3.50768	
.102964	.100625	-2.05	VARIABLE	COEFFICIENT	T-STATISTIC
			3 LEQ	.0943011	5.03
			5 L1	.115673	4.86
			INTERCEPT	-7.78381	
.102752	.100413	-1.87	VARIABLE	COEFFICIENT	T-STATISTIC
			5 L1	.112600	4.67
			7 L10	.0885467	5.01
			INTERCEPT	-7.42398	
.102616	.100276	-1.76	VARIABLE	COEFFICIENT	T-STATISTIC
			5 L1	.150593	6.96
			9 L90	.0647426	5.00
			INTERCEPT	-8.20505	
.102601	.100261	-1.74	VARIABLE	COEFFICIENT	T-STATISTIC
			5 L1	.152344	7.06
			8 L50	.0623476	5.00
			INTERCEPT	-8.28271	
.101177	.098833	-.53	LOGNPL	EMER	
.100450	.098105	.08	LEQ	LOGNPL	
.099003	.096654	1.31	L5	LOGNPL	
.098768	.096418	1.51	NPL	L5	
.098700	.096351	1.57	L5	EMER	

**** SUBSETS WITH 2 VARIABLES ****

Moderate Annoyance

R-SQUARED	ADJUSTED R-SQUARED	CP		
.976206	.976144	7765.16	L1	L10
.939247	.939189	21013.11	L5	LOGNPL
.937462	.937299	21653.19	NPL	L5
.934929	.934759	22561.22	L1	L5
.934139	.933967	22844.30	L5	EMER
.933479	.933305	23080.99	LEQ	L5
.932930	.932755	23277.58	L5	L50
.932485	.9323[illegible]	23437.27	L5	L10

TABLE XVIII. BETTER REGRESSIONS AFTER ANALYSIS OF ALL THE COMPARISONS WITH 9 VARIABLES, FOR THE INDIVIDUAL AND MODERATE ANNOYANCE.

Individual Annoyance

STATISTICS FOR 'BEST' SUBSET	
MALLOWS' CP	-2.14
SQUARED MULTIPLE CORRELATION	.10306
MULTIPLE CORRELATION	.32103
ADJUSTED SQUARED MULT. CORR.	.10072
RESIDUAL MEAN SQUARE	3.040466
STANDARD ERROR OF EST.	1.743693
F-STATISTIC	44.07
NUMERATOR DEGREES OF FREEDOM	2
DENOMINATOR DEGREES OF FREEDOM	767
SIGNIFICANCE	.0000

VARIABLE NO.	VARIABLE NAME	REGRESSION COEFFICIENT	STANDARD ERROR	STAND. COEF.	T-STAT.	2TAIL SIG.	TOL-ERANCE	CONTRIB TO R-SQ
	INTERCEPT	-3.50768	1.44863	-1.908	-2.42	.016		
5	L1	.116228	.0237369	.186	4.90	.000	.806460	.0
11	EMER	2.88777	.573109	.192	5.04	.000	.806460	.0

THE CONTRIBUTION TO R-SQUARED FOR EACH VARIABLE IS THE AMOUNT BY WHICH R-SQUARED WOULD BE REDUCED IF THAT VARIABLE WERE REMOVED FROM THE REGRESSION EQUATION.

Moderate Annoyance

STATISTICS FOR 'BEST' SUBSET	
MALLOWS' CP	7.66
SQUARED MULTIPLE CORRELATION	.99788
MULTIPLE CORRELATION	.99894
ADJUSTED SQUARED MULT. CORR.	.99786
RESIDUAL MEAN SQUARE	.000763
STANDARD ERROR OF EST.	.027621
F-STATISTIC	44791.68
NUMERATOR DEGREES OF FREEDOM	8
DENOMINATOR DEGREES OF FREEDOM	761
SIGNIFICANCE	.0000

VARIABLE NO.	VARIABLE NAME	REGRESSION COEFFICIENT	STANDARD ERROR	STAND. COEF.	T-STAT.	2TAIL SIG.	TOL-ERANCE	CONTRIB TO R-SQ
	INTERCEPT	-3.57285	.0775915	-5.986	-46.05	.000		
4	NPL	.0122235	.000563921	.206	21.68	.000	.030715	.0
5	L1	.138151	.00226968	.683	60.87	.000	.022134	.01
6	L5	-.0978484	.00261943	-.616	-37.35	.000	.010239	.0
7	L10	.126405	.00244134	.852	-51.78	.000	.010287	.0
8	L50	.0414917	.00316234	.355	13.12	.000	.003811	.0
9	L90	-.0963795	.00332209	-.796	-29.01	.000	.003702	.0
10	LOGNPL	-.167374	.0192738	-.109	-8.68	.000	.017715	.0
11	EMER	-3.09379	.0566360	.633	-54.63	.000	.020722	.0

