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DEVELOPMENT OF AN ACOUSTIC RATING SCALE FOR ASSESSING ANNOYANCE CAUSED BY WHEEL/RAIL NOISE IN URBAN MASS TRANSIT

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16. Abstract

This report has been prepared under the Urban Rail Noise Abatement Project sponsored by the Urban Mass Transportation Administration, Office of Research and Development. The Transportation Systems Center acts as Systems Manager on behalf of UMTA in directing this effort as part of the Rail Supporting Technology Program.

A number of recent studies of the impact of train noise on the community are reviewed. From this information and the results of other noise-annoyance studies, a scale for rating the annoyance of urban transit system operators and patrons, as well as the surrounding community, caused by wheel/rail noise is recommended. In general, the peak A-weighted sound-pressure level for the given exposure should be used, with an additional 5 dB if there are pure tones present (squeal). If in comparing the different kinds of train noise (squeal, impact, wheel roar, etc.) the *total* exposure is to be assessed, an additional term, 10 log T, should be added to the mean peak noise (where T is the total exposure in seconds during any 24-hour period).

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PREFACE

This report on acoustic rating scales for wheel/rail noise is a verbatim excerpt from a complete review of the state of urban rail system wheel/rail noise control technology presently nearing completion by Bolt Beranek and Newman Inc. under contract DOT-TSC-644. The complete review, and the wheel/rail noise control technology development to be conducted under the same contract, are part of the Urban Rail Noise Control Program managed by Transportation systems Center, Cambridge, Mass. under sponsorship of the Rail Programs Division (URD30), Urban Mass Transportation Administration, Washington, D.C. The complete review report will appear shortly. The present report has been issued as an independent self-contained document in the interest of rapid dissemination of the information and because many of those concerned with rating the noise of urban rail systems are less interested in the technical details of noise generation mechanisms and associated noise control technology.

This effort is an intergral part of the Urban Rail Supporting Technology Program (UM404). The work was technically monitored by Robert Lotz (Code TMP) and was performed principally by Theodore J. Schultz, of Bolt Beranek and Newman Inc.

CONTENTS

CONTENTS (Cont'd)

LIST OF FIGURES

1. INTRODUCTION

Before embarking on any noise abatement program, it is essential to have a means of rating the noise in question as to the annoyance it creates. The reason is that, strictly speaking, we are not so much interested in abating the noise, itself, as in reducing the amount of annoyance it causes. If possible, the noise rating should be one-dimensional, so that all the steps and improvements developed during the program can be evaluated along a single, continuous scale, and thus can be rank-ordered as to their effectiveness in reducing annoyance.

It was too much to hope, however, that the same criterion would apply optimally to all the people impacted by urban rail systems, namely, the system patrons, the system operators and the community at large. But it turns out that there is a welcome consistency in the requirements for these three classes of people.

2. NOISE AFFECTING THE COMMUNITY

So far, no one has been able to devise a *universal* noise-rating scale that satisfactorily rates noises in the community coming from all kinds of sources [*1*]. Instead, there are different ratings for automobile noise, for aircraft noise, for industrial noise, etc. Each of these ratings was developed only when the impact of the corresponding noise source on the community became a problem serious enough to warrant the research needed to develop a reliable rating.

For some reason, the noise of rail vehicles is an anomaly: people do not seem to be annoyed by railway noise as much as by noise of the same level from, say, road traffic or aircraft. This fact is documented in the literature chiefly by the relative scarcity of papers dealing with the subject of railway noise; but it was mentioned explicitly in the [British] Wilson Report [*2*] and is confirmed by private communication with acoustical scientists over most of Europe. (See also Sec. 2.2 below.)

It is not clear whether this lack of concern comes about because railways have been around for so long that people have grown to accept their noise; or because people still cherish railroads as a reminder of a happy earlier era; or because the railway (operating over a fixed path on a strict schedule) is not a source of fear nor surprise, but a token of dependable service; or because the only people strongly impacted are those situated next to the right-of-way and they are comparatively few; or because there has been a long-term migration of noise-sensitive people away

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1. T.J. Schultz, *Community Noise Ratings*, Applied Science Publishers, Ltd., London, 1972.

2. *Noise — Final Report*, Cmnd. 2056, July 1963; Her Majesty's Stationary Office, London.

from rail lines. Whatever the cause, there has been no *widespread* public complaint, and, until recently, very little research effort has been undertaken to develop a suitable rating for railway noise.

2.1 Developing a Rating of Acceptability for Community Noise

The method usually used to develop a rating of acceptability for noise from a specific source is to combine the results of a large-scale social survey with those from a corresponding program of noise measurements [3], both surveys being carried out in areas strongly impacted by the noise source in question. Comparison of these results permits one to determine what aspects of the noise are most important in generating annoyance, and then to develop a rating that combines assessments of the relative severity of these various aspects, to be used as a tool for evaluating different degrees of exposure to this noise. Finally, one can select a maximum acceptable value for the rating, based on economic and political considerations as much as on the technical results of the surveys, that corresponds to the maximum exposure that the average person, weighing cost against comfort, will find acceptable.

For example, in the development of the Noise and Number Index [3], currently used in the United Kingdom for evaluating the noise from aircraft, nearly 2,000 people were interviewed in the area within ten miles of London's Heathrow Airport, covering a rather wide range of severity of exposure to aircraft noise. Extensive measurements of the noise in that area were also made at about the same time. The subjects' responses to a series of 42

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3. Dwight E. Bishop, "Program for the Measurement of Environmental Noise," Appendix B: "Review of Previous Surveys," by Theodore J. Schultz, Report No. 2424, Bolt Beranek and Newman Inc., July 1973.

questions indicated that their annoyance is determined by only two aspects of the noise: namely, the average peak noise level during aircraft fly-bys and the number of flight events occurring per day. The Noise and Number Index (NNI) was accordingly formulated as the sum of two terms:

$$\mathrm{NNI} = \overline{\mathrm{PNL}} + 15 \log N - 80$$

where N is the total number of aircraft operations heard* during a specified period (e.g., one day or one night); and

> $\overline{\mathrm{PNL}}$ is the average, over the N aircraft operations, of the maximum Perceived Noise Level occurring during the flybys.

Since the survey indicated no appreciable annoyance until the sum of $\overline{\mathrm{PNL}}$ and 15 log N exceeded 80, this number was subtracted from the sum, so that annoyance would be expected at locations where the values of NNI are greater than zero.

Similar studies of aircraft noise, coupling social surveys with noise measurement programs, have been carried out in Sweden, France, Germany, The Netherlands, a second time in London, and the United States, each leading to a noise rating slightly different from the others [*3*]. For assessing the noise of roads and street traffic, surveys combining interviews and noise measurements have been conducted in England, Austria, France, Sweden, and the United States [*3*]; again, the ratings developed in these studies and currently used to assess the impact of road noise are somewhat different. But in any case, at least for the noise of

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*Note that the definition of N as the number of operations actually "heard" smuggles into the rating the concept of the background noise!

air and road traffic, rationally developed rating schemes do exist, and they are similar if not identical from one country to another.

One particular noise related problem has not, however, received much attention, i.e., the problem of secondary radiation. By this is meant radiation into the interior of the buildings due to ground vibration set up by the passage of heavy surface vehicles, such as trucks or trains. In general, vibration in the audio frequency range is rapidly attenuated in the ground as one moves away from the source. However, the low frequency vibration that is not well attenuated (or intense low frequency acoustic excitation) can lead to rattling of china, glassware or windows. It is clear that to quantify the "rattling" would be extremely difficult and as a result no emphasis will be placed in this report on this type of secondary radiation (see Question 37, p. 24 and Table 1, p. 26).

Until as recently as June 1973 when this present contract was begun, however, no such survey results for railroad noise, combining a social survey with noise measurements, were available from *any* country! It was expected that the evaluation of various measures for controlling wheel/rail noise for this project would have to depend on the considerable amount of already published work dealing with the effects of *other* kinds of noise in residential neighborhoods.*

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*Such an approach would simply continue the practice already adopted for setting criteria of acceptability for the noise of the Bay Area Rapid Transit (BART) and Southern California Rapid Transit Division (SCRTD) systems, and for railway noise in general. After consideration of a number of possible ratings .... the Speech Interference Level (SIL), the Noise Criterion (NC) curves, the A-weighted Sound Pressure Level, and the Perceived Noise Level (PNdB), all of which are ratings developed in

Fortunately, the results of three surveys dealing explicitly with rail noise have been published just recently, in England, France and Japan. Although one is little more than a pilot study, the other two present much valuable data. All three contain some surprises!

Continuation of preceding footnote:

*studies of noise from sources other than railroads .... the BART system [*4*] settled on the Noise and Number Index (NNI), a rating developed in England for aircraft noise. Based on these same BART studies, a similar rating was adopted by the SCRTD [*5*]. Assuming 40 train passages per night, SCRTD concluded that an acceptable maximum A-weighted sound pressure level during a train passage would be 70 to 75 dB in residential areas at night, and 75 to 80 in the daytime, presumably measured at the property line.

