



NASA TECHNICAL MEMORANDUM

NASA TM-75495

NASA-TM-75495 19810016457

EFFECTS OF STREET TRAFFIC NOISE IN THE NIGHT

B. Wehrli, J. Nemecek, V. Turrian, R. Hoffman,
and H. Wanner

FOR INTERNAL USE
NOT TO BE REPRODUCED IN THIS ROOM

Translation of "Auswirkungen des Strassenverkehrslaerm in der Nacht",
Kampf dem Laerm, Vol. 25, 1978, pp. 138-149.

NOTICE. BECAUSE OF COPYRIGHT RESTRICTION THIS TRANSLATION HAS NOT BEEN
PUBLISHED. THIS COPY IS FOR THE INTERNAL USE OF NASA PER-
SONNEL AND ANY REFERENCE TO THIS PAPER MUST BE TO THE ORIGINAL
FOREIGN SOURCE.

LIBRARY COPY

MAR 13 1980

LANGLEY RESEARCH CENTER
LIBRARY, NASA
HAMPTON, VIRGINIA

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION
WASHINGTON, D.C. 20546
MARCH 1980

1. Report No. NASA TM-75495	2. Government Accession No.	3. Recipient's Catalog No.	
4. Title and Subtitle EFFECTS OF STREET TRAFFIC NOISE IN THE NIGHT		5. Report Date March 1980	
		6. Performing Organization Code	
7. Author(s) Brigit Wehrli, J. Nemecek, Verena Turrian, R. Hoffman, and H.U. Wanner Institute for Hygiene and Work Physiology of the ETH, Zurich		8. Performing Organization Report No.	
		10. Work Unit No.	
9. Performing Organization Name and Address Leo Kanner Associates Redwood City, California 94063		11. Contract or Grant No. NASw-3199	
		13. Type of Report and Period Covered Translation	
12. Sponsoring Agency Name and Address National Aeronautics and Space Administration, Washington D.C. 20546		14. Sponsoring Agency Code	
		15. Supplementary Notes Translation of "Auswirkungen des Strassenverkehrs-laerm in der Nacht", Kampf dem Laerm v. 25, pp. 138-149 (1978)	
16. Abstract In order to obtain bases for the establishment of threshold values, a random sample survey with 1600 persons in urban and rural areas has been made on the degree of disturbance by street traffic noise in the night.			
17. Key Words (Selected by Author(s))		18. Distribution Statement U.S. Government and Contractors Only,	
19. Security Classif. (of this report)	20. Security Classif. (of this page)	21. No. of Pages	22.

EFFECTS OF STREET TRAFFIC NOISE IN THE NIGHT

B. Wehrli, J. Nemecek, V. Turrian, R. Hoffman, and H. Wanner¹

1. Formulation of the Question

The present investigation aims to establish threshold values by /138* demonstrating the still largely unknown relationships between traffic noise and the degree of disturbance experienced at night.

Because the investigation depends on the degree of subjective disturbance as a yardstick for the actual individual carrying capacity, a few hypotheses about an occurrence of perceived disturbance must be formulated and tested.

2. Hypotheses

2.1. Disturbance Experienced as a Result of Noise

Not every perceived noise stimulus is also simultaneously felt to be strongly disturbing or irritating; on the contrary the degree of disturbance experienced subjectively is determined by three completely independent areas of influence:

- by the type of stimulus components (acoustical-physical variables)
- by the perception capability (physiological variables)
- by the individual reference system in which the perceived stimulus is assimilated (psychological variables).

Besides the intensity of the noise occurrence (the absolute dB (A)-values), the stimulus frequency, sequence, and background are ~~equally significant among the physical variables with regard to the experienced disturbance.~~ It is to be assumed that in the night especially,

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

1- Institute for Hygiene and Work Physiology of the ETH, CH-8092 Zurich, EMPA, Acoustic Division, CH-8600 Duebendorf, Switzerland

the appearance of single noise peaks against a low base level can call forth an equally strong disturbance as a higher but constant noise level.¹

The physiological variables would have to be the subject of a separate physiopsychological investigation (e.g. like that of Griefahn [2]). In a study of of subjectively experienced disturbance one can proceed so that personal differences in physiological perception are equalized in the total population and hence may be disregarded.

The psychological variables are of great significance for the degree of disturbance experienced. The stimulus is evaluated and assimilated in one's personal reference system: stimulus meaning and stimulus assimilation stand in a close relationship with the disposition and intention of the individual concerned, as also with the place which the noise source occupies in his own value system [3].

In order to be able to determine the direct dependence of the disturbance experienced by an afflicted population on the measurable noise burden, one must be able to control the various influence factors which are stimulus-independent.

2.2. Stimulus-Independent Influences on the Degree of Disturbance

Stimulus-independent influences on the stimulus evaluation and thus on the degree of disturbance experienced are to be found:
in an individual range:

- personal predispositions such as age, health conditions, and general physical-psychic constitution;

Hypothesis: the worse the general physical-psychic constitution, the more severe the reaction to noise.

- intentions and dispositions of the afflicted parties which arise from their personal life rhythms (requirements for quiet, sleep, communication, and concentration);

Hypothesis: the more that intentions are disturbed or rendered impossible by noise, the more disturbing the noise

1- According to Klosterkoetter [1] level discontinuities (differences between the peak and the mean value) of more than 10 dB (A) lead directly to significant reactions in sleep.

is felt to be.

- the individual reference system, in particular the attitude towards traffic;

Hypothesis: the more negative one's attitude towards cars and traffic in general, the more severe one's reaction to noise.

in a contextual range:

- relationship to the spatial surroundings, to one's own living environment, to the quality of living environment, to the degree of living satisfaction;

Hypothesis: the greater the satisfaction with living arrangements, the less the sensitivity to noise.

- significance of traffic for the afflicted subject (delivery traffic or through traffic: functionality of the traffic);

Hypothesis: the more functional the traffic is for the neighboring resident, the less severe his reaction to noise.

- centralness of residence location (urban location as opposed to quieter one on periphery of the city or in rural setting);

Hypothesis: the more central the location, the less severe one's reaction to noise.

3. Structure of the Investigation

3.1. Random Sample and Questioning

The formation of a random sample takes place in three steps (cp. fig. 1); the first is the selection of the region to be investigated, i.e. of the contextual background.

At the first level one must decide between urban and rural conditions. Within the general concept of urban conditions one still however has to distinguish between pure inner city districts (centrally placed residences with a clear urban character) and typical outlying districts, which show a resemblance to rural areas with regard to noise emissions (with the exception of much-travelled thoroughfares).

