an airport demonstrates that it is achieving its noise-allocation objectives. Alternatively, the regional agencies will argue for more-stringent conditions to be included in the variance if sufficient progress is not being achieved.

CONCLUSION

This paper has outlined the major elements of a regional noise-allocation program that provides an areawide approach to development of airline service and airport noise control. Future experience will determine the success of this concept. The methodology is straightforward and requires only the monitoring of noise levels on an annual or semi-annual basis and a comparison of actual noise impacts with the annual noise allocations. The approach relies on the proprietary powers of the three Bay Area airports to achieve the desired results. It is easily understood by local communities and provides considerable flexibility to the airports in determining how to meet the annual objectives. In addition, this approach has significant merit as a noise-management tool--not just for a regional system of airports, such as the Bay Area, but for individual airports in other parts of the country as well.

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Comparison of Irritation Caused by Noise Generated by Road Traffic and Aviation Traffic

WERNER BRÖG, GÜNTHER-FRITZ HÄBERLE, AND BARBARA METTLER-MEIBOM

Acoustic measurement methods are necessary in order to measure noise objectively. On the other hand, the use of decibel values to determine the degree to which persons subjectively perceive noise to be disturbing is a distortion because no acoustic measurement methods can objectively reflect how persons perceive noise. In light of this, one is justified in wondering whether dB(A) measurement can possibly account for the level of discomfort that intervals of quiet or noise cause to humans. The answer can be found if one compares the effects that two sources of noise that have the same dB(A) but different intervals of quiet between the noise have on persons exposed to the noise. In this paper, two different sources are discussed—noise generated by road traffic (which is continuous noise) and noise generated by aviation traffic (which is noise interspersed with longer or shorter periods of quiet). For our study a sample group of persons was first exposed to noise caused by aircraft traffic and then to noise caused by road traffic; the dB(A) for both was the same. The test persons then filled out questionnaires that dealt with their reactions to these different sources of noise. A laboratory situation was deliberately avoided, since this can never be comparable to the actual conditions found in real-life situations and, thus, necessarily results in errors. The hypothesis of the study—that the same dB(A) can be very differently perceived by persons when the source of the noise is different—was clearly proven to be true. Not only were a greater number of persons irritated by noise from road traffic than by aircraft noise, but the perceived degree of disturbance was also more intense. The study discussed here was a pretest that used a sample of only 107 persons and could not take into consideration the long-term effect of their past experiences with noise.

A whole spectrum of social scientific and acoustic studies explain and analyze specific aspects of the problem of noise as an environmental pollutant. These studies usually deal with the irritation to persons who are exposed to noise daily or, at least, regularly. Thus, noise is directly dealt with; that is, persons who have been exposed to noise over a long period of time are studied, and the sample group usually knows that its reactions to noise are being tested. The present study, sponsored by the German Federal Office of Environment (1) was structured so that test persons would be exposed to noise

generated by road traffic and by aviation traffic on the same day. (This was to ensure that the results be as comparable as possible.) The conditions under which the persons experienced the different types of noise were also to be as similar as possible. However, this approach, like most approaches, had its limits. The experiment was restricted to one day (literally, since it was impossible to do the testing at night) and previous experiences with noise of the test persons were, initially, ignored.

The design of the study required that a number of factors be taken into consideration:

1. Test persons had to be selected irrespective of any experiences that they had had with noise,
2. Test persons were not to know what the purpose of the study was since this knowledge would sensitize them to noise and would influence the results of the study, and
3. Test persons needed to be studied under controlled conditions in which a specific routine had been established and in which conditions were not totally different from those at home or at work.

Since this type of comprehensive standardization of the external conditions and daily routine is somewhat problematical, the requirements for the methodological design of the social scientific study were thus very specific.

METHODOLOGICAL DESIGN

It was of utmost importance that the following be clarified:

1. Type and structure of activities for the periods in which the test persons were exposed to noise,
2. Composition of the sample,
3. Choice of survey methods,
4. Length of time exposed to noise, and
5. Size and sociodemographic composition of the group of test persons on each of the six sampling days.

Furthermore, a fundamental question needed to be answered, Should the test persons be informed about the purpose of the study or should the study be done as a blind analysis?