THE CONTRIBUTION TO R-SQUARED FOR EACH VARIABLE IS THE AMOUNT BY WHICH R-SQUARED WOULD BE REDUCED IF THAT VARIABLE WERE REMOVED FROM THE REGRESSION EQUATION.

V. Discussion - Conclusion

The results of the responses to psychological annoyance as a function of the various experimental situations are as follows:

- the expressed annoyance is in one statistically significant aspect influenced by the Leq level as well as by the frequency of passages of H.V., but there is no interaction between these 2 variables.

- the subjects do not make a distinction between the expressed noise and the expressed annoyance.

- the estimated annoyance in an experimental situation is compared with the acoustical situation of their own apartment by the subjects.

- the imagined annoyance in the person's apartment at night and just before going to bed follows a development parallel with the psychological annoyance in an experimental situation, but each time is displaced to a higher level.

- the estimation of the annoyance due to the number of H.V. is specifically identified by the subjects, contrary to the estimation of the annoyance due to background noise, which is not independent of the frequency of passage of the H.V.

- the predictive value of the acoustical Leq index on the level of expressed annoyance could be improved considerably by using a composite index (including the number of H.V. and the Leq), of the general form, $G = Leq\ \alpha + nHV\beta + cte$, or more precisely:

$$G = 0.12\ Leq + 0.027\ nHV - 2.36$$
$$G = 0.12\ Leq + 0.75\ Log\ nHV - 2.82.$$

- a better composite index of the expressed annoyance could be for

the individual annoyance $IA = \alpha L1 + \beta EMER + cte$
the moderate annoyance $MA = \alpha L1 + \beta L10 + cte$

Yet, let us note that the predictive advantage of these 2 new indexes is not significantly different from the index of type $G = Leq\ \alpha + nHV\beta + cte$.

- the graphic analysis of the development of the moderate annoyance as a function of the number of H.V. and the Leq level has shown that:
. the expressed annoyance increases sharply from 3 to 5 H.V. and then more slightly from 5 to 30 H.V. for the Leq of 50 and 55 dB(A), /53
. the expressed annoyance increases sharply from 3 to 5 H.V. and then is saturated from 5 to 30 H.V. for a Leq of 60 dB(A).

We think that the "weight" of the influence of the number of H.V., in fact, depends not on the Leq level but on the difference in level between the peak H.V. levels and the background noise level; more precisely, an Leq of 50 dB(A) represents a moderate difference of 24 dB(A), an Leq of 55 dB(A) a moderate difference of 18 dB(A), an Leq of 60 dB(A) a moderate difference of 12 dB(A).

The schematic curve of development of the annoyance is represented in Fig. 17.

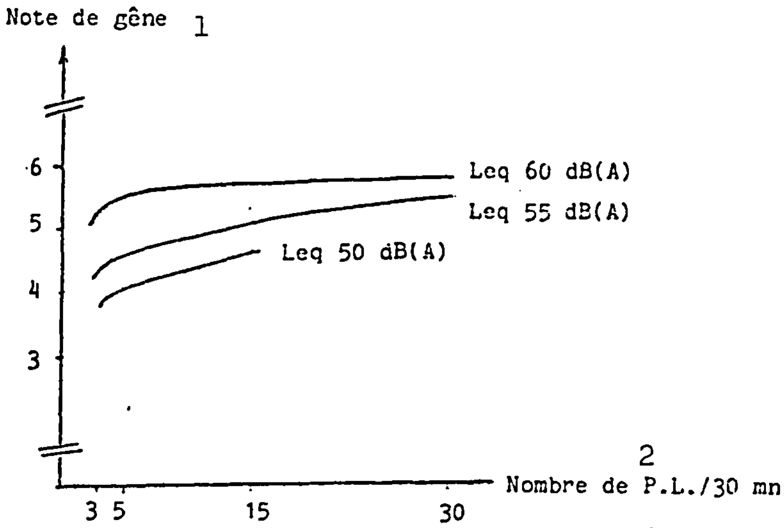

Fig. 17. Schematic development of the annoyance as a function of the Leq and of the number of H.V.