For the second step one must consider the social status of the residential districts: there are selected districts in the city of

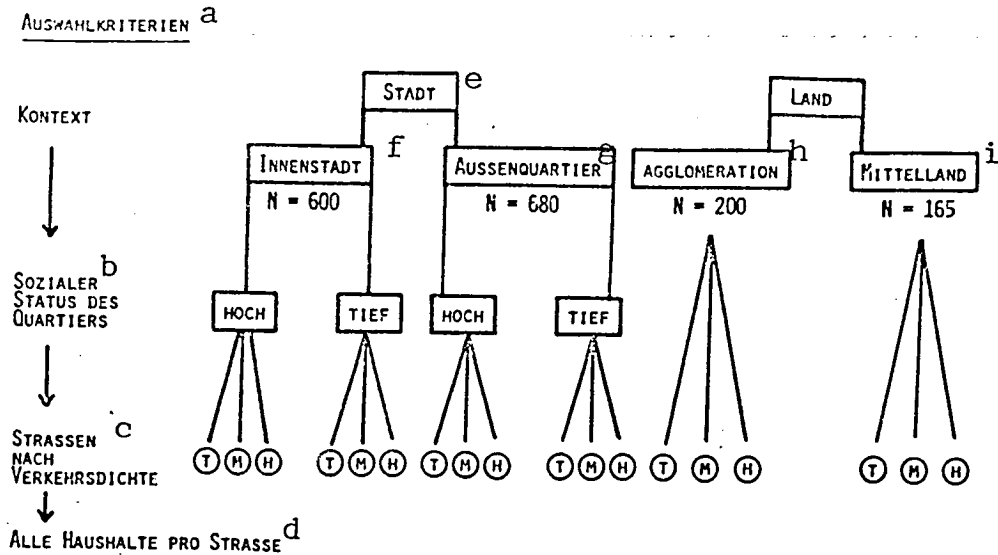


Fig. 1. Structure of Investigation; T = tief (low), M = middle, H = hoch (high); for classification see text.

Key:

- a - Selection criteria
- b - Social status of district
- c - Streets acc. to traffic density
- d - All households per street
- e - City
- f - Inner city
- g - Outlying districts
- h - Built-up areas
- i - Open country

Zurich, both in the inner city and the outlying areas, which contain more highly esteemed and therefore more expensive neighborhoods as well as less highly esteemed and thus cheaper ones.

The third step in forming a random sample involves the selection of street characteristics in each context.

In each of the six areas selected for investigation at least three streets were chosen which differed significantly in their traffic density: thus each environment should include a thoroughfare with a high traffic density (at least 400 vehicles/hour at night), a connecting street with average traffic density (between 100 and 300 vehicles/hour at night) and also a quiet residential street (less than 50 vehicles/hour at night).

A total census of all the households on these streets is taken for each sample. A total of 1607 people were questioned, and the questioning took place in written form.

3.2. Noise and Traffic Measurements

Continuous monitoring measurements were conducted directly on the streets under investigation, for 2-3 or 3-4 days on end depending on the traffic density. Next four tape recordings, each of 30 minutes duration, were made simultaneously for the rearward, shielded rows of houses. Thus the decrease in noise for the back rows of houses could be determined and the corresponding noise gradient estimated.

For the measurement process relating to sound level statistics the apparatus of Brüel & Kjaer was employed. From the measurement data ascertained for each hour over many days average values were calculated for 24 hours, for day and night, and for six time periods.

In the same section of streets in which the monitoring measurements were performed, the traffic density was also counted.

4. Results

4.1. Measurement Results

The average values of the L_{eq} -level and the traffic density for the six day-periods and also for day and night are graphically represented in fig. 2. Each horizontal stroke in the single column of graphics corresponds to an average value of the L_{eq} -level or of traffic density for the given environment. In this way the streets with high, middle, and low traffic densities may be clearly distinguished from /140 each other.

The analysis of the measured data produces the following most important results:

- The nighttime values scatter more than the daytime ones, and the values from much-travelled streets scatter less than those from seldom-travelled ones.

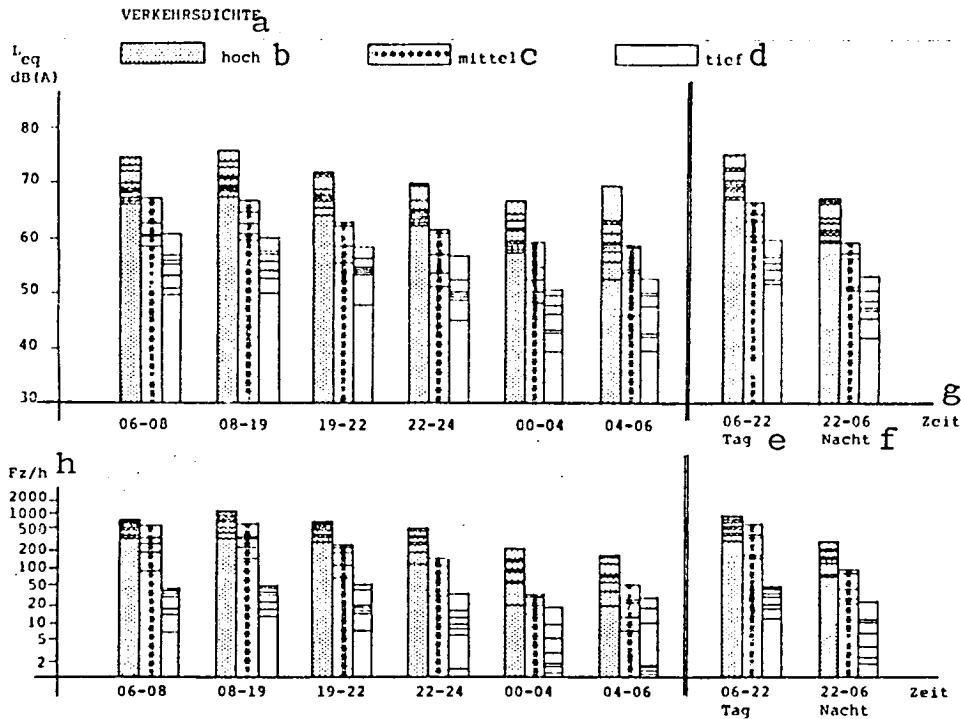


Fig. 2. L_{eq} -values and traffic densities at individual measurement sites.

Key: a - Traffic density e - Day
 b - high f - Night
 c - medium g - Time
 d - low h - Vehicles/hour

- The average variation in the L_{eq} -values between day (0600-2200) and night (2200-0600) for all streets investigated is 7.65 dB units.
- The correlations between traffic density and noise increase with the traffic density: at higher traffic densities the correlations are the strongest, and at lower densities the weakest.

4.2. Relationships between L_{eq} -values and Disturbance Experienced during the Day and during the Night

To estimate the threshold values we must consider the correlations over all the measurement points. Fig. 3 shows the relationship between noise burden and disturbance² for each location during day and night.

² - The degree of disturbance was quantified by means of a "thermometer scale" on which the subjects could register the degree of their dis-

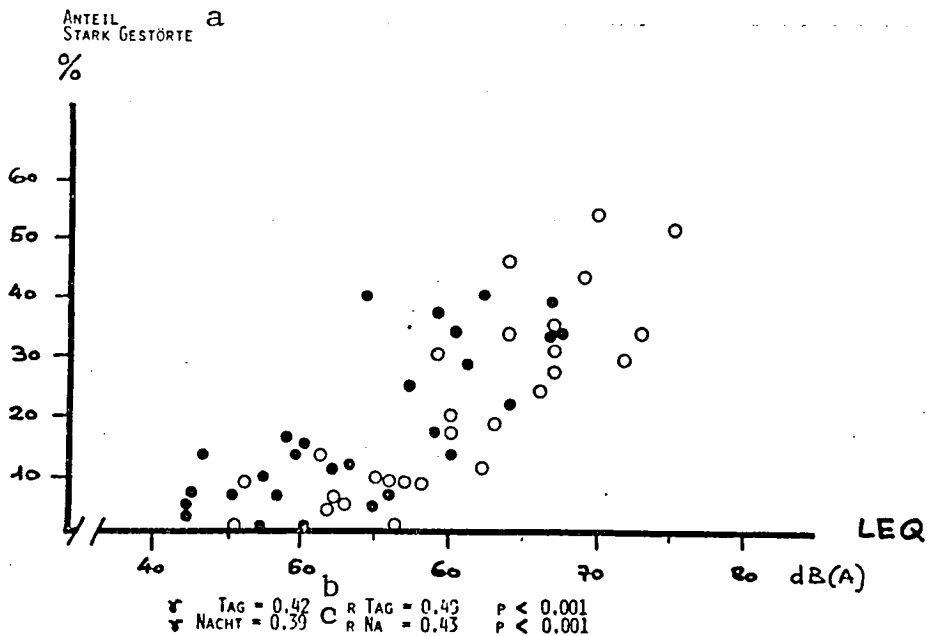


Fig. 3. Disturbance experienced dependent upon the noise burden during day and night.
 N= 1,607; 28 measurement sites
 O day values; ● night values

Key: a - Fraction severely disturbed
 b - Day
 c - Night

Both for day and night a distinct increase in the "severely disturbed" emerges with increasing noise level. The correlations³ are 141 relatively high in comparison to other field studies [4,7,8].