The pros and cons of telling the test persons the reason for the study were considered. Both alternatives had definite advantages and disadvantages; therefore, the two alternatives were combined and tested. The first study of exposure to noise (which took place in the morning) was done as a blind analysis. In the second exposure to noise (in the afternoon), the test persons knew that noise was relevant to the study because they had to fill out a questionnaire at noon that contained questions concerning the effect that the noise in the morning had on them.

However, the purpose of the study was deliberately never explicitly explained to the test persons. However, as was desired, all of the test persons did make use of the lunch break to talk with each other about noise.

This approach made it possible to determine whether, and to what degree, being informed about the goal of the study had an effect on the responses made by the test persons. In order to compare results with that of a control group, the entire group was divided into two. The one half began in the morning in the room exposed to road traffic noise; the other half began in the room exposed to aircraft noise. This made an analytical observation of subsample groups possible. The following table is a schematic depiction of the course of events as they occurred:

	Sequence of Traffic Noise	
Day	Morning	Afternoon
1	Road	Aviation
2	Road	Aviation
3	Aviation	Road
4	Road	Aviation
5	Aviation	Road
6	Aviation	Road

The sample was split into groups that were to come on different days. The groups were approximately the same size and their sociodemographic characteristics were comparable. The approach selected ensured that those errors that could result from exposure to one source of noise before exposure to another source of noise would be eliminated.

The definition of specific activities and times for these activities was as important as the decision about whether test persons should be told the reasons for testing. Thus, two similarly structured sets of activities were designed for the persons to participate in while they were exposed to the noise generated by the two different sources. The course of the two sets of activities had to be similar in content, time, and chronological order. This was a necessary prerequisite if the actual perception of noise and the perception of the irritation caused by the noise in the two different rooms was to be compared directly.

The design of a differentiated series of activities had to comply with the following requirements:

1. The activities had to be somewhat similar to activities that might take place at home or at work,
2. The activities should make it possible to measure perception of noise by persons involved in a broad spectrum of activities that are perceived differently by the individuals and result in a variety of emotional and vegetative states, and
3. Boredom was to be avoided.

Activities needed to be varied and call for different responses--physical exercise and mental concentration, passive reception and action, individual activities, and group activities. The chronological sequence of the activities had to be logically structured. A specific amount of time was to be spent on each activity. The length of time spent on different activities should also not be too divergent, since the amount of time spent on an activity is related to the way in which an activity is perceived.

The planning of the activities was somewhat difficult because, for methodological reasons, the activities in the morning and afternoon had to be as similar to one another as possible and the mental states of the persons in response to the activities also had to be the same for the different activity sets. However, a physiological given is that persons tend to be a bit drowsy after lunch. Therefore, an after-lunch pep pill was served. The second half of a Hitchcock thriller (A Lady Disappears, 1938) was shown after lunch; the test persons had seen the first half of the film in the morning.

The entire day's program was carefully structured to induce specific physical and mental states. The activity program used is depicted below. Included are the times for different activities and the times when the questionnaires were presented. Although the times fluctuated a bit, they were basically adhered to.

8:55 a.m. Greeting; persons were told where to sit for the remainder of the session;
9:05 a.m. Film, part 1;
9:50 a.m. Exercise break;
10:10 a.m. Questionnaire 1;
10:25 a.m. Break;
10:45 a.m. Drawing and writing task on dream house;
11:25 a.m. Music played (a record);
12:00 p.m. Questionnaire 2a;
12:20 p.m. Questionnaire 2b;
12:35-2:15 p.m. Communal lunch, then drive to second test room;
2:15 p.m. Film, part 2;
3:00 p.m. Exercise break;
3:20 p.m. Questionnaire 3;
3:35 p.m. Break;
3:55 p.m. Essay and sketch on conserving energy;
4:35 p.m. Music played (a record);
5:10 p.m. Questionnaire 4;
5:25 p.m. Questionnaire 5; and
5:40 p.m. Farewell; test persons driven back to meeting place.

The daily program consisted of six activity blocks in the morning and six activity blocks in the afternoon. Type of activity, time of activity, and order of activities was the same in the morning and in the afternoon.