Northwood [*6*] had suggested earlier that a range from NC-55 to NCA-65 (a rating based on studies of *office* noise) would be suitable for noise inside subway cars, corresponding approximately to A-levels of 67 to 77 dB. For noise transmitted to the neighborhood, his "conservative objective" would be to keep the train noise level below the existing ambient noise levels so that it is largely inaudible. More recently, Cremer [*7*] has also proposed matching the existing ambient noise as an acceptable criterion for the Washington Metropolitan Area Transit Authority (WMATA) subway train noise.

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4. V. Salmon and S.K. Oleson, "Noise Control in the Bay Area Rapid Transit System," Stanford Research Institute, February 1965.
5. George Paul Wilson, "Acoustical Considerations in the Design of the Southern California Rapid Transit System," Preliminary Report to SCRTD from Wilson, Ihrig and Associates, Berkeley, California, August 1967.
6. T.D., Northwood, "Rail Vehicle Noise," ASME-AIEE-EIC Joint Railway Conference Paper No. 62-EIC-RR1, 1962.
7. Lothar, Cremer, "Acoustical Concepts for the Washington Metropolitan Area Transit Authority," Harry Weese & Assoc., Architects, Chicago, February 1968.

Before looking at these recent studies in detail, it is worth asking what relevance these noise surveys made in *other* countries would have to the United States; and, perhaps even more critical, what relevance surveys made in the vicinity of high-speed, long-distance railway lines would have to urban rapid transit noise.

The first question bears on whether the cultural differences between the populations of England, France, Japan, and the United States may be so great that conclusions validly drawn for one population would not hold for another. It appears, however, that the conclusions of three surveys from countries of quite different life-styles agree sufficiently among themselves to suggest that it is legitimate to apply the results to the United States, with certain reservations. We would not, for example, adopt an American criterion of acceptable noise levels based on such

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Continuation of preceding footnote:

*Embleton and Thiessen [*8*], on the other hand, adapted the anti-noise by-law of a certain (un-named) township to apply to train noise. They concluded that, for an urban residential community exposed to a certain amount of noise other than that from the trains, and for a train traffic density amounting to ten passages during an eight-hour night-time period, a peak noise level during a night-time train passage of 60 dB(A) is the maximum acceptable exposure. [They actually gave maximum acceptable octave band levels, approximately defining the NCA-50 curve; this is equivalent to 60 dB(A).] They give corrections ranging from -15 to +10 dB to be applied for different types of neighborhoods and for different train traffic volume. This procedure is similar to that of the earlier Community Noise Rating (CNR), which was based largely on studies of the noise of aircraft around air force bases and more-or-less continuous industrial noise [*1*].

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8. T.F.W. Embleton and G.J. Thiessen, "Train Noises and Use of Adjacent Land, *Sound*, 1, No. 1, 10-16, January-February, 1962.

surveys; but it seems quite reasonable that American annoyance reactions to train noise would scale with the same noise rating as in the other countries.

As to whether data from the study of high-speed trains can be applied to urban rapid transit, one can say first that there is practically nothing else to go on; but further, the results of the surveys indicate that the dominant source of annoyance for people near the tracks is the wheel/rail noise, and this is an aspect of long-distance train noise that has much in common with rapid transit noise.

Accordingly, we welcome this freshet of new survey information and combine it with long-term consulting experience in dealing with the noise of transportation systems to recommend a suitable acoustic rating for the wheel/rail noise in urban mass transit systems.

2.2 The British Pilot Study

A promising study was begun in England, in 1968, in an attempt to evaluate the annoyance caused by the noise of high-speed electric trains passing in direct view of residences [*9,10*]; but

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9. David Walters, "Railroad Noise in Housing Areas," Research Report 2, Birmingham School of Architecture, Birmingham, England, December 1968.

10. Walters, "Annoyance Due to Railway Noise in Residential Areas," *Architectural Psychology:* Proceedings of the Conference held at Dalandhui, University of Strathclyde, 28 February — 2 March 1969.

the results of the early phases of that study were inconclusive and the study was apparently never completed. The preliminary results suggested (to no one's surprise!) that people's annoyance decreases as their distance from the tracks increases, though the dependence was neither strong nor consistent. (As an example of this inconsistency, people living at 70 m distance expressed more annoyance than those at 45 m, according to one set of interviews.) There was a suggestion that people living in high background noise from other sources (children, dogs, etc.) are *more* sensitive to the railway noise than people in quieter locales, contrary to our usual expectations! This implies, perhaps, that in conditions of persistent noisiness, people experience an increased, rather than reduced, sensitivity to the occasional extra noise of the railroad. A similar trend was found in a French survey (see Sec. 2.3.4).

Another unexpected feature of the preliminary results was how surprisingly unannoying the railway noise turned out to be: there were quite a few houses where train passages (57 in the day-time, 30 at night, at about 85 mph) produced levels of 90 dB(A) just outside the bedroom windows, yet the inhabitants did not seem to be unduly concerned about it. The British study (very tentatively) concluded that the external noise level must exceed 95 dB(A) during train passages before serious annoyance becomes evident: this implies houses within 30 meters of the track!*

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*For comparison, HUD's Noise Assessment Guidelines would find a housing site to be "Clearly Unacceptable" if the median peak-sound-level during train passages exceeds 75 dB(A), and "Normally Unacceptable" if it exceeds 60 dB(A). These limits are

Because these results were tentative, mostly qualitative, and not quite consistent with those from the other two surveys, we do not give much weight to them here.

2.3 The French Survey [*12*]

A combination of social survey and physical noise measurement survey has just been completed in France, near Paris. After a series of free interviews to identify the important aspects of the annoyance due to train noise, a questionnaire was designed and administered to 350 subjects living in different locations where the train noise had previously been measured. Their responses were coded and punched onto cards for computer analysis.

Continuation of preceding footnote:

*based on ten or more train passages during the night; the guidelines permit progressively higher noise levels (up to 10 dB increase) for fewer night-time operations [*11*].

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11. Theodore J. Schultz, "Technical Background for Noise Abatement in HUD's Operating Programs," Report No. TE/NA 172, 3, U.S. Department of Housing and Urban Development, Washington, D.C., 1972, see Sec. IV-D.

12. Dominique Aubrée, "Enquête acoustique et sociologique permettant de definir une echelle de la gêne eprouvée par l'homme das son logeument du fait des bruits de train" (Acoustical and Sociological Survey to Define a Scale of Annoyance Felt by People in their Homes Due to the Noise of Railroad Trains), Centre Scientifique et Technique du Batiment, 4 avenue du Recteur Poincaré, Paris, June 1973. (Translation available from BBN as Technical Information Report #88, August 1973).

2.3.1 The questionnaire

The 90 questions were divided into three groups, one (38) evaluating different aspects of the annoyance, another (37) bearing on attitudes towards noise in general, towards trains, and towards the neighborhood, and the third (15) being descriptive questions about the subject and his house.

The responses to the questions were initially screened to select the most reliable indicators of annoyance; all but three manifestations of annoyance were discarded; these were the different ways in which an individual can respond to the noise stimulus:

- With a statement that the noise interferes with an activity like reading;
- With a judgment about the noise, itself ("It is intolerable");
- With overt action to change the situation (like moving away or soundproofing the house).

In order to derive a more refined evaluation of annoyance, the responses to two or more questions were sometimes combined, and, using factorial analysis of all the resulting responses, a group of "elementary annoyances" were identified, chiefly expressing disturbance of important activities, such as reading, conversation, listening to radio or television, daytime relaxation, sleeping, etc. Finally, these elementary annoyances were combined into an overall rating of annoyance due to train noise, along a ten-point scale.

Both the elementary annoyances and the overall rating were compared with the various noise parameters measured at the home of the interviewee for possible correlation, to discover which noise parameters or group of parameters would be most successful in predicting annoyance due to the train noise, and also to define the maximum acceptable exposure to train noise for the average person.

2.3.2 The noise measurements

The noise measurements at the various sites were analyzed to derive a number of parameters that were expected to be useful for predicting annoyance, as follows:

• rate of increase of noise level	in dB(A)/sec
• maximum noise level during train passage, L_{max}	in dB(A)
• duration of audible train noise	in sec
• duration of the maximum level, L_{max}	in sec
• duration of level within 10 dB of L_{max}	in sec
• rate of decrease of noise level	in dB(A)/sec
• ambient noise level	in dB(A)
• equivalent noise level, L_{eq}* (over 24 hrs)	in dB(A)

These parameters form two principal groups within each of which the internal correlation in very high; however, the two groups are not correlated at all with each other. One group has to do

*The equivalent noise level, L_{eq}, (also called the average sound level) is the level of a constant sound which, in a given situation and time period, has the same sound energy as does the time-varying sound. Technically, it is the level of the mean-square A-weighted sound pressure, over a time period that must be stated.

with variables related to traffic speed and volume (such as rate of increase of level or duration of the noise), and the other has to do with the noise levels themselves (such as the intrusion of the maximum level above the ambient noise, or the distance from the tracks). That is, annoyance is a function of at least two statistically independent variables.

2.3.3 Some results

Only 40 persons failed to mention train noise among the three most noticeable sources of noise in the neighborhood; and of the remaining 304 persons, 62% cited the train noise as the source of greatest annoyance.