In comparison to the day values the night values exhibit a broader distribution; this however can be traced experimentally to two variant cases. Both these cases concern measurement locations in the back house rows of much-travelled streets. Here it is a question of a "situative" influence, to which we shall return in section 4.7.

One may observe in the distribution of values that as much in the day values as in the night ones no linear relation persists, but instead

turbance. The scale points 8 to 10 were interpreted as "severe disturbance". These methods have previously been applied in various other field studies [4], [5], [6].

3 - γ after Goodman and Kruskal, r after Pearson.

TABLE 1. DISTURBANCE EXPERIENCED DEPENDENT ON GRADED NOISE BURDEN

Noise Burden in dB (A) L_{eq} -values	Number Questioned per Noise Grade		Fraction "Se- verely Disturbed"	
	L_{eq} -day	L_{eq} -night	Days %	Nights %
< 50	—	617	0	6
50-55	262	168	5	12
55-60	435	335	9	24
60-65	168	304	27	26
65-70	559	183	37	34
70-75	183	—	38	—
Total	1,607	1,607	$\gamma = 0.47/p < 0.001;$ $\gamma = 0.46/p < 0.001$	

a sudden rise occurs at a certain point. The rise begins at about 55 dB (A) for the night values, and about 60 dB (A) for the day values. These increases become clearer if one considers the graded values. In Table 1 the fraction "severely disturbed" is compiled dependent upon the graded L_{eq} -values.

In the lower noise ranges up to 60 dB (A) the disturbance is much more severe at night than during the day-- the subjects are more sensitive to low noise burdens by night than by day. In the range 55-60 dB (A) the fraction of "severely disturbed" doubles in comparison to that fraction in the 50-55 dB (A) range, up to 24 %. Thus in this range already roughly a quarter of the afflicted population is severely disturbed: what in Switzerland serves as the limit of toleration in planning for new environmental protection laws. This limit is in the daytime reached by L_{eq} -values of more than 60 dB (A). Here also a distinct increase appears: the fraction "severely disturbed" climbs from 9 % at 55-60 dB (A) to 27 % at 60-65 dB (A).

The intercorrelation between the day and the night thermometers is, as the distribution leads one to suppose, very high, with a γ of 0.71. But of all the subjects questioned only 9 % feel equally "severely" disturbed in the daytime as at night, while on the other hand 15 % feel disturbed neither during day nor night. Despite the high correlation one may yet differentiate in the statement about the degree of disturbance: thus for example 8 % classify themselves during the day as "severely disturbed", but at night as only "moderately disturbed";

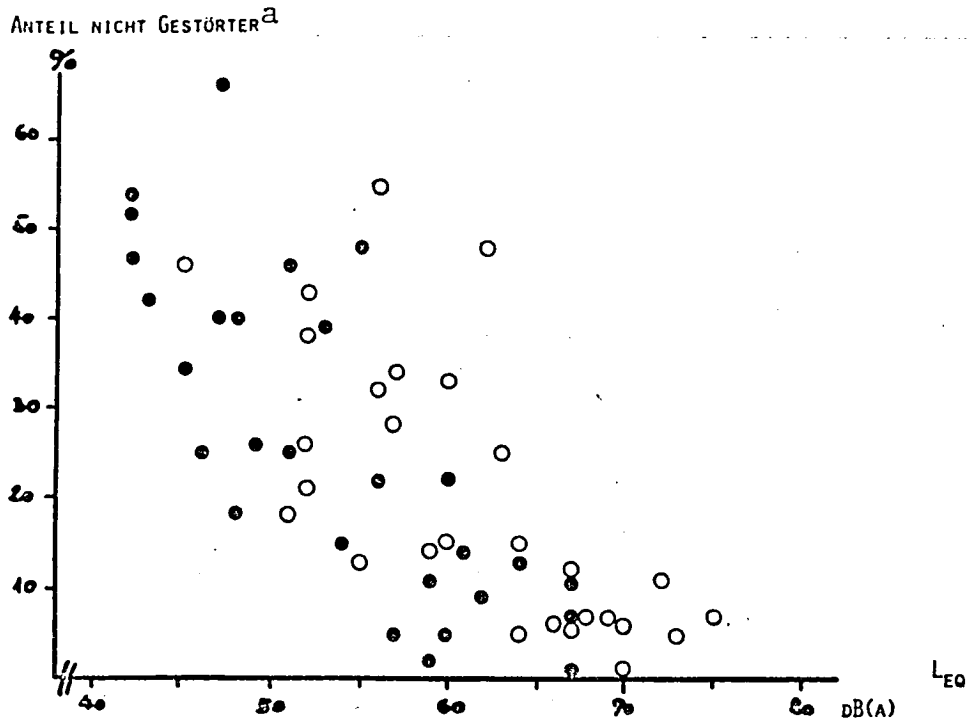


Fig. 4. "Not Disturbed" dependent upon noise burden during day and night.
 N = 1,609; 28 measurement sites
 ○ during day ● during night

Key: a - Fraction not disturbed

TABLE 2. FRACTION "NOT DISTURBED" DEPENDENT ON NOISE BURDEN

Noise Burden in dB (A) L _{eq} -values	Number Questioned per Noise Grade		Fraction "Not Disturbed"	
	L _{eq} -Day	L _{eq} -Night	Days %	Nights %
< 50	—	617	46	45
50-55	262	168	34	33
55-60	435	335	36	8
60-65	168	304	20	14
65-70	559	183	6	7
70-75	183	—	7	—
Total	1,607	1,607		

6 % are "severely" disturbed nights and "moderately" days. If one combines the day or night "severely disturbed", there are thus 31 % whose well-being is impaired at some time or other of the day by traffic noise.

Besides the distribution of "severely disturbed", the relationship between the fraction "not disturbed", i.e. those who had marked steps 0 or 1 on the thermometer, and the actual noise burden, is also of interest. This relationship is represented in fig. 4.

If one compares the distribution of the "not disturbed" with that of the "severely disturbed" (fig. 3), it becomes clear that the criterion "not disturbed" is less directly dependent on the effective noise situation.

A very broad scattering appears predominately in the lower and middle noise ranges, while at about 60 dB (A) the fraction of those "not disturbed" begins to fluctuate at around 10 %. These 10 % can be designated "noise-insensitive"; there is also a corresponding group of about 10 % "noise-sensitive" people who always declare themselves to be disturbed. This broad scattering implies that the question of whether one feels disturbed by the noise in lower noise ranges or not depends on various other influence variables.