The study used written questionnaires. This made it possible to question all of the test persons simultaneously directly after a certain activity had taken place. The written questionnaires also guaranteed that the responses would not be influenced by the interviewers. In an area as soft and sensitive as noise perception, it is especially important that the possibility that the interviewers might bias the responses is avoided. The experiment leader and an assistant were trained to avoid influencing the responses under all conditions. In order to reinforce the data supplied in the questionnaires, the respondents were also carefully observed for any noise-related behavior they might show.

An average of 18 test persons were in each group. The largest group consisted of 21 persons and the smallest group consisted of 15 persons. Group size is important because, if the group is too small, the members of the group will interact with one another and with the group leader. However, a large group of persons will produce its own background noises. This might interfere with the perception of background noises. Also, in a large group, the situation is hardly comparable with an average person's home or work situation.

The length of exposure to the source of the noise was directly related to the time available. Thus, in the given experiment, three hours were available in which persons participating in carefully structured activities could be exposed to a particular type of noise.

The different activity blocks lasted a minimum of 15 min in order to give the test persons enough time to register the activity and their perception of the noise to which they were exposed during this activity. The maximum time block was limited to 45 min to ensure that boredom would not set in.

The sociodemographic composition of the sample was carefully selected in order to ensure that the sample was as similar as possible to the population as a whole; only the very young were excluded. The desired sociodemographic structure was nearly attained (see Table 1).

SUMMARY OF RESULTS

Even when the dB(A) level is the same, the table below shows that the degree to which persons are irritated by noise generated by aviation traffic and by noise generated by road traffic is different. This is because different types of noise are perceived differently, and this noise perception cannot be measured by measuring dB(A).

	Perception of Test Persons (%) (n = 107)	
Classification	Noise Generated by Aviation Traffic	Noise Generated by Road Traffic
Very great nuisance	24	40
Great nuisance	28	42
Nuisance	42	17
Hardly or not a nuisance	6	1

In identifying those factors that determine the degree to which noise is perceived to be irritating, factors that have to do with the source of the noise and factors that have to do with the respondents themselves must be differentiated. This is of primary interest here--the existence or lack of periods of quiet between periods of noise is important when studying the effect that noise sources have on persons. The majority of the test persons responded to periods of quiet positively (i.e., it reduced the irritation caused by the noise). Only a minority of persons perceived irregular sources of noise, rather than steady noise, to increase the irritation effect of noise. However, for persons who were particularly sensitive to noise, it was irrelevant whether the noise was interspersed with periods of quiet or not. These persons were equally irritated by both sources of noise.

Noise Disturbance of Test Persons	Perception of Nuisance Effect (%) Morning (n = 49)	Afternoon (n = 58)	Total (n = 107)
More by aviation traffic	14	21	18
More by road traffic	78	67	73
Equally by aviation and road traffic	6	10	8
Not by either aviation or road traffic	2		1

A differentiation of different sources of noise showed the main factors that influence noise perception

Noise Perception of Test Persons	Noise Generated by Aviation Traffic (%) (n = 106)	Noise Generated by Road Traffic (%) (n = 106)
Noise increased	6	21
Noise decreased	11	
Noise occasionally increased and occasionally decreased	69	36
Noise stayed the the same	9	42
No response	5	1

Thus, the following cause particular irritation when noise is generated by aviation traffic (see Table 2):

1. Intensity of the noise, especially since it is possible to compare the periods of sudden noise with intervals when it is quiet;

Table 1. Number of test persons in sample.

Day of Sampling	Percent	Number of Test Persons: Day 1	Day 2	Day 3	Day 4	Day 5	Day 6	Ideal No.[a] (%)
Age								
15-18	6	2	1	2		2		6
18-21	7	1	2	1	1	2	1	6
22-45	44	7	8	10	13	6	3	42
46-60	17	5	4		3	3	3	22
61-65	6		2		2	1	1	5
65 and over	20	3	2	4	2	3	7	19
Total		18	19	17	21	17	15	
Sex								
Male	57	13	11	12	12	9	4	53
Female	43	5	8	5	9	8	11	47
Total		18	19	17	21	17	15	
Occupation								
Employed or now unemployed	42	7	7	9	13	5	4	42
Housewife	20	5	3	3	4	5	2	20
School	15	3	4	3	1	4	1	19
University	2		1		1			2
Retired	20	3	4	2	2	3	8	17
Total		18	19	17	21	17	15	

Note: Sampling was done from November 6 to November 13, 1979.
[a]According to secondary statistics.