1 -- annoyance; 2 -- number of H.V./30 min.

This curve of the development of the annoyance approaches the logarithmic relationship found by Rasmussen, but it does not seem to confirm the inverted-U relationship proposed by Rylander.

The analysis of their studies leads to the following observations:

As in the experiment of Rylander, it appears difficult to understand certain parts of the annoyance curve; the percentage of annoyance for 3 H.V./45 min is 50%, with 4 H.V./45 min it climbs roughly to 62%, but, in contrast, with 6 H.V./45 min it descends again to 50%. Rylander notes a very great diversity in the answers of the subjects about annoyance for each H.V. density. /54

Moreover, he shows that if the relationship annoyance-number of H.V. seems to draw a curve, in contrast, when we test the same with the χ^2 test, we do not find a significant difference with a straight line.

Finally, let us note that this interpretation of the results would be more in agreement with the data of the test done by Rylander [6] himself; starting from a study done in two Swedish cities, Stockholm and Visby, he has shown that the level of psychological annoyance increased progressively from 1 to 1200 H.V./24 h, to then stabilize at a fixed level of 1200 to 3000 H.V./ 24 h (Fig. 18); it appeared here to be a phenomenon of saturation but not of redescent of the annoyance.

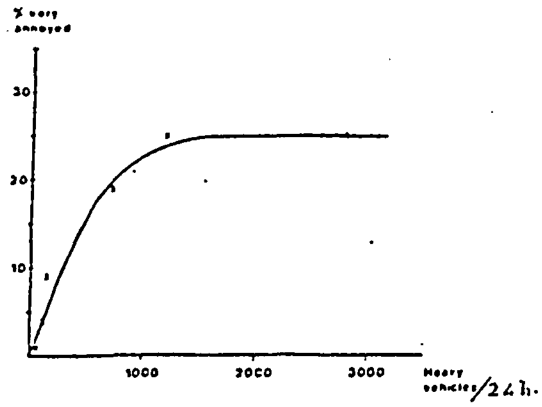

Fig. 18. Relationship between the annoyance and the number of H.V. for sites exposed to peak levels of around 80 dB(A).

The major criticism of the Rasmussen experiment comes from the relationship of the number of H.V. with the annoyance, which does not prove the specific effect of the number of events in any way, since the Leq level increases with the number of H.V. In short, to summarize these two experiments, we note that, if Rylander has established a relationship between the annoyance and the number of H.V., we do not have any certainty whether this relationship is in a curve or in a straight line; on the other hand, if Rasmussen seems to have established a straight-line relationship annoyance-number of H.V., nothing prevents us from thinking that there could just as well be a relationship annoyance-Leq level.

Thus, the importance of our study consists of having isolated an experimental area where the variations of the Leq level and the frequency of H.V. are independent of each other and in showing in these conditions that /55
the Leq and the number of H.V. each have an effect on the psychological annoyance. More precisely, we hold that:

- for peak sound level emergences of H.V. ≤ 12 dB(A), in relation to ground traffic noise (situations where the Leq ≅ 60 dB(A)), it seems that the number of vehicles has only a slight effect on the annoyance and the Leq level suffices as a predictive index of the annoyance.

- for peak sound level emergences of H.V. ≥ 16 dB(A), in relation to background noise (situations where the Leq levels are 50 and 55 dB(A)), the annoyance develops proportionately to the number of H.V. and in this case a composite acoustical index combining the Leq level and the number of H.V. is a better predictor of the annoyance.

VI. Prospects for Future Research

Our study opens the door to a series of studies on the composite indexes which in certain specific situations of traffic noise could be more predictive of the expressed annoyance than the Leq index alone.

To be more exact, if our results have been established for weak and moderate noise levels (Leq from 50 to 60 dB(A)), in order to draw more general conclusions it appears to be necessary to extend this experiment to noise levels higher than Leq 65, 70 and 75 dB(A).

In the case where our first results were confirmed, research on the better composite indexes, predictors of the annoyance, must be conducted for certain conditions of traffic noise and, in particular, for traffic at night (where the Leq does not seem to be an entirely satisfactory predictor).

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