If one relates the fraction "not disturbed" to the graded noise values (Table 2), threshold values appear which substantially correspond to those of Table 1.

At night the fraction "not disturbed" falls off at 55 dB (A) from 33 % to 8 %, and in the daytime at 60 dB (A) from 36 % to 20 %; at 65 dB (A) moreover a strong decrease from 20 % to 6 % appears. These threshold values correspond rather exactly to those which were found in the distribution of the "severely disturbed".

4.3. The Most Disturbed Time of Day

The interactions investigated up to now between noise burden and disturbance are based on L_{eq} average values for the night and for the day.

The effective traffic burdens are however variably strong during these periods, as we have already seen in fig. 1; this is expressed also in the degree of disturbance, as might be expected. A more re-

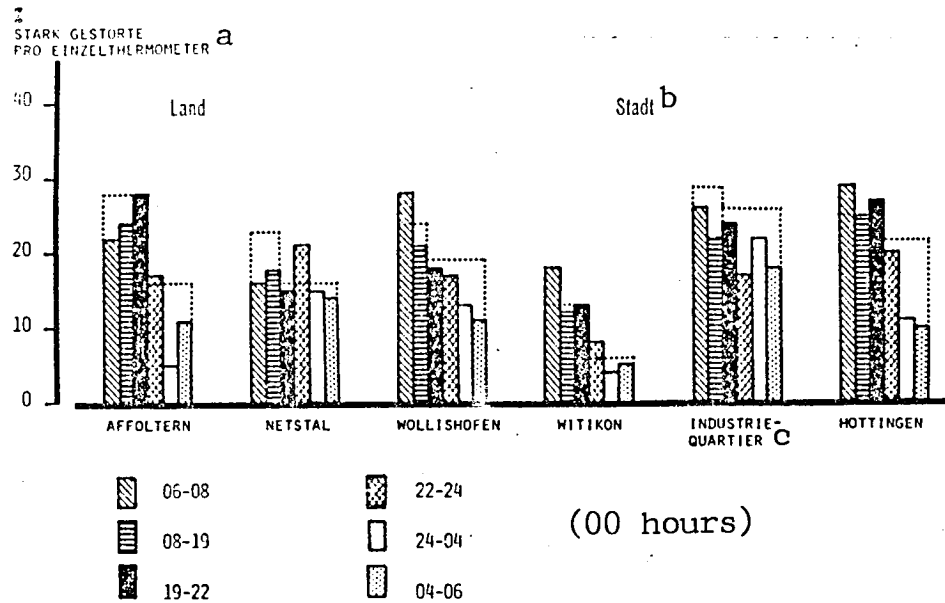


Fig. 5. Strongly disturbed subjects in various day and night periods for each region under investigation (individual thermometers)
 = Degree of general disturbance by day and at night

Key: a - Strongly disturbed (subjects) per individual thermometer
 b - City
 c - Industrial District

finer differentiation of disturbance according to individual periods of day and night was investigated in the following ways:

- by means of six different thermometers, with which the disturbance during a particular time period could be quantified,
- by means of a question about the "most disturbed time of day".

Fig. 5 gives an overview concerning the degree of disturbance in the various day and night periods.

The comparison of the individual thermometers with that for the whole night or the whole day (which here was compared only with the subjective feeling corresponding to the period up to 1900 hours) shows that in most regions subjects reacted more sharply to the first "spontaneous" question than to questions about disturbance in particular time periods, which require more detailed answers. The comparison also allows one to draw conclusions regarding which particular time

periods the general day or night disturbance refers to; this is of special significance for night noise. During the "acoustic night" from 2200 to 0600 hours, it is in all districts, with the exception of industrial ones, the 'falling asleep period' of 2200 to 2400 which produces the greatest share of severely disturbed persons; the subjects are in all cases clearly less disturbed in the actual sleeping period between 2400 and 0600 hours.

The morning, day, and early evening are most of all disturbed. They represent the most severely disturbed time periods in all regions with the exception of Netstal.

The actual night hours from 2200 to 0600 are substantially less disturbed. An exception has already been mentioned; this is Netstal, where the residents frequently complain about coming and going by ①. The same problem prevails-- as previously mentioned-- to a high degree in the industrial districts of Zurich, which are travelled by pleasure-seekers primarily in the late night hours (2400 to 0400).

In the other cases disturbances during the actual sleeping period seem to represent a smaller problem than that during the day or in transition periods.

The explicit question about the "most disturbed time of day" asked additionally corroborates the earlier results, in that once again 26 % indicate the morning hours (0600 to 0800) as most disturbed, 21 % the day (0800 to 1900), and of the night hours the period 2200 to 2400 is /143 named most frequently as most disturbed time period by 13 %.

The question concerning the most representative time period during the night occurs also in this context. In fig. 5 the thermometers for the individual time periods are contrasted with those for general disturbance during day or night respectively, readily allowing a comparison to be set up. The results become by all means more clearly discernable in the correlation analysis (Table 3).

TABLE 3. CORRELATIONS BETWEEN THE L_{eq} -VALUES FOR INDIVIDUAL NIGHT PERIODS, THE CORRESPONDING DISTURBANCE AND THE GENERAL NIGHT DISTURBANCE (%)

Disturbance	Correlations (K_{L_S})			
	1900-2200	2200-2400	2400-0400	0400-0600
Thermometer for the specific time period	0.39	0.35	0.28	0.32
Thermometer for the general disturbance	0.38	0.41	0.37	0.36

The correlation coefficients are at their highest for the noise of the first period (2200 to 2400 hours). This is also the most representative period for the entire night, because here the highest correlation exists with the thermometer for the general disturbance. However the evening hours, which do not belong to the acoustic night, obviously form a strong subjective connection with the night.

One may say in summary that the 'falling asleep period' is the critical period for nighttime disturbance.

4.4. Effects of Traffic Noise at Night

With regard to disturbances by street traffic noise in the night it is above all a question of sleep disturbances. Sleep disturbances pertain to the study by Kastka and Buchta on "somatic-emotional components of irritation" [3], which first begins to become of pressing importance at high noise values. Sleep disturbances can manifest themselves as "being unable to fall asleep", as "waking up in the night", or as "waking too early in the morning". Fig. 6 compares the frequencies of these disturbances.

The most frequently cited disturbance is "waking too early in the morning", which coincides with the previous results in which the morning (0600 to 0800 hours) emerged as the most disturbed time of day.