Table 2. Description of noise.

Reason for Disturbance	Responses to Aviation Traffic (%) (n = 17)[a]	Reason for Disturbance	Responses to Road Traffic (%) (n = 56)[a]
Noises were very loud	35	Never a minute's peace, constant background noise	48
Noise makes one afraid, nervous, sick, startled; difficult to concentrate; one feels like screaming, cursing, closing one's ears	35	Noise volume and type vary, multiply, and are so different (screeching brakes, acceleration, blowing horns, big trucks)	34
Noise comes suddenly	29	Noise makes one feel afraid, helpless, aggressive; cannot concentrate	21
Roar, boom, thunder, fizzle, whiz	23	Noise always equally loud, monotonous	5
Noise come so quickly and unexpectedly	6	Noise is very loud	4
Noise increases, decreases, echoes	6		
Total	134	Total	112

[a]Multiple responses given.

Table 3. Activities during noise exposure.

Responses	Comparison of Degree to Which Noise Perceived to Be a Nuisance: Exposure to Aviation Traffic (%) — Persons More Disturbed by Aviation Traffic (n = 19)	Exposure to Aviation Traffic (%) — Persons More Disturbed by Road Traffic (n = 78)	Exposure to Road Traffic (%) — Persons More Disturbed by Aviation Traffic (n = 19)	Exposure to Road Traffic (%) — Persons More Disturbed by Road Traffic (n = 78)
While film was playing				
Very great	37	14	5	32
Great	42	32	32	39
Total	79	46	37	71
While exercising				
Very great	10	1	0	3
Great	0	6	5	9
Total	10	7	5	12
While questionnaire was filled in				
Very great	21	5	0	20
Great	26	14	21	39
Total	47	19	21	59
During coffee break				
Very great	21	3	0	4
Great	16	3	11	13
Total	37	6	11	17
While drawing or writing				
Very great	21	3	10	8
Great	21	13	11	44
Total	42	16	21	52
While music was playing				
Very great	32	17	37	61
Great	37	37	26	31
Total	69	54	63	92

2. Character of the noise (slowly increasing sound volume, loud noise, decreasing volume, sound echoes); and
3. Effects such as fear or that persons are startled by the sudden noise.

When noise is generated by road traffic, the following cause particular irritation (Table 2):

1. Consistency of the noise, since there are no intervals when it is quiet;
2. Effect of different types of noise and different sound volumes; and
3. Problems such as not being able to concentrate even a moment because the noise never lets up.

An analysis of the relation between irritation caused by noise and activity in which a person is involved showed the following (see Table 3):

1. During recreational periods (e.g., coffee break, exercise periods), the irritation caused by noise is minimal;
2. Purely acoustic occupations (such as listening to music) are affected the most severely by noise; during these activities road traffic noise was considered to be much more irritating than aircraft noise;
3. Activities in which acoustics and optics were combined (e.g., the movie) are affected by road traffic noise more than by aircraft noise;
4. In activities that require mental concentration (e.g., drawing, describing a problem), noise caused by road traffic is perceived to be more irritating than noise generated by aviation traffic; and
5. For all types of activities, persons generally perceive that type of noise to be more irritating to which they are basically more sensitive.

A study of the effect that prior experiences with noise at work and at home had on the present perception of noise is shown in the following in-text table and Table 4.

Table 5. Socioeconomic characteristics of test persons.

Characteristic	Disturbance (%)			
	More by Aviation Traffic (n = 19)	More by Road Traffic (n = 78)	Equal (n = 9)	Total (n = 106)
Sex				
Male	52	41	56	44
Female	48	59	44	56
Age				
18-21	23	65	12	
22-45	13	76	11	
46-60	19	76	5	
≥61	22	74	4	
Education				
Grammar school	50	24	11	27
High school diploma or better	50	76	89	73
Total	18	74	8	

Table 4. Comparison of test noise with noise in usual environment.