More than half the people interviewed (54%) stated that, of all the kinds of noise made by trains, the noise that they notice most is that of the train passage itself, that is, the wheel/rail noise. Next in order of importance (34%) were the noises of shunting, including switching, locomotives, braking and the impacts of cars; naturally, these noises were cited more frequently in locations near Paris. About 5% of the people also mentioned the noise of horns, whistles, and bells, and the noise of work on the tracks during the night-time. Clearly, these results strongly support the need for a study on reducing wheel/rail noise!

Not all of people's activities are equally sensitive to disturbance by train noise: there was little or no annoyance expressed about interference with reading or daytime relaxation, but great annoyance about disturbance of television listening and conversation; radio-listening held an intermediate position in this respect.

Eighty-four percent of the people interviewed stated that their visitors frequently comment on the noise of the trains.

While 43% of the subjects said that the noise keeps them from opening the windows in hot weather, 55% said they open the windows in spite of the noise.

It made a great deal of difference in the expressed annoyance whether *all* the rooms of the dwelling face onto the tracks or there is at least one room that does *not* face the tracks and therefore, can be regarded as a haven of escape from the trains. For people whose rooms all face the tracks, it hardly mattered how loud the train noise is; more than 80% of these people regarded the train noise as the most disturbing neighborhood noise, whatever its absolute level in decibels. For people with at least one sheltered room, there was found a gradual increase of disturbance with increase of maximum noise level during a train passage, from 35% at 67 dB(A) to 100% at 88 dB(A).

No influence of individual variables such as age, sex, socio-professional category, etc. was found.

Certain contradictions turned up in the responses: some of the people described themselves for the most part as having become adapted to the noise, but at the same time they looked forward to the opportunity of either moving away from the railroad or of soundproofing their dwelling. The authors comment that such a contradiction points up clearly that adaptation to noise is by no means an expression of absence of annoyance: habituation is merely the manifestation of a defense mechanism. Lacking adequate exterior protection against the noise, and finding it practically impossible to move away to escape the noise, the subject's only possible defense is adaptation.

2.3.4 Some correlations

Significant correlations were found between the expressed annoyance and the following noise parameters, in order of importance:

Parameter	Correlation Coefficient
L_{eq} for 24 hours	0.33
Logarithm of traffic volume	0.30
Total duration of train passages	0.26
Ambient noise	0.23
Maximum noise level	0.22
Maximum noise level of noisiest type of train	0.20
Distance from track	0.12

Neither the number of trains alone (as reflected in the traffic volume or the duration of train passages) nor the peak noise level during a train alone gave the best prediction of annoyance. Instead, the best prediction* was given by the Equivalent Noise Level, L_{eq}, whose value increases when either the number of trains or the noise of the trains increases.

No correlation was found between annoyance and the rate of increase or decrease of the noise level (i.e., startle is not very important); nor (surprisingly) with the difference between the ambient noise level and the maximum noise of train passages;

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*A correlation coefficient of 0.33 is rather good correlation, as survey results go, concerning subjective response to noise *alone*. Considerably improved prediction is usually found when attitudinal variables are also taken into account.

to the contrary, notice the positive correlation with ambient noise, implying greater annoyance with train noise where the noise from other sources is higher (as found in the British survey).

2.3.5 Increase of annoyance with increasing noise level

The responses to question #57 represented an overall evaluation of the train noise by the subjects: "From a general point of view, the train noise, in your opinion, is: "Quite acceptable"....."Completely intolerable" (along a seven-point scale). Regarding responses of 1, 2 or 3 along the scale as representing generally favorable response to the train noise and responses from 5 to 7 as generally unfavorable, we can plot the trends of favorable and unfavorable responses as the noise exposure, in terms of the Equivalent Noise Level, becomes more severe. This is shown in Fig. 1. It is seen that the proportion of favorable responses drops sharply and the proportion of unfavorable responses rises sharply as the value of L_{eq} increases above 72–75 dB(A). At this exposure, 36.5% of the people are responding with annoyance above the middle of the scale of overall annoyance. Accordingly, it was concluded by the French researchers that L_{eq} of 72 dB(A) represents a maximum acceptable exposure to train noise.

2.3.6 Effects of attitudes and dwelling exposure

It was found that a more successful prediction of people's annoyance could be made if the formula for the annoyance rating includes terms to account for certain topographical and attitudinal factors in addition to the train noise level:

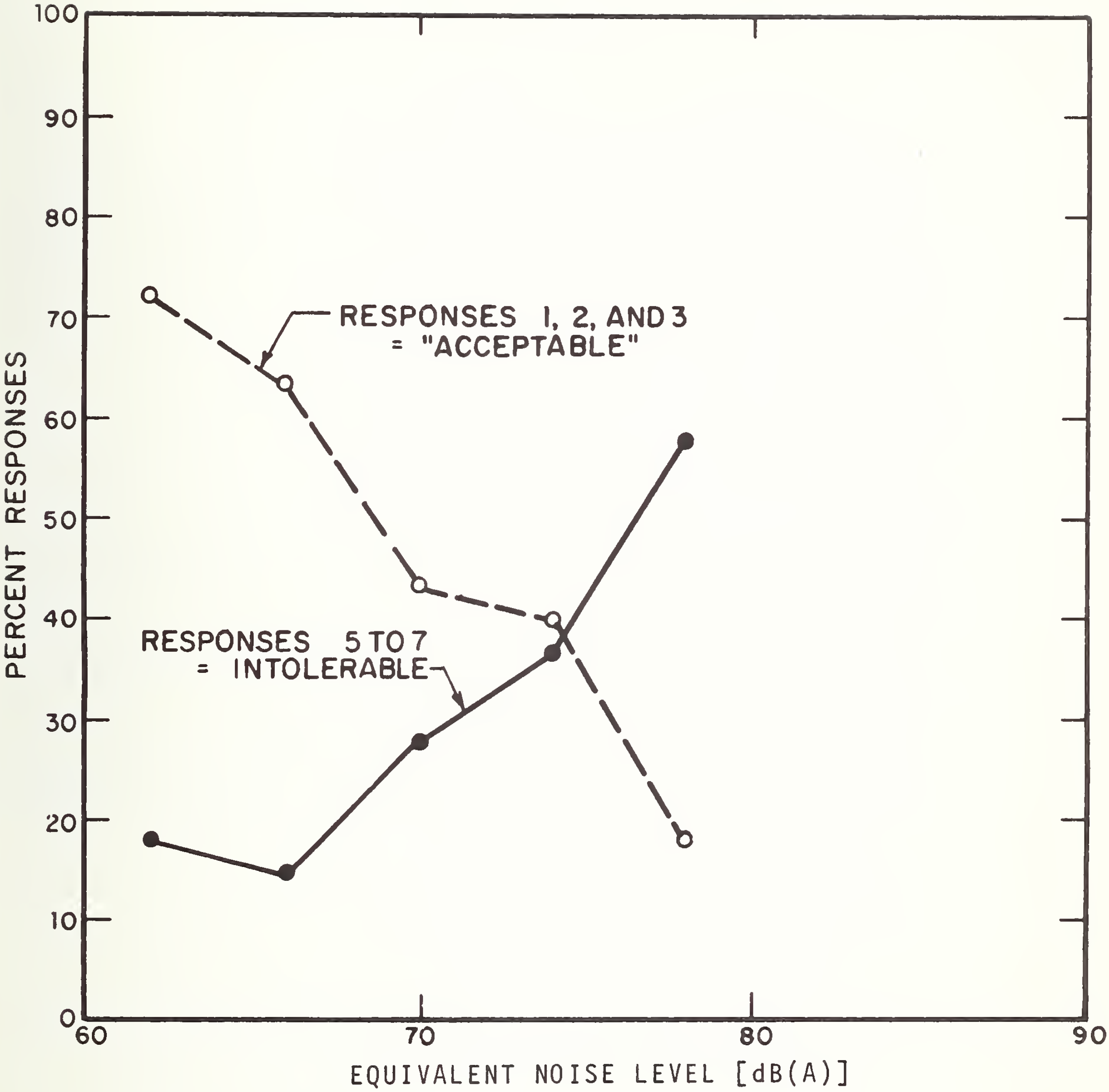

FIG. 1. "ACCEPTABLE" AND "INTOLERABLE" RESPONSES VS EQUIVALENT NOISE LEVEL, WITH NO CORRECTIONS FOR EXPOSURE OR ATTITUDE.

$$\text{Index of Annoyance} = 0.23\,(L_{eq} + 4\,\text{EXPO} + 2\,\text{B} + 4\,\text{T} - 4\,\text{N}) - 12 \qquad (1)$$

where L_{eq} is the Equivalent Noise Level over 24 hours and the other terms are corrections for the degree of exposure of the dwelling, and the person's attitudes to noise in general, trains in general, and the environment, as follows:

The exposure index for the dwelling (symbol = EXPO) takes the values: 0 if at least one room of the dwelling does *not* face the track, either directly or from the side; 1 if all the rooms face the track.