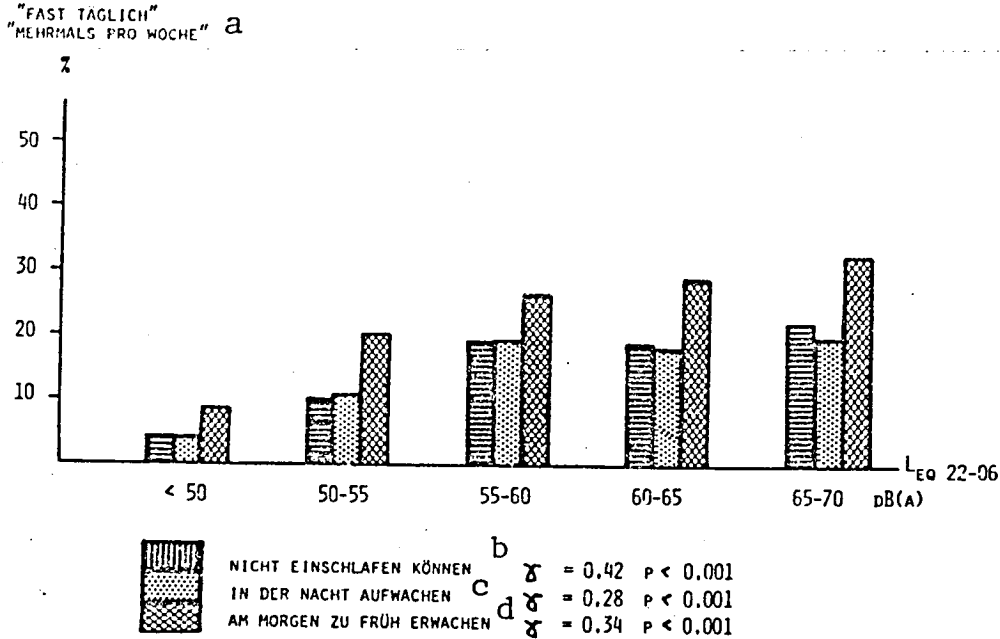


Fig. 6. Effects of traffic noise in the night.
N = 1,607

Key: a - "almost daily" "several times a week"
b - unable to fall asleep
c - waking up in the night
d - waking too early in the morning

TABLE 4. FRACTION OF SUBJECTS WAKING TOO EARLY BECAUSE OF NOISE, DEPENDENT ON THE L_{eq} -VALUES BETWEEN 0600 AND 0800

L_{eq} -Value 0600-0800	Fraction of Subjects per Noise Grade	Fraction of Those who Wake too Early %
< 50	112	4%
50-55	176	12%
55-60	403	8%
60-65	153	23%
> 65	723	30%
Total 1,567		

The period 0600 to 0800 of course belongs acoustically to the day, as already seen, but corresponds to the time for waking and getting up for the majority of subjects. This leads to the conclusion that disturbances in this time period are still subjectively considered to belong to the sleeping period.

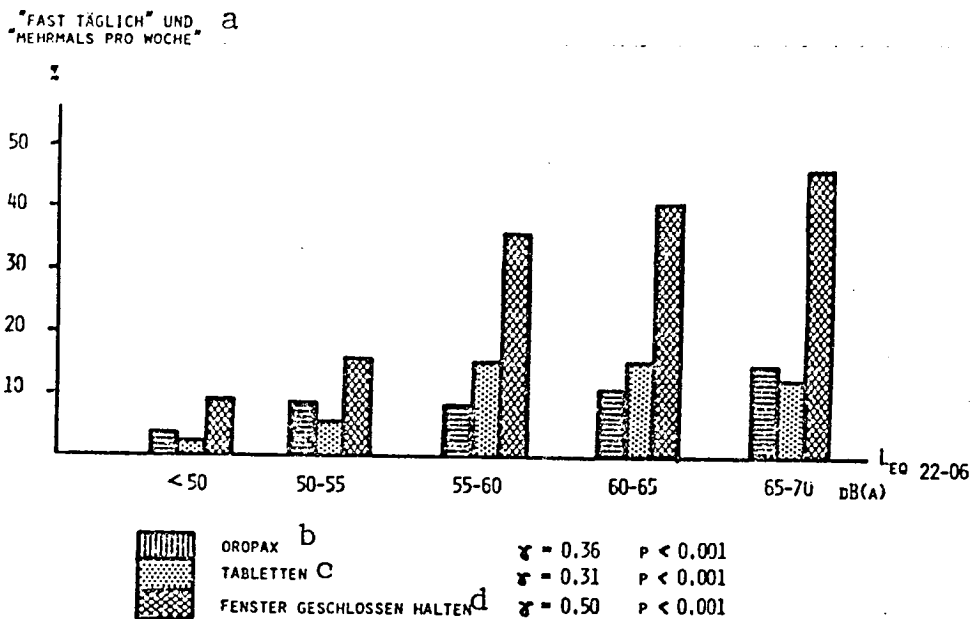


Fig. 7. Reactions to street traffic noise-in the night

Key: a - "almost daily" and "several times a week"
 b -
 c - tablets
 d - keeping windows closed

If one correlates the statement "waking too early" with the L_{eq} -value of the period between 0600 and 0800 one obtains the results appearing in Table 4 above.

Over 50 % of the subjects questioned have a morning L_{eq} -value of more than 60 dB (A). Of these, 30 % are awakened almost daily or at least several times a week by street traffic noise. In the range from 60 to 65 dB (A) there are 23 % who are awakened mornings by noise; the range around 60 dB (A) must be considered a critical threshold value.

In actual night disturbances this threshold is lower: at a noise burden of 55 dB (A) there are approximately 20 % who suffer from regular falling-asleep or mid-sleep disturbances. Since regularly-occurring /144 sleep disturbances are in any case injurious to health in the long run [1], [2], the value of 55 dB (A) in the night must be considered the highest permissible threshold value.

4.5. Reactions to Traffic Noise in the Night

Interference between noise and the need for relaxation, quiet, and sleep leads to a feeling of disturbance and simultaneously to the need to protect oneself against it. Fig. 7 portrays various possible reactions to disturbance by street traffic noise.

The simplest reaction to the disturbance experienced because of noise is shielding oneself from the noise: closing the windows. At > 55 dB (A) already 1/3 of the subjects keep the window closed on account of noise. Of these, however, 39 % are still always severely disturbed (even with closed windows). Besides this 15 % in the range from 55 to 60 dB (A) take sleeping or sedative tablets "almost daily" or "several times a week" on account of noise, which represents a significant portion of the "zero value" of 4 % (without noteworthy noise burden). The use of _____ also climbs considerably with increasing noise level, up to 14 % at a noise burden of more than 65 dB (A).

There seems to be an apparent contradiction between the relatively small fraction of "severely disturbed" and the yet quite strong reactions to sleep disturbances. It is to be assumed that disturbance in the night is only cognitively perceived if it leads to actual sleep interruption. This also often results in preventative measures (_____, windows, etc.). If the noise doesn't result in sleep interruption, it is unperceived for practical purposes at night-- in contrast to during the day. Kastka and Buchta in Duesseldorf have obtained similar conclusions [3].

4.6. Most Disturbing Noise Sources in the Night

A qualitative analysis of nighttime traffic has been conducted in addition to the quantitative one. To the question "What disturbs you most of all at night?" we obtain from the total population the results following in Table 5.

The most often cited noise sources are private cars, motorcycles, and mopeds, as well as "doors closing" and arrivals. It seems plain that on the streets with high noise burdens-- the thoroughfares--

TABLE 5. MOST DISTURBING NOISE SOURCES IN THE NIGHT

Noise Source	Fraction Designating	
	"most disturbing" %	"second-most" %
Quickly-passing private cars	22	11
Trucks	7	8
Brakes, gears, accelerators	12	12
Doors closing, arrivals	25	20
Motorcycles	17	20
Mopeds	11	21
Streetcars ⁴	4	4
Other	3	4
Total	100	100

the passing traffic constitutes the disturbance: private cars and motorcycles. Trucks, which otherwise always occupy the peak among disturbing noise sources, are here so little cited for the reason that from 2200 to 0600 hours there is a night travelling ban.

On the quieter residential streets it is on the other hand the source traffic: departures, getting in and out, doors slamming, etc., and also the local moped traffic, which disturbs the neighbors. This type of noise is measured mostly in the lower range of L_{eq} -values, but disturbs on account of the isolated character of the noise occurrences, which moreover are oftentimes connected with negative evaluations (moped drivers).