Perception	Disturbance (%)			
	Total (n = 106)	More by Aviation Traffic (n = 19)	More by Road Traffic (n = 78)	Equal (n = 9)
Aviation traffic in comparison with usual environment				
Much louder	44	90	33	45
Somewhat louder	18	0	22	22
Just as loud	10	0	13	11
Somewhat quieter	9	0	12	0
Much quieter	13	5	14	22
No response	6	5	6	0
Road traffic in comparison with usual environment				
Much louder	55	37	59	56
Somewhat louder	8	16	5	11
Just as loud	11	16	9	11
Somewhat quieter	3	5	3	0
Much quieter	9	16	6	22
No response	14	10	18	0

Table 6. Perceptions of test persons.

Perception	Disturbance (%)			
	More by Aviation Traffic (n = 19)	More by Road Traffic (n = 78)	Equal (n = 9)	Total (n = 106)
Sensitive to noise				
Yes	42	61	67	58
No	58	39	33	42
Too little or nothing is being done				
To reduce noise from aviation traffic	63	63	67	63
To reduce noise from road traffic	69	76	78	74
Noise from aviation traffic is unhealthy				
Yes	84	53	89	61
No	16	47	11	39
Noise from road traffic is unhealthy				
Yes	63	85	89	86
No	37	15	11	14

Table 7. Results of technical noise level measurements for aircraft noise area and road traffic noise area.

Measurement Area	Outside Measurement [dB(A)]			Inside Measurement [L_{AFm} dB(A)]			
	L_{AFm}	L_1	L_{95}	Window Closed	1 Window Open	1 Window Tilted	2 Windows Tilted
Aircraft noise							
Area 1	72.3					53.3	56.0
Area 2	57.4					43.2	46.0
Area 3[a]	70.1					52.5	55.0
Road traffic noise							
Area 1	72.2	77.3	63.0	53.0[b]	60.5		
Area 2[a]	71.4	76.6	62.0	44.8	57.5	52.2	
Area 3	72.2	77.3	62.8	50.6	60.8		

[a] Selected noise area.
[b] Volume is 1-2 dB(A) too high because, on the testing day, extra noise was created by road construction.

At Workplace	Response to Study (%): More Disturbed by Aviation Traffic (n = 19)	More Disturbed by Road Traffic (n = 78)	Equally Disturbed (n = 9)	Total (n = 106)
Disturbed by aviation traffic	32	19		20
Not disturbed by aviation traffic or not employed	68	81	100	80

Prior experiences with aircraft noise at work increased the sensitivity to such noise. Prior experiences at work with noise generated by road traffic increased sensitivity to such noise only minimally. If a person is exposed to much noise at his or her place of work, he or she is generally less sensitive to noise generated by road traffic (see table below):

Response to Study	Respondents (%): Exposed to Noise at Workplace (n = 20)	Total (n = 106)
More disturbed by aviation traffic	20	18
More disturbed by road traffic	65	74
Equally disturbed	15	8

In general, prior experiences with noise at home cause a person to be less affected by the noise generated by sources to which he or she is frequently exposed. Persons who have prior experience with aircraft noise react to aircraft noise, as well as to noise generated by road traffic, more than do persons who have prior experiences with road traffic noise. Prior experiences with aircraft noise result in a stronger sensitivity toward aviation traffic noise than does prior experiences with road traffic noise to road-traffic-generated noise.

An analysis of sociodemographic variables is given in Table 5. In general, women perceive noise generated by road traffic to be much more irritating than do men. Youngsters are less sensitive to road traffic noise than are other age groups. The elderly are more irritated by aircraft noise than are other age groups. Persons without formal higher education are more irritated by aircraft noise than are persons who have higher degrees.

Table 6 gives attitudes to noise pollution policies. It shows that persons who consider themselves to be sensitive to noise are relatively more irritated by noise generated by road traffic than by noise generated by aviation traffic. The belief is widespread that less is done to deal with noise generated by road traffic than with aircraft noise. However, a relation between this opinion and the degree to which different noise sources were considered to be irritating could not be established. When the dB(A) is the same, the noise caused by road traffic is considered to be more irritating than aircraft noise. Persons consider that source of

Table 8. Aircraft noise area.