The attitude index with regard to noise in general (symbol = B) takes the values:

0 if the person is not at all or only a little unfavorable
1 if the person is somewhat unfavorable
2 if the person is very unfavorable.

The attitude index with regard to trains in general (symbol = T) takes the values:

0 if the person has a favorable attitude
1 if the person has a neutral attitude
2 if the person has an unfavorable attitude.

The attitude index with respect to the neighborhood* (symbol = N) takes the values:

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*Concerning the attitude towards the neighborhood, it is interesting that satisfaction (or not) with such things as the kinds of facilities available in the neighborhood (schools, shops, public transportation, etc.) has no connection with the person's annoyance due to train noise. Apparently these facilities are so fundamental and concrete that the appreciation of them is "kept in a separate part of the mind" and is independent of the

0 if the person is not completely happy

1 if the person is completely satisfied.

When the annoyance responses are plotted against the Index of Annoyance, as expressed in the formula given above, a considerable improvement in correlation is found. Whereas the correlation coefficient for a comparison of annoyance with L_{eq} alone was 0.33, it increases to 0.64 when the four corrections of the formula are included.

The correlation is just as good if a combination of the average noise level during train passages and either the logarithm of traffic volume or the logarithm of the total duration of train passages is used in the formula in place of L_{eq}. L_{eq} was retained for the formula because one term is simpler to deal with than two.

Figure 2 shows plots of the favorable and unfavorable responses as a function of the Index of Annoyance, that is, the "attitude-corrected" L_{eq}. It is seen that annoyance increases sharply for values of corrected noise exposure above 90 dB(A).

Continuation of preceding footnote:

*reaction to noise. What *does* influence the subject's reaction to the train noise is (1) his general satisfaction with the neighborhood, (2) the appearance of the neighborhood, (3) the other people living in the neighborhood, and (4) the appearance of the houses and buildings: in short, the "class" or "standing" of the neighborhood, a judgment that embodies both an esthetic/architectural aspect and a human aspect, and is largely a matter of taste. These four items correlate significantly with annoyance ($r = 0.13$ to 0.37), but, of course, are independent of the train noise.

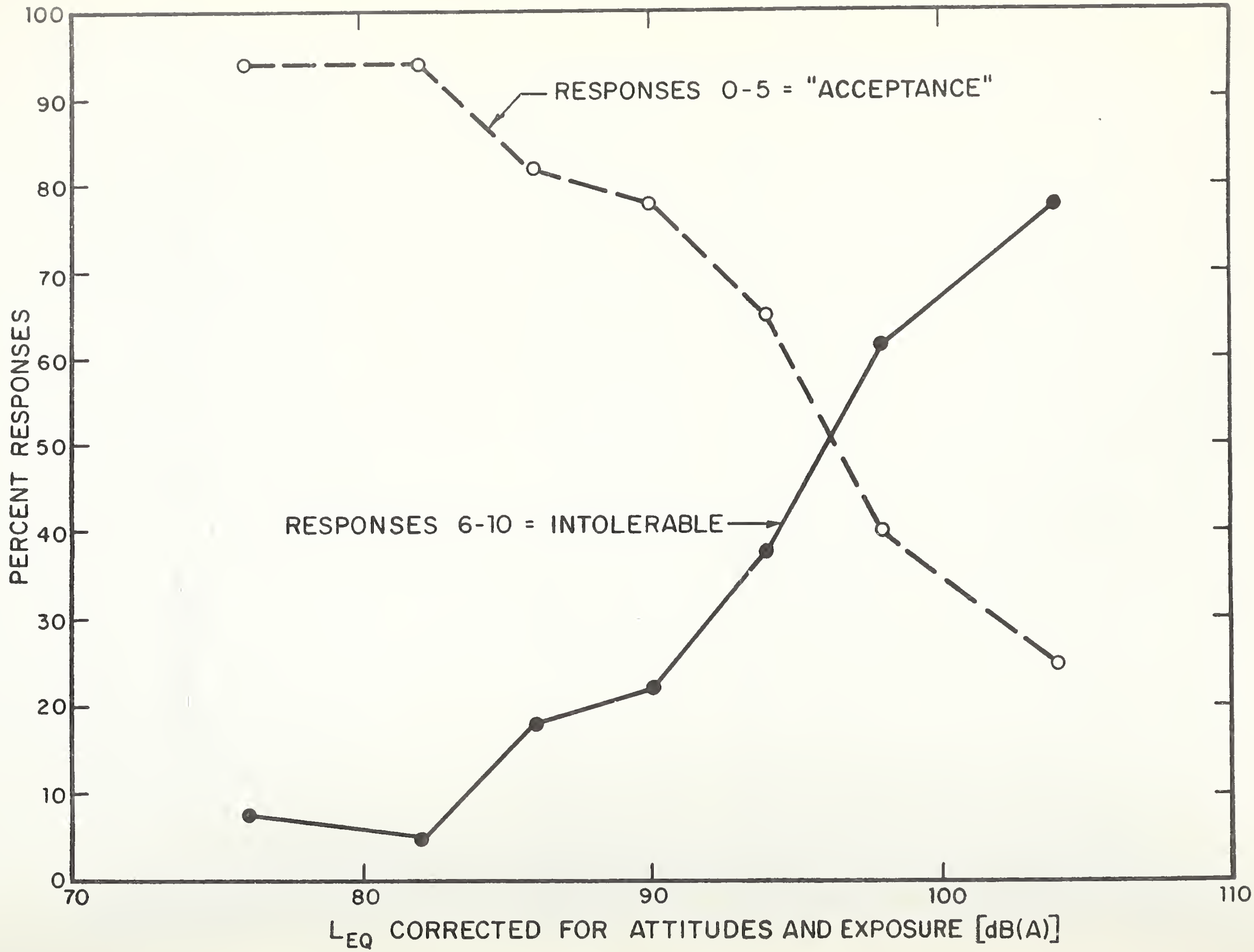

FIG. 2. "ACCEPTABLE" VS "INTOLERABLE" RESPONSES VS L_{eq} CORRECTED FOR ATTITUDES AND EXPOSURE.

2.4 The Japanese Survey [*13,14*]

In connection with the planning for new railroad lines in Japan, a survey was made in July 1972 to determine the effects of high-speed train noise on people living between 10 and 200 meters from the tracks. Noise measurements and interviews were carried out along both the Tokaido Line (opened to traffic for eight years) and the new Sanyo Line (opened only four months before the survey).

The Tokaido Line covers the 515 km distance between Tokyo and Osaka in 3 hrs 10 min at a top speed of 210 km/hr; more than half the track is constructed on embankment roadbed; there are about 200 trains per day. The New Sanyo Line covers the 161 km distance between Osaka and Okayama in one hour, at a top speed of 210 km/hr; most of the track is carried on an elevated concrete structure; there are about 80 trains per day. In both lines, the make-up of the trains is very much the same (12 or 16 cars) and the trains run at prescribed speeds along each section of the track; consequently the reported noise levels at any given location show little variation (±1 dB) from train to train.

It was intended that the survey area should extend far enough away from the tracks that the train noise impact would be negligible, so that a continuous range of noise exposure, from extreme

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13. Toshio Sone, Kono Shunichi, Nimura Tadamoto, Kameyama Shunichi, and Kumagai Masazumi, "Effect of High-Speed Train Noise on the Community Along a Railway," *J. Acoust. Soc. Japan,* **29** (4), 214–224, April 1973. (Translation available from BBN as Technical Information Report #87, August 1973).

14. T. Nimura, T. Sone, and S. Kono, "Some Considerations on Noise Problem of High-Speed Railway in Japan," *Proceedings of INTER-NOISE 73,* 22–24 August 1973, Copenhagen, Denmark, Paper #D22Y17.

to none at all, could be investigated. However, within this distance the houses were separated rather widely and, because of budget limitations, the number of samples was restricted. Consequently, the survey was not as detailed (in terms of noise exposure) as desired. The final number of samples was 182 for the New Sanyo Line (87 within 50 m of the tracks) and 242 for the Tokaido Line (150 within 50 m), altogether 424 subjects. More than 80% of the informants were housewives.

2.4.1 The questionnaire

In order to avoid focusing only on the railroad noise, the interview included general questions about the living environment; the 52 questions can be divided into five categories:

1. Conditions with respect to the house. } 16 questions
2. Information about the informant and his/her family. } 16 questions
3. Feelings about the neighborhood (14 questions).
4. Effects of the noise of the trains (17 questions).
5. Sensitivity of the informant to noise in general (5 questions).

The relations between five-step Likert scales,* describing the direct effects of train noise on the community, and the maximum A-weighted levels of train noise during train passages were obtained from the response data; also, the maximum train noise levels that correspond to "neutral points"† along the various

*A Likert scale is a well-known type of psychological measure of human response, ranging from favorable to unfavorable, to some kind of stimulus.

†A neutral point is the boundary on the Likert scale between the response "not disturbed" and "sometimes disturbed".

disturbance scales were determined. In addition, relations were found between the percent of positive responses (indicating disturbance) to a question and the maximum level of train noise at the location.