4.7. Stimulus-Independent Influences on the Degree of Disturbance /145

Environmental, Situative, and Structural Influences

Contrary to the hypotheses no systematic and/or significant distinctions could be found in noise sensitivity among the individual areas

4- The noise source "streetcar" was confined to a few city streets; of these there are two on which the streetcars run and a few more on which they can be heard.

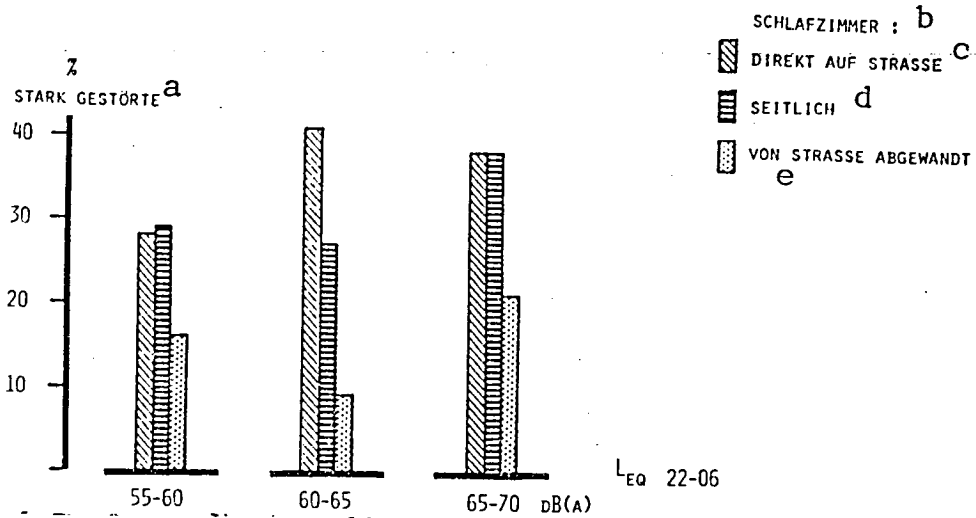


Fig. 8. Disturbance experienced at various noise burdens dependent on bedroom position

Key: a - Severely disturbed
 b - Bedroom
 c - Directly on the street
 d - On the side
 e - Removed from the street

investigated. Such differences have appeared neither between city and country, nor between inner city districts and peripheral ones.

There were on the other hand clear influences of a situative kind: therefore as already mentioned, measurements were taken and questions asked in the rear house rows on various main and connecting streets with sideways- or rearward-facing buildings. From this it has appeared-- analogous to an earlier study in Zurich [5]-- that the residents in such back houses, whose noise burden is comparable with that of neighbors on quieter residential streets, are significantly more disturbed. Here is an example from one of the six study environments:

Main street	front	60.3 dB (A)	13 %	} fraction severely disturbed at night
	2nd house row	48.3 dB (A)	10 %	
	3rd house row	45.3 dB (A)	6 %	
Residential street		47.0 dB (A)	1 %	

Although the residents of the houses behind the main street are subjected to an equally low noise burden as the residents of the quiet residential street, they feel more disturbed. This finding is valid also for other streets with a corresponding arrangement. It may be con-

cluded that those afflicted evaluate not only the noise in their own homes but also that in their immediate living environment from the street across the garden, entry, etc., up to the house.

A structural aspect relevant to the degree of disturbance⁵ is the location of the living area within the house, in particular the position of the bedroom. Fig. 8 represents the disturbance experienced dependent on the position of the bedroom.

It appears that the subjects with bedrooms completely removed from the street are substantially less disturbed. Subjects with side bedrooms are however hardly less disturbed than those with bedrooms directly facing the street.

Especially protected are the residents of a house which is completely oriented toward the back; this is the case for only 4 % of all dwellings on streets with a noise burden of more than 55 dB (A).

In the critical range from 55 to 60 dB (A) 28 % of the subjects with bedrooms directly facing the street are severely disturbed, but only 16 % of those with bedrooms toward the back. The difference appears more clearly in terms of closing windows: of the subjects in the critical range from 55 to 60 dB (A), 51 % keep the windows closed at night on account of noise in case they go out on the street. In rooms isolated from the street the windows are kept closed only by 23 %.

This is indeed the reason why the differences in actual sleep disturbances between the subjects with differing bedroom locations are so small: whoever has the bedroom directly facing the street keeps the window carefully closed most of the time, while the one having the bedroom toward the back really prefers to leave it open, but suffers for it again and again in sleep interruptions. Thus there are for example in the range from 55 to 60 dB (A) 24 % with front bedrooms who wake up too early in the morning, and among those with rear bedrooms there are only 2 % less.

5- In the following when the discussion only concerns "disturbance", this always refers to disturbance during the night.

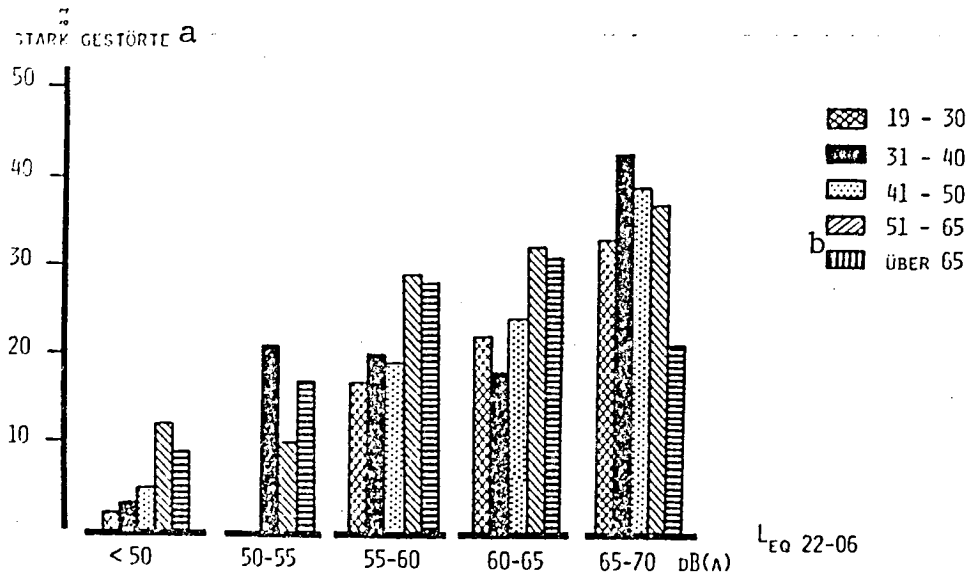


Fig. 9. Noise and disturbance experienced in various age groups.

Key: a - Strongly disturbed
b - over 65

A further structural variable, the building floor, has no significant influence on the degree of disturbance felt. It must by all means be taken into account here that only 20 % of all the subjects questioned live higher than the second floor.

Individual Influences

As described at the beginning, we presume that there are influences from the individual aspect of life on the degree of disturbance experienced.

The influence of age on noise sensitivity was examined as an important variable of the sociodemographic domain. Fig. 9 represents the relationship between noise and disturbance for various age groups.

There are no recognizable systematic differences in noise sensitivity among the different age groups. In the lower and middle noise ranges the older people are severely disturbed sooner, but in the range from 65 to 70 dB (A) this tendency can no longer be established.