Date (1979)	Time	L_{AFm} [dB(A)]	Noise Without Street Construction[a] [dB(A)]
Nov. 6	2:00-5:30 p.m.	72.3	72.0
Nov. 7	2:00-5:00 p.m.	76.1	74.0
Nov. 8	8:30 a.m.-12:00 p.m.	72.4	71.5
Nov. 9	2:00-5:00 p.m.	75.0	
Nov. 12	8:45-11:45 a.m.	74.5	
Nov. 13	9:00 a.m.-12:00 p.m.	70.9	
Energetic mean		73.9	73.3

[a]Estimated by using results of trial measurement.

Figure 1. Road traffic noise area 2.

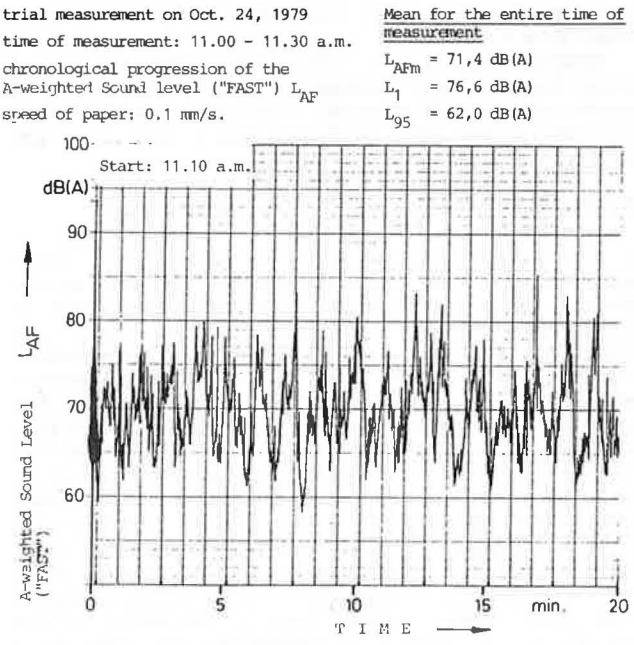
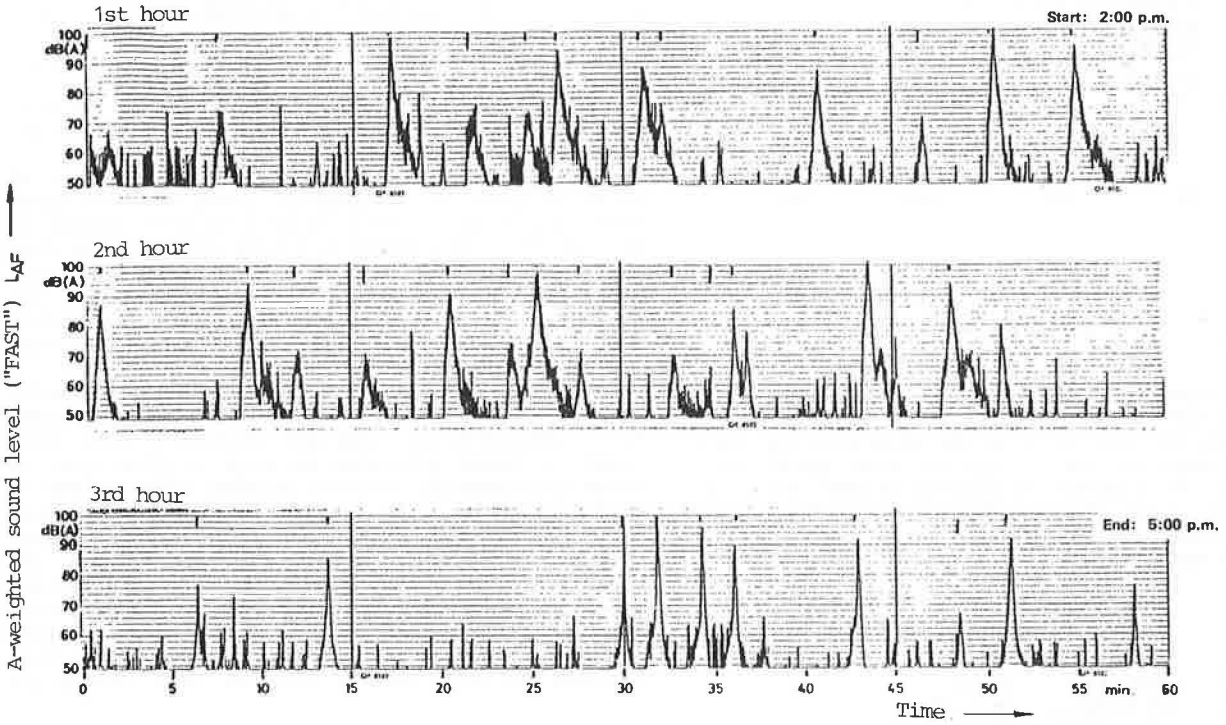