2.4.2 Noise measurements

A-weighted sound pressure levels of train noise were recorded outside each informant's residence, during the interview period, at the same distance from the track as the house wall facing the track. (Distances were measured from the center-line between the two tracks.) The noise parameter retained for comparison with people's annoyance was the maximum level attained during a train passage. Since this level will be different for trains on the near track than for trains on the far track (about 8 dB at 10 m, 5 dB at 100 m and 0 dB at 200 m), the question arose whether to use the near-track maximum levels or an energy-average of the maximum levels from *both* tracks to characterize the noise exposure; the latter was adopted.

2.4.3 Effects of the train noise

Effects of the train noise may be divided into three categories: noise, vibration and radio-wave interference. Although these must be dealt with separately from the physical viewpoint, the neighbors of the railway track are likely to lump them together as disturbance from the trains. Moreover, all three effects behave similarly in their dependence on distance from the tracks. Consequently, the noise survey also included questions on "house vibration" and "TV picture flicker", and the responses were treated like those concerning train noise.

The questions on the effects of the trains were as follows:

Item 30: Does railroad noise ever keep you from going to sleep?

31: Have you ever been wakened by railroad noise?

32: Do you have trouble hearing the telephone because of the railroad noise?

33: Do you have trouble in listening to TV or radio because of the railroad noise?

34: Does the TV picture flicker when the trains pass?

35: Have you ever been startled by the train passing?

36: Have you ever been disturbed in conversation by the railroad noise?

37: Have you ever felt vibration of the house by the train passing?

38: Has it become noisier since the new express line started operating?

39: Has the railroad noise increased recently?

43: Do your children feel that the trains are noisy?

44: Does the railroad noise disturb your children while studying?

45: Have your children become nervous because of the train noise?

28: How noisy do you think the railroad is? (Evaluation along a seven-point scale from 1 to 7; 4 was regarded as the neutral point along the scale and a response of 5 or more was regarded as a positive response.)

Responses from some of the 13 items listed above (omitting Item 28) were combined into single scales; for example, items 30 and 31 were formed into a general sleep interference scale; 32, 33 and 36 into a speech interference scale; 43 and 44 into a scale of disturbance with the children's lives; etc.

Table I gives, for ten of the individual annoyance scales and three of the combination scales, the relationship between the maximum noise level during a train passage and the percent of positive (disturbance) responses to the question; it also shows the neutral point that indicates the transition from "little disturbance" to "some disturbance" along the Likert scale for the activity in question.*

Figures 3 to 13 present these results in graphic form, for easier comparison. For example, when the maximum level during train passages is less than 70 dB(A), virtually no one is disturbed in their sleeping near the 8-year-old Tokaido Line, and even around the 4-month-old Sanyo Line less than about one-quarter of the people were disturbed in sleeping (Figs. 5–7).

---

*It is rather surprising at first glance, that these neutral points identifying the *onset* of disturbance should correspond to such high noise levels [73 to 86 dB(A), except for interference with radio/TV-listening]. Nearly one-third of the French informants gave "intolerable" responses when L_{eq} reached 70 dB(A)! It is particularly puzzling in view of the phrasing of the questions, (except for Item 28) which seem to require a positive response even for rare occasions of disturbance ("Have you *ever* been wakened..."). It may be that the English translation of the questions fails to give the exact flavor of what was asked. On the other hand, it may be that the well-known Japanese tendency to give a polite reply to all questions biased the interview so that a positive (unfavorable) response was withheld out of consideration of the interviewer, except in locations where the disturbance is pretty severe. A further consideration is that, for low traffic volume, a value of 70 dB(A) for L_{eq} would imply a considerably higher value for the maximum noise level during a train passage. Finally, note that presumably because of the method of constructing the Likert scales, when the maximum train noise level has reached the neutral point. approximately 50% of the informants have responded that they are sometimes disturbed by the noise. Thus, the French and Japanese data may not be inconsistent after all.

TABLE I. RELATIONSHIP BETWEEN PROPORTION OF POSITIVE RESPONSE TO EACH ITEM AND PEAK LEVELS OF TRAIN NOISE

Scale	Item	Line	Positive Response in % 60	50	40	30	20	10	Neutral Point of Scale
					dB(A)				dB(A)
Single-Question Scales	Disturbance of falling asleep (30)	NSL NTL	82 87	78 84	75 82	71 80	67 77	-- 75	78 85
	Awaking from sleep (31)	NSL NTL	80 87	77 85	74 82	71 79	69 76	66 73	77 85
	Interference with telephone (32)	NSL NTL	79 81	76 79	73 77	70 74	67 72	64 69	78 .78
	Interference with listening to TV or radio (33)	NSL NTL	71 72	67 68	64 65	61 62	-- --	-- --	68 69
	Startle (35)	NSL NTL	84 88	81 85	77 83	74 80	71 77	68 75	81 86
	Interference with conversation (36)	NSL NTL	77 80	74 77	72 75	70 73	67 71	65 69	74 77
	Bothering children (43)	NSL NTL	79 87	75 84	71 81	67 78	62 75	58 72	77 85
	Disturbance of children's study (44)	NSL NTL	82 88	79 86	76 84	74 81	71 79	68 77	82 85
	Annoyance	NSL NTL	72 77	69 73	66 70	-- --	-- --	-- --	69 73
					m				m
	House vibration (37)	NSL NTL	61 78	77 104	94 130	108 160	124 --	138 --	79 93
	TV picture flicker (34)	NSL NTL	89 103	112 133	140 160	160 190	-- --	-- --	118 125
					dB(A)				dB(A)
Combined-Question Scales	Interference with sleep (30,31)	NSL NTL	80 87	78 84	75 82	72 79	69 76	66 74	78 85
	(Speech Interference) Disturbance of hearing (32,33,36)	NSL NTL	75 78	72 76	69 73	66 70	63 68	60 65	73 76
	Disturbance of children's life (43,44)	NSL NTL	82 89	80 87	77 84	74 82	71 79	69 76	77 85

NSL: New Sanyo Line
NTL: New Tokaido Line

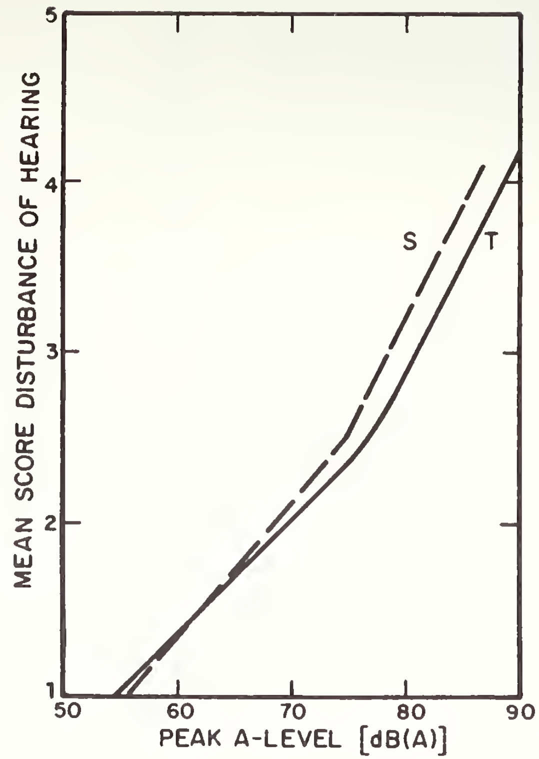

FIG. 3

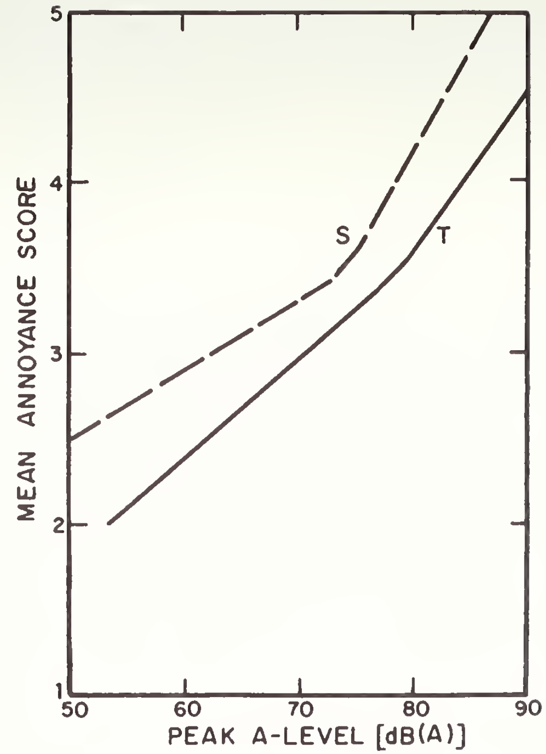

FIG. 4

TOKAIDO LINE [Symbol = T] — Opened September 1964, 8 years before survey. Track mostly on embankment.

NEW SANYO LINE [Symbol = S] — Opened March 1972, 4 months before survey. Track mostly on concrete elevated structure.

Train speed in both cases is about 210 km/hr (130 mi/hr).

THE SCALE VALUES WERE 1 FOR THE MINIMUM ANNOYANCE ("NOT DISTURBED AT ALL") AND 5 FOR MAXIMUM ANNOYANCE ("VERY FREQUENTLY DISTURBED").

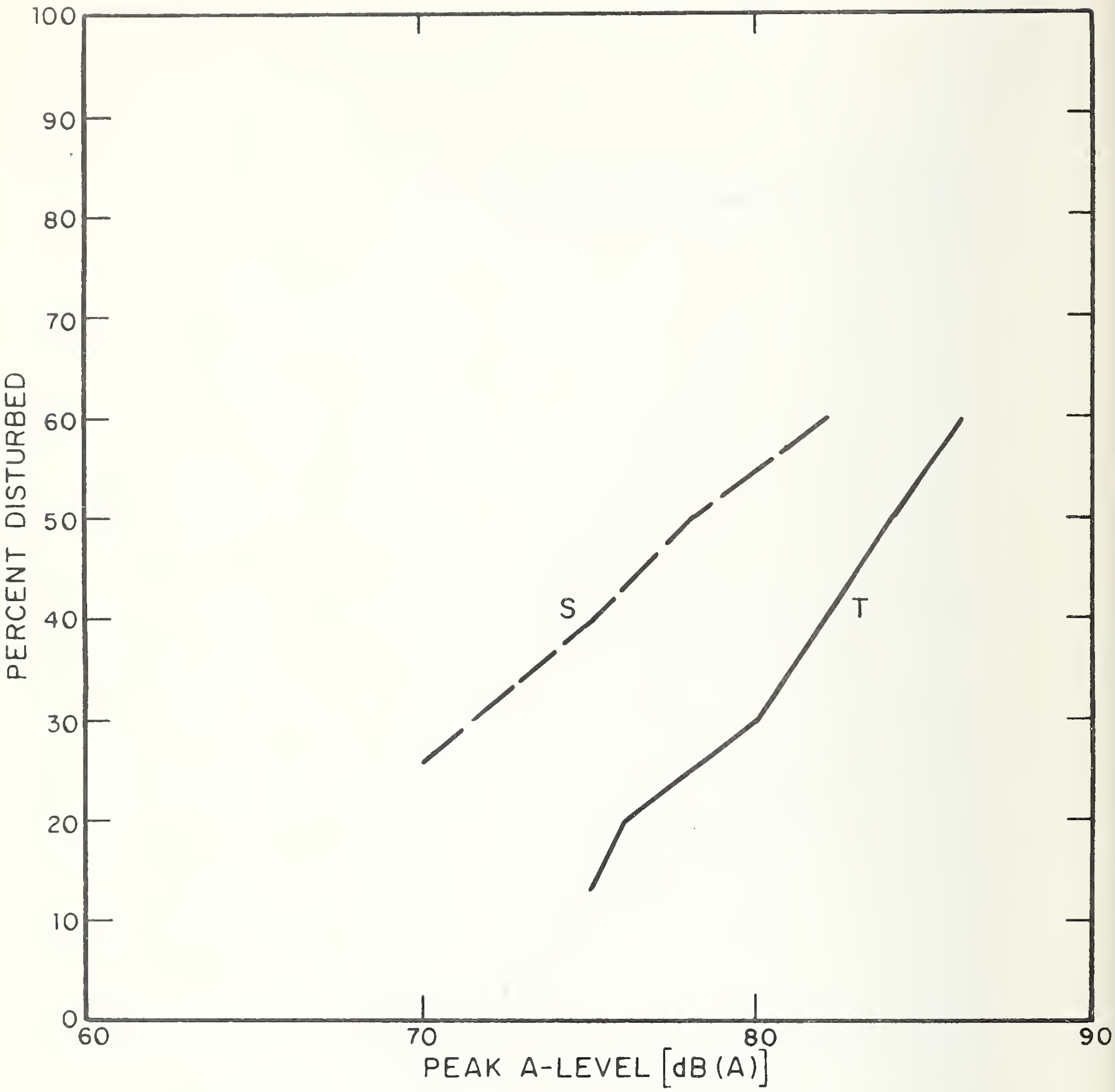

FIG. 5. PREVENTS FALLING ASLEEP (30).

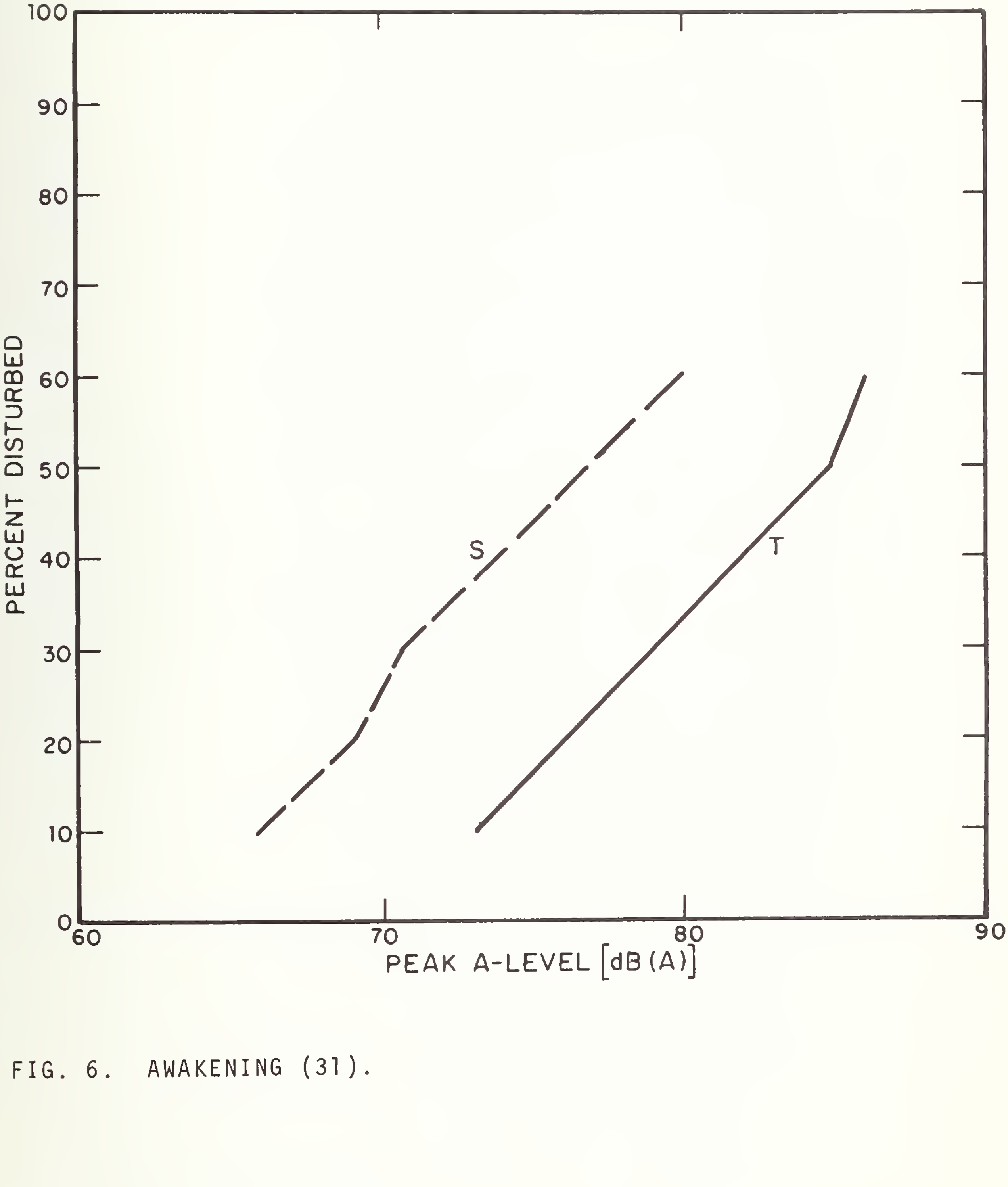

FIG. 6. AWAKENING (31).