If one examines the course of the fraction "severely disturbed" /146 out of the various groups over the different noise ranges, a few distinctions appear: in the older age group (51 years or older) a clear threshold can be recognized at 55 dB (A), at which value the fraction "severely disturbed" climbs sharply. Among the younger groups the increase proceeds rather more continuously, with the exception of the 31-40 year-olds, for whom a perceptible threshold is noticeable first at 65 dB (A).

This interpretation must by all means not be overestimated, since here as well the situative variables of individual streets-- which would tend to differ in their age structure to some extent-- play a role. The analysis of age influence along individual streets has in any case produced no significant evidence.

With reference to the disturbance levels of children under 12, 16 % of parents were of the opinion that they were rather more severely disturbed, while 39 % thought they were rather less disturbed. The largest group with 45 % were of the opinion that the children were disturbed to about the same degree as they themselves.

To the complex of sociodemographic influence variables belong besides age also variables dictating life rhythm such as occupation, level of occupational activity, and in connection with this also the amount of time one spends at home on the whole.

The level of occupational activity had just as little influence on noise sensitivity in the night as the time one spends at home during the day.

This has an influence purely on disturbance during the day: the more time spent at home days, the sooner one is disturbed.

Other sociodemographic variables such as professional status, degree of education, citizenship, or sex have no recognizable influence.

Auto owners on the other hand are above all significantly less severely disturbed in the lower noise ranges (up to L_{eq} -values of 65

dB (A) from 2200 to 0600 hours) than the subjects without autos.

Another variable of an individual nature is the length of residence in the particular district or dwelling. It is often maintained that one becomes accustomed to noise. An appropriate question was included on the question sheet.

Thereby there were:

- 8 % of the opinion that everyone could grow accustomed to noise
- 77 % of the opinion that there were people who could become accustomed to a certain degree of noise
- 15 % who believed that one could not grow accustomed to noise.

The answer to this question is in other respects completely independent of one's personal noise burden.

If one then tests the question about habituation in degree of disturbance for dependence on the length of residence, in no noise grade does a clear dependence appear for the total population. In the urban districts no connection at all exists between length of residence and degree of disturbance. In rural communities those people however are more severely disturbed by traffic noise who have lived longer on the corresponding street, though this relation is significant only in Netstal.

The assertion that people become accustomed to traffic noise with the passage of time must therefore be considered false. The opposite tendency must rather be established, that people who have already lived a long time in a district and have witnessed a steady increase in traffic without being able to do anything about it, are rather more severely disturbed than those who from the beginning have had to reckon with the noise.⁶

With newcomers it is a question of relatively noise-insensitive persons or of persons with a low income, who must bear with a certain quantity of noise in order to have inexpensive rent. In our investiga-

6- These results coincide with those of Graf, Meier, and Mueller [4].

TABLE 6. JUDGMENT ABOUT RENT BY "NOT DISTURBED"
AND BY "SEVERELY DISTURBED" SUBJECTS.

Judgment about rent	"Not disturbed"	"Severely disturbed"
"too high"	7 %	18 %
"acceptable"	50 %	53 %
"favorable"	43 %	29 %
total	100 % (N = 385)	100 % (N = 240)

$$\chi = 0.16/p < 0.001$$

tion rent has only been taken into account in the subjective estimation of those questioned.

The correlation between opinion about the rent and degree of disturbance is represented in Table 6.

In the positive correlation between the negative opinion about rent and a higher noise sensitivity the direction of causality may not be unequivocally defined; each can determine the other. It is interesting, however, that this correlation is only significant in the lower noise ranges. /147

To be able to analyze the correlation between degree of noise disturbance and opinion about rent also in the regions with higher noise burdens, we fundamentally placed the question: "Would you be willing to pay a higher rent for a quieter location?". This produced the results in Table 7 following.

Although the strict dependence of the answer to this question on the actual noise burden is obvious, a few details are especially worthy of mention:

The distinct threshold in the region of 55 to 60 dB (A) appears once again here: at lower noise burdens only 16 % are ready to pay more for a quieter location, while in the range from 55 to 60 dB (A) 33 % are ready.

TABLE 7. READINESS TO PAY A HIGHER RENT FOR A QUIETER LOCATION, DEPENDENT ON THE NOISE BURDEN

Noise burden in dB (A) L_{eq}^{-22-06}	Prepared to pay a higher rent %	Not prepared to pay a higher rent %	Living quietly already %
< 50	12	14	74
50-55	16	36	48
55-60	33	49	17
60-65	45	44	11
65-70	51	40	9
Total	28% = 425	32% = 499	40% = 623

$$\gamma = 0.61 / p < 0.001, N = 1,547^7$$

It is interesting in addition that in the range 65 to 70 dB (A), thus under a very severe noise burden, 40 % would still rather not or else could not pay higher rent for a quieter location. That it is indeed practically always a question of "not being able to pay" is shown by the fact that even of the "severely disturbed" in this noise range 38 % would still not be willing to pay any higher rent for a quieter location.

4.8. Residential Satisfaction and Experienced Disturbance

There is a strong connection between the disturbance experienced and a variable which is at the same time of an environmental and an individual nature: the subjective perception of living surroundings--the residential satisfaction.

If one compares the satisfaction of residents of areas with differential noise burdens, which is quantified by a polarity profile [9], considerable differences appear in certain regards (fig. 10).

If one then condenses the items from the polarity profile to a "satisfaction index" and tests the relation between residential contentedness and degree of disturbance at constant noise burden, the correlation visible in Table 8 is produced.

7- Does not include the owners of single-family houses and owner-occupied apartments (11 %), who do not significantly differ in their noise sensitivity.

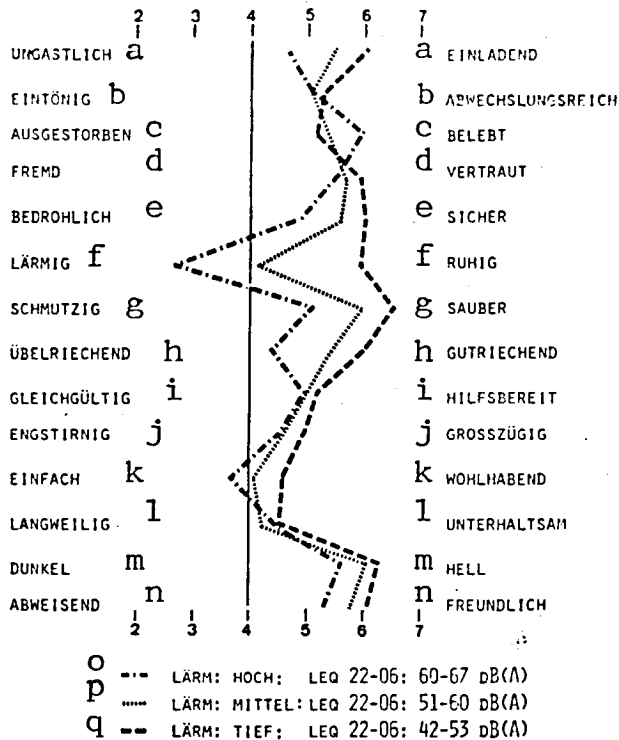


Fig. 10. Judgment about personal living satisfaction according to noise burden. N high = 809, N middle = 413, N low = 385

TABLE 8. CORRELATION BETWEEN DISTURBANCE EXPERIENCED AND LIVING SATISFACTION

Degree of disturbance	Satisfaction with Surroundings	
	low %	high %
disturbed little or not at all	24	62
moderately disturbed	29	26
severely disturbed	47	12
Total	100 % = 137	100 % = 318

$\gamma = 0.44/p < 0.001$ N = 728
 Measurement sites with higher noise burden:
 ($L_{eq} 22-06 > 60$ dB (A))

At higher noise burdens this correlation becomes very clear: in spite of an L_{eq} -value of more than 60 dB (A), only 12 % of those who are contented with their living environment are severely disturbed.