Table 9. Calculation and measurement for road traffic noise area 2.

Date (1979)	Time	Vehicles per Hour[a]: n_{PKW}	n_{LLKW}	n_{SLKW}	Measurement Value [dB(A)][a]: L_m	L_1	L_{95}
Nov. 6	10:35-10:50 a.m.	1668	176	48	71.7		
Nov. 7	9:35-9:40 a.m.	1696	244	36	72.1		
Nov. 12	3:00-3:30 p.m.	1872	164	22	71.3		
Nov. 13	3:00-3:30 p.m.				71.7	77.8	63.0
Oct. 24[b]	11:00-11:30 p.m.				71.4	76.6	62.0

Note: Calculated equivalent sound level of long-term counts is 71.5 dB(A).
[a]See Equation 1 (2). [b]Trial measurement.

Figure 2. Aircraft noise area 3.



4th sample: 11/9/79; time of measurement: 2:00-5:00 p.m.; and chronological progression of the A-weighted Sound level ("FAST") L_{AF} speed of paper: 0.1 mm/s.

noise to be more unhealthy, which generally irritates them more.

Finally, we should once again emphasize that these results were obtained by using a very small sample of only 107 persons. The study was a pretest and the results must be tested again with a larger sample.

OVERVIEW OF TECHNICAL NOISE LEVEL MEASUREMENTS

A detailed description of technical noise level measurement was deliberately avoided in this study. However, some of the basic information pertinent to such measurement is summarized below for those who might be interested in the technical measurement techniques that were used (1). The measurements were done by a group of specialists (Müller BBM Company) under the direction of Rüdiger Wettschureck, who has much experience in the field. First, three different areas were selected to study noise generated by road traffic and three different areas were selected to study noise generated by aviation traffic. In each of these areas, three different values were measured: the outside decibel, A-weighted, equivalent sound level, measured with time constant fast (L_{AFm}), the sound volume L_1, which was exceeded 1 percent of the time while the measuring was being done, and the sound volume L_{95}, which was exceeded 95 percent of the time while the measuring was being done. The results of the measurements are summarized in Table 7.

While the social scientific tests were taking place, the noise made by aircraft was measured continuously. For noise generated by road traffic, on the other hand, some of the values were measured, but others were calculated. The calculation was done by using a formula that had been developed in a special study that took 400 measurements of the dB(A) in urban streets (2):

$$L_m = 32.2 + 10\log(n_{PKW} + 8 \cdot n_{LLKW} + 20 \cdot n_{SLKW}) + 10\log(25/S) + \Delta L_F \quad (1)$$

where

L_m = equivalent sound level (L_{eq}) dB(A),
n_{XXX} = number of vehicles that belong to class XXX per hour,
PKW = all vehicles with two axles that weigh less 2.8 tons,
LLKW = trucks that weigh between 2.8 and 9 tons and buses,
SLKW = trucks that weigh more than 9 tons and agricultural tractors,
S = distance from middle of the road (m), and
ΔL_F = facade correction, ΔL_F = 2.5 dB(A) in front of a facade.

The results of these measurements and calculations are shown in Tables 8 and 9. In order to depict the exact noise volume, the records of two measurements are depicted as an example in Figures 1 and 2.

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