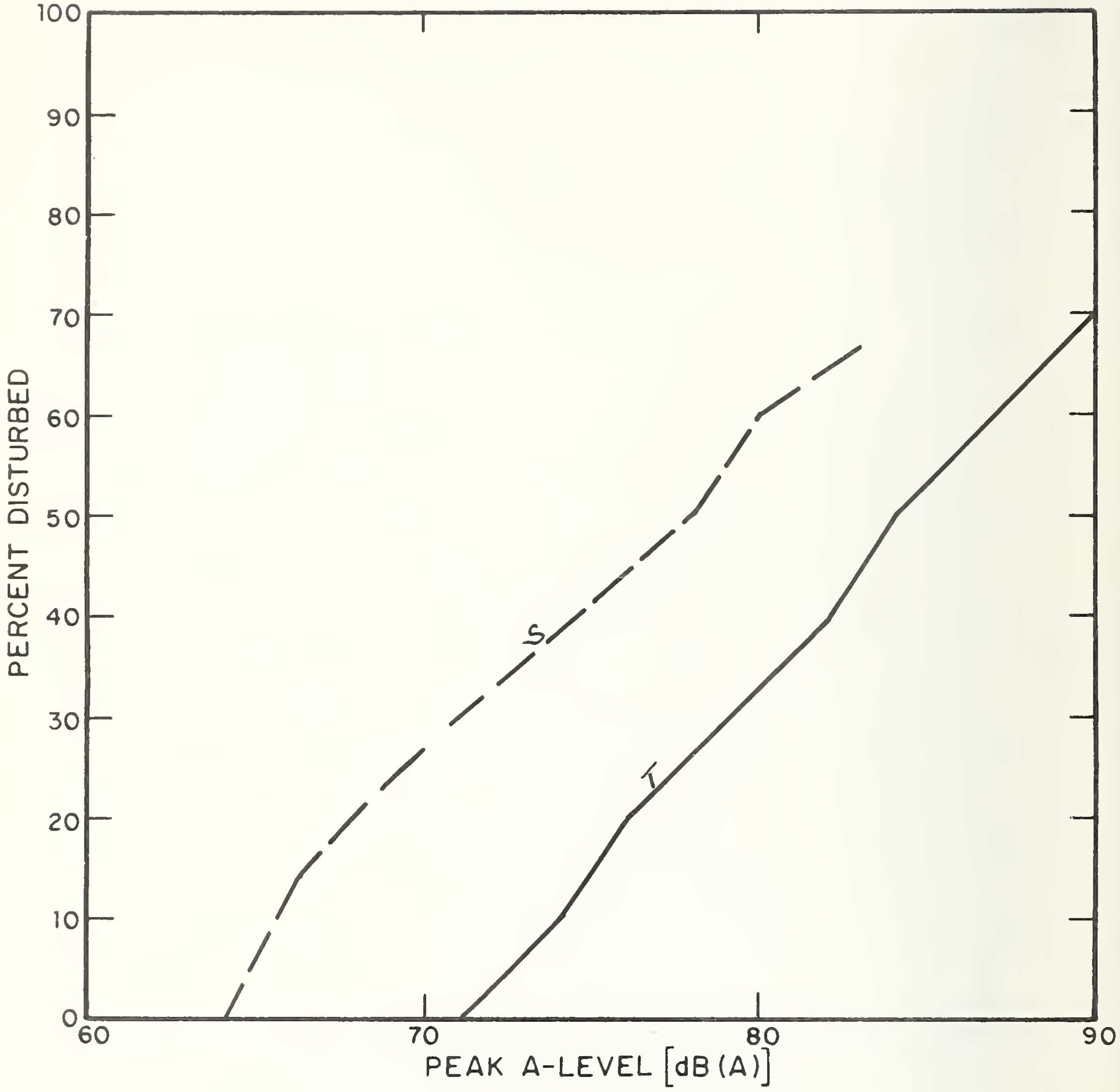

FIG. 7. SLEEP INTERFERENCE: GENERAL.

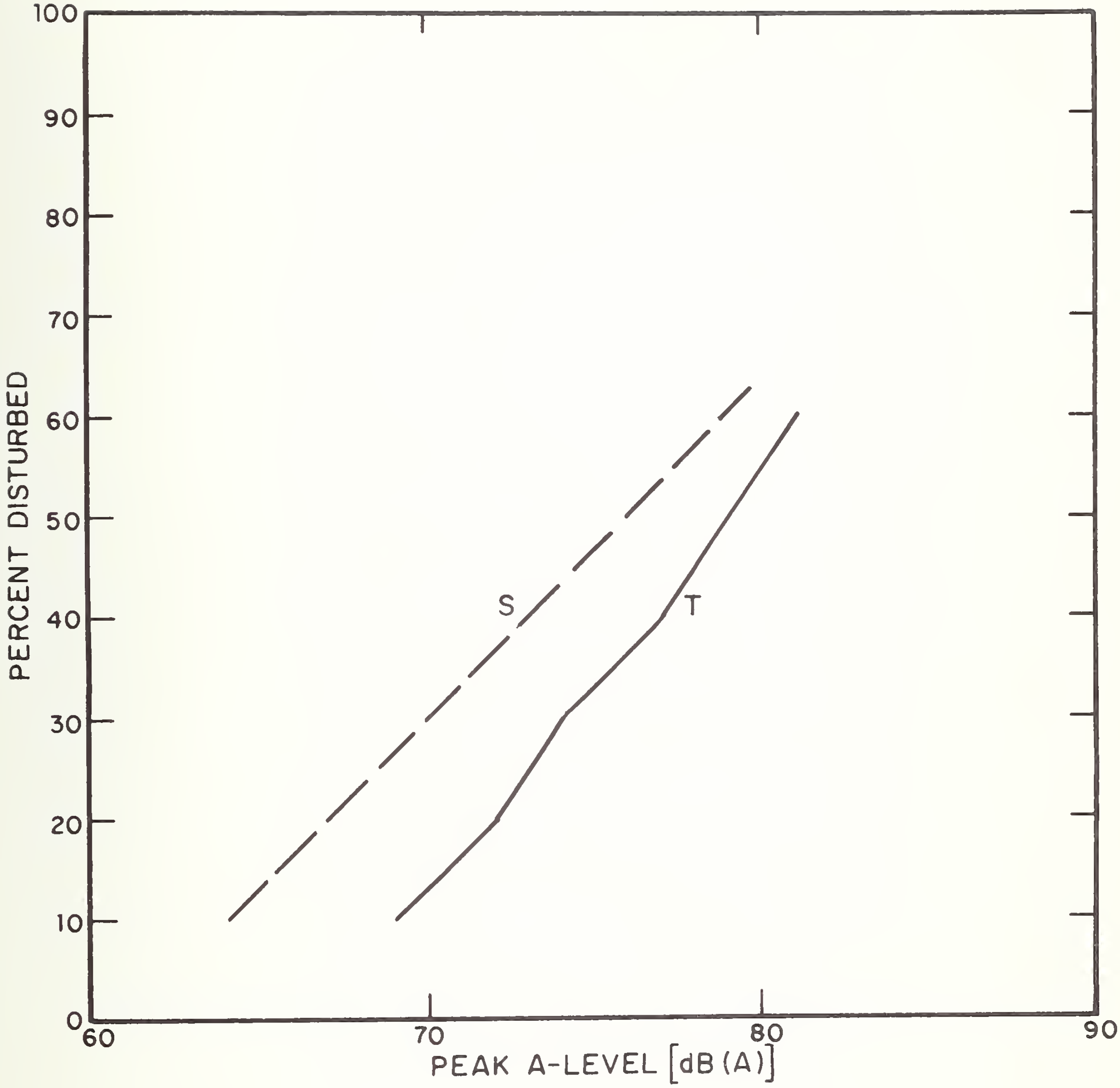

FIG. 8. TELEPHONE (32).

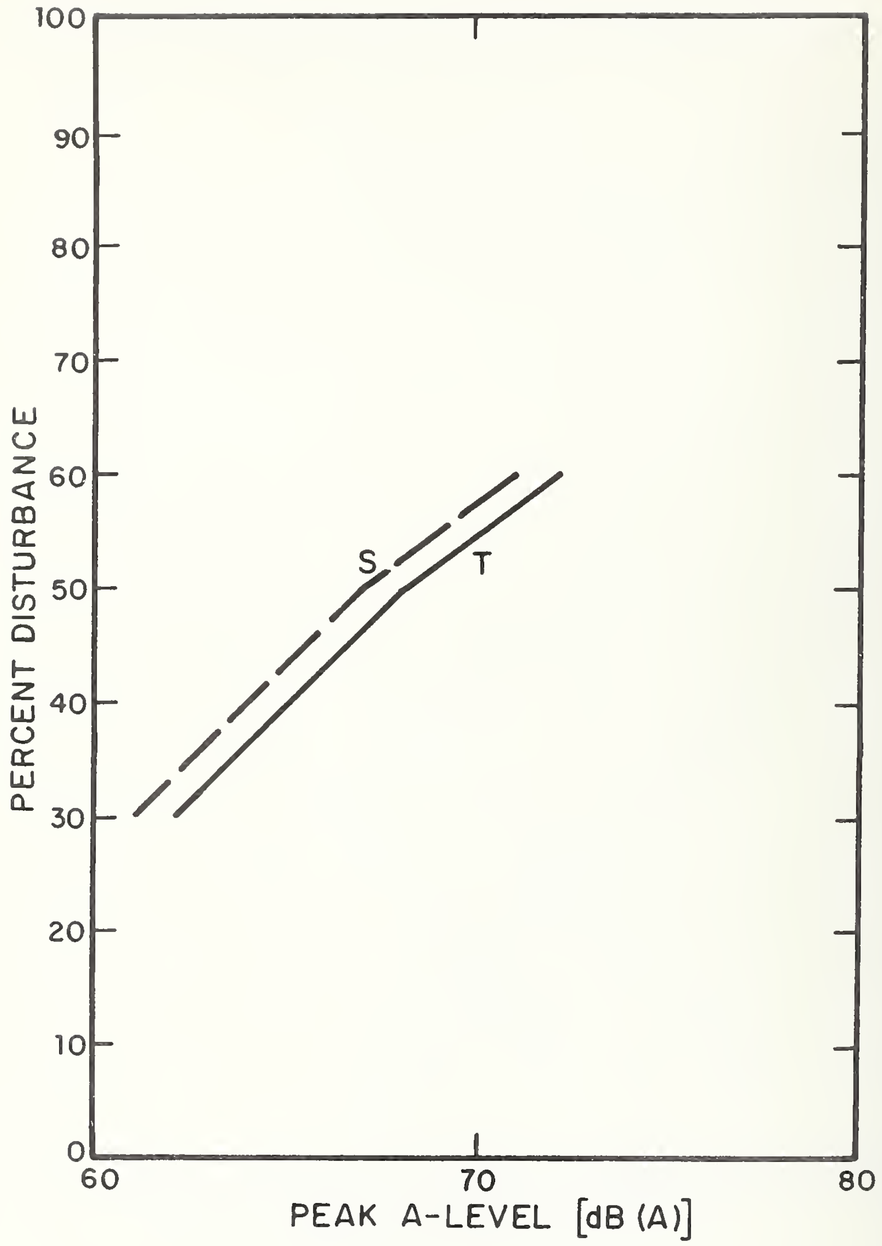

FIG. 9. TV AND RADIO (33).

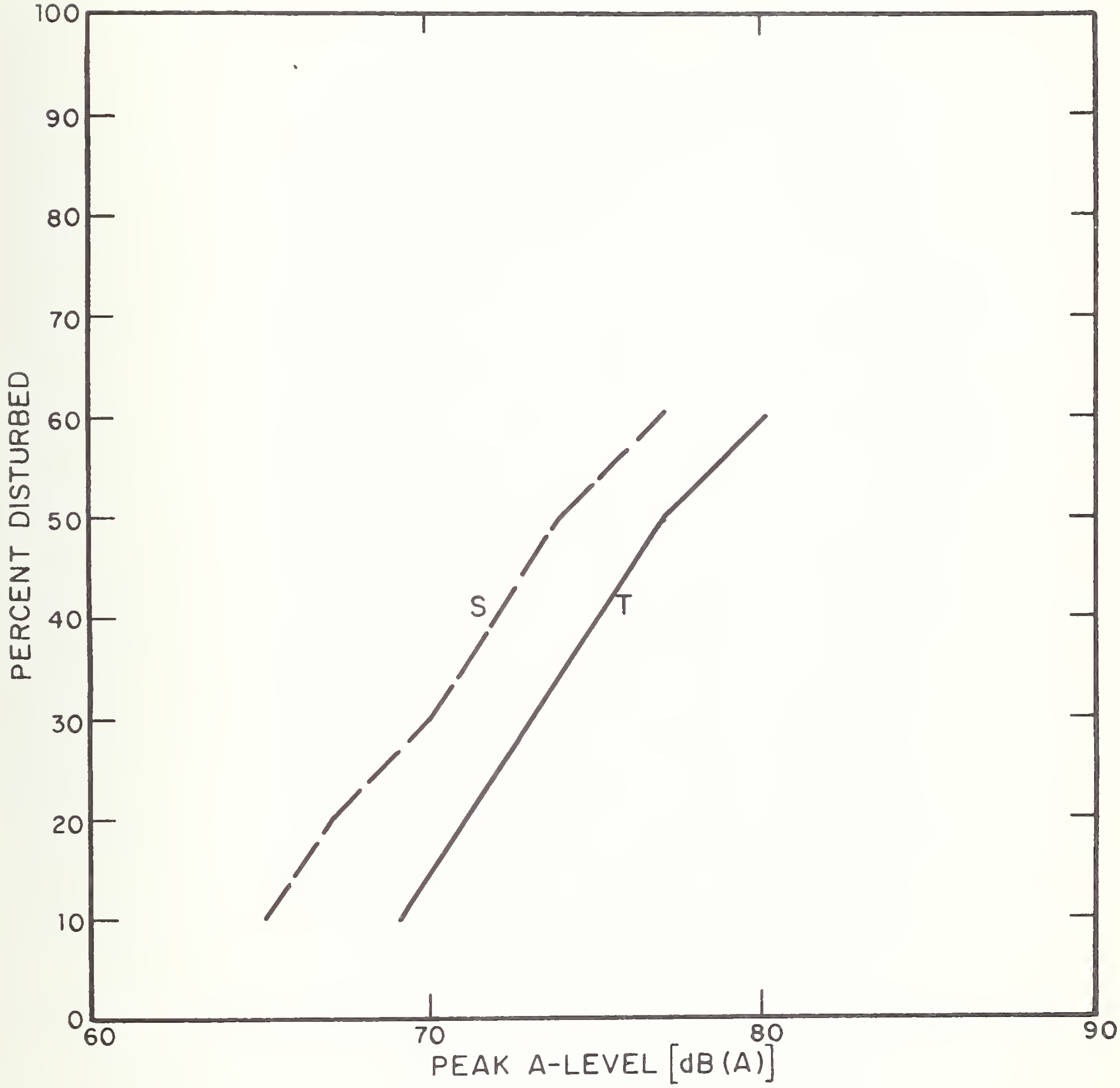

FIG. 10. CONVERSATION (36).

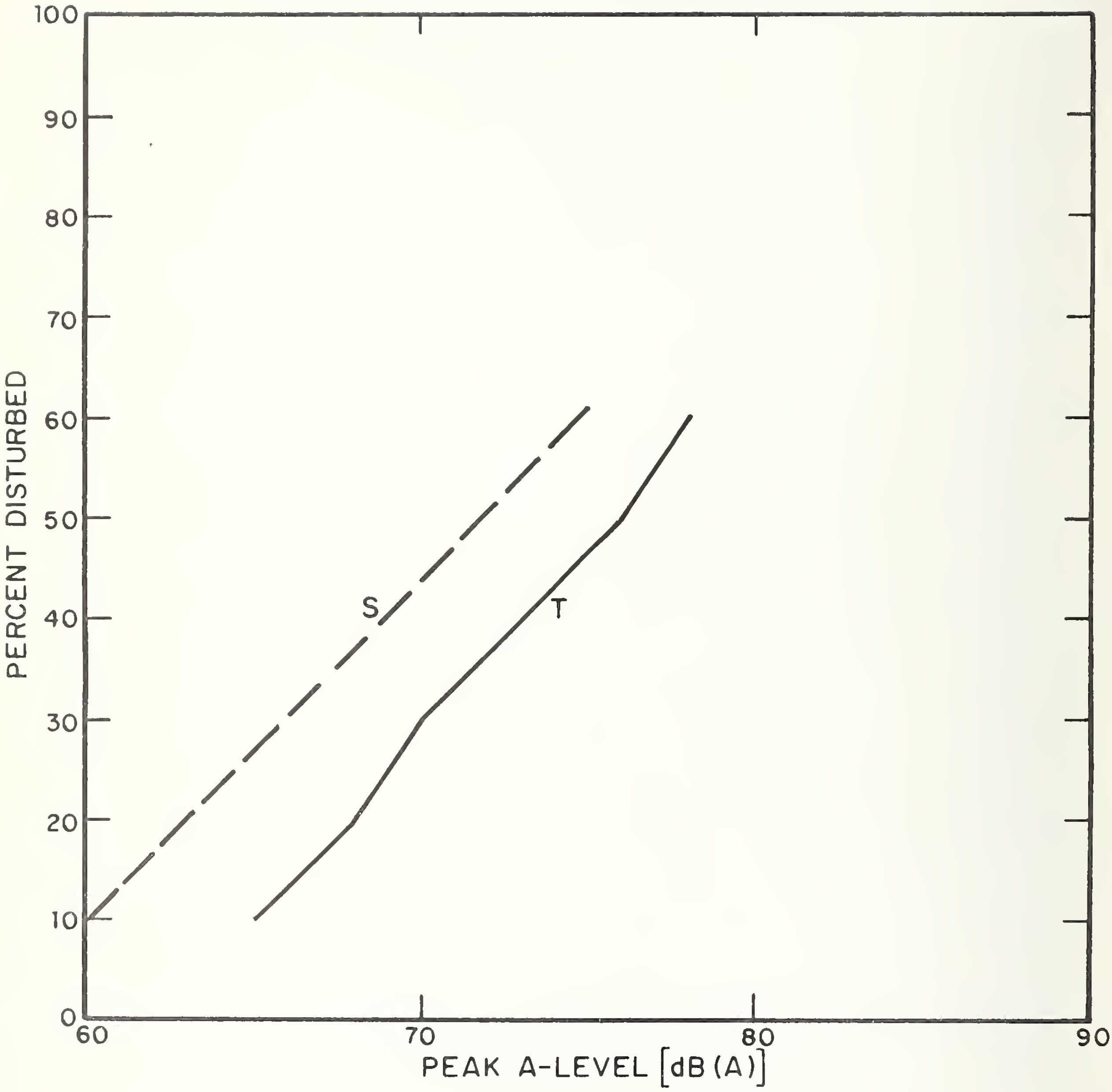

FIG. 11. DISTURBANCE OF HEARING: GENERAL [TELEPHONE, TV, RADIO, CONVERSATION].