On the other hand among the discontented the fraction is 47 %.

One could therefore surmise that there are neighbors on these streets who are pleased by this environment and for that reason subjectively experience noise less strongly.

Over against these there are others who are generally dissatisfied /148 with their living environment and therefore feel particularly strongly disturbed by noise. If this causality has not manifested itself decisively, there is yet another result to support it: the residents who are contented with their quarters are more likely to be of the opinion that one can become accustomed to noise; however, this translates to a tendency which is only significant in the nocturnal noise range from 55 to 65 dB (A). In this range 9 % of the satisfied subjects agree with the acclimatization principle, whereas of the dissatisfied, no-one voices this opinion. At a noise burden of 60 to 65 dB (A) the fractions are 8 % as opposed to 2 %.

These two contexts are also the ones which for comparable noise burden (over 60 dB (A) at night) respectively produce the greatest (36 %) and least (11 %) numbers of "severely disturbed" subjects.

One may say in recapitulation that an interdependence takes place between residential satisfaction and degree of disturbance: Fig. 10 shows that the satisfaction is dependent on the degree of noise burden. Conversely the results from Table 8 have shown that under constant noise burden contentedness influences the degree of disturbance experienced. This implies that traffic noise must always be viewed in connection with the remaining aspects of environmental quality.

5. Conclusions

This study has yielded the results that the degree of disturbance by street traffic noise in the night is less severe than in the daytime. At an average difference of 7.65 dB units between the L_{eq} -values during the day (0600 to 2200) and during the night (2200 to 0600), from a total of 1607 subjects 17 % were severely disturbed at night, versus 23 % in the daytime.

The comparison of noise values and subjective disturbance shows that in the night the range from 55 to 60 dB (A) is critical: here the "disturbance curve" begins to ascend steeply. In the daytime the critical range lies at 60 to 65 dB (A).

In the nighttime critical range from 55 to 60 dB (A) already a quarter of the subjects characterize themselves as severely disturbed. This threshold value has manifested itself not only in the actual question about disturbance, but also in the question about reactions to and consequences of traffic noise. Thus nocturnal traffic noise of over 55 dB (A) produces in 20 to 25 % of the subjects sleep disturbances such as "not being able to fall asleep", "waking up in the night", or "awakening too early". In order to circumvent such sleep disturbances the subjects take measures, most frequent of which is shutting the windows: at 55 to 60 dB (A) more than a third of the subjects keep their window closed practically all the time. Nevertheless at the same noise load 15 % take sleeping tablets "almost daily" or "several times a week".

The correlations between L_{eq} and disturbance experienced are high in comparison to the literature, and likewise the correlations are rather high with the traffic density; this indicates that good conclusions about the noise burden can be drawn directly from the traffic.

The most disturbed time periods are the morning (0600 to 0800 hours) and the day (0800 to 1900 hours). Of the night hours the period from 2200 to 2400 is the most severely disturbed. It is also the most representative time period for general nighttime disturbance.

The most disturbing noise sources at night are on the streets with much private car and motorcycle traffic. However on the local residential streets with little traffic mopeds are the predominate cause, together with slamming doors and arrivals. In this context it is a matter of isolated noise peaks which can have a very disturbing effect, especially if the average noise burden is very low.

No distinction in noise sensitivity can be established between urban and rural environments. In addition no systematic differences

can be found within the urban environment between central districts and outlying ones.

However, situative influences developing from the layout of a street have proven to be of definite importance. It has been shown that the noise shielding of the back rows of houses on much-travelled streets indeed objectively lowers the noise burden considerably, although the residents subjectively feel significantly more disturbed than those on a street with the same noise burden but less traffic. This points to the fact that not only the absolute noise values produce disturbing effects, but also the traffic burden of a residential area which is of no use to the residents themselves (through traffic), but brings along with it dangers and pollution from beyond, is felt to be very disturbing.

Another correlation that likewise points to the conclusion that traffic noise should not be regarded as an isolated factor, but rather viewed in a greater context with other circumstances, is the connection between residential satisfaction and the degree of disturbance by noise. The general satisfaction of the resident lowers with the increasing noise burden of a region; conversely the residents who are content with their living environment feel significantly less disturbed by noise at the same noise burden than those who are discontented.

For the establishment of threshold values the stimulus-independent influences-- both environmental and contextual-- appear to be irrelevant, since they are not of a systematic nature. No bases for threshold-value zones may be deduced from the results; on the contrary the threshold values for quiet homes ought also to be applied to urban situations. In the case of thoroughfares criteria must be discovered to prevent the generation of "noise slums".

REFERENCES

- [1] Klosterkoetter, W., Kriterien zur Gewinnung eines einheitlichen Beurteilungsverfahrens fuer Verkehrs- und Gewerbe-laerm aus medizinischer Sicht [Criteria for Achieving a Uniform Estimation Procedure Regarding Traffic and Industrial Noise from a Medical Perspective], VDI-Report No. 234, 1975.
- [2] Griefahn, B., Zum Problem der Gewoehnung an Schallreize waehrend des Schlafes [On the Problem of Acclimatization to Noise Stimuli during Sleep], Z. Sozial- Praeventivmed., 22, 116-120 (1977).
- [3] Kastka, J., and Buchta, E., Zum Inhalt der Belaestigungsreaktion auf Strassenverkehrs-laerm [Characterization of the Annoyance Reaction to Street Traffic Noise], Kampf dem Laerm, 24, 158-166 (1977).
- [4] Graf, P., Meier, H.P., and Mueller, R., Sozio-psychologische Fluglaermuntersuchung im Gebiet der drei Schweizer Flughaeften Zuerich, Genf und Basel [Sociopsychological Investigation of Flight Noise in the Region of the three Swiss Airports Zurich, Genf, and Basel], Bern: Eidgenoessisches-Luftamt Swiss Federal Air Office , May 1974.
- [5] Wanner, H.U., Wehrli, B., Nemecek, J., and Turrian, V., Die Belaestigung der Anwohner verkehrsreicher Strassen durch Laerm und Luftverunreinigungen [The Irritation of Neighbors on Congested Streets by Noise and Air Pollution], Sozial- Praeventivmed., 22, 108-115 (1977).
- [6] Wehrli, B., Huser, S., Egli, H., and Bakke, P., Wohnen im Neubau-- Eine interdisziplinaere Untersuchung ueber die Wohnbedingungen in Zuercher Neubauwohnungen und deren Beurteilung durch die Bewohner [Living in Reconstruction-- An interdisciplinary Investigation of the Living Conditions in Zurich's Reconstructed Dwellings and Estimation of Them by the Residents], Bern: P. Haupt, 1976.
- [7] Centre scientifique et technique du batiment SCTB, Etude de la gene due au trafic automobile urbain [Study of the Annoyance Due to Urban Automobile Traffic], Compte-rendu scientifique, Paris: CSTB, 1971.
- [8] Ministere de l'Equipement (SETRA), IRT-CERN, Aspects de la gene due au bruit de la circulation routiere [Aspects of the Annoyance Due to Street Traffic Noise], February 1976.
- [9] Osgood, C.E., and Tannenbaum, A., The Measurement of Meaning, Urbana: Univ. of Illinois Press, 1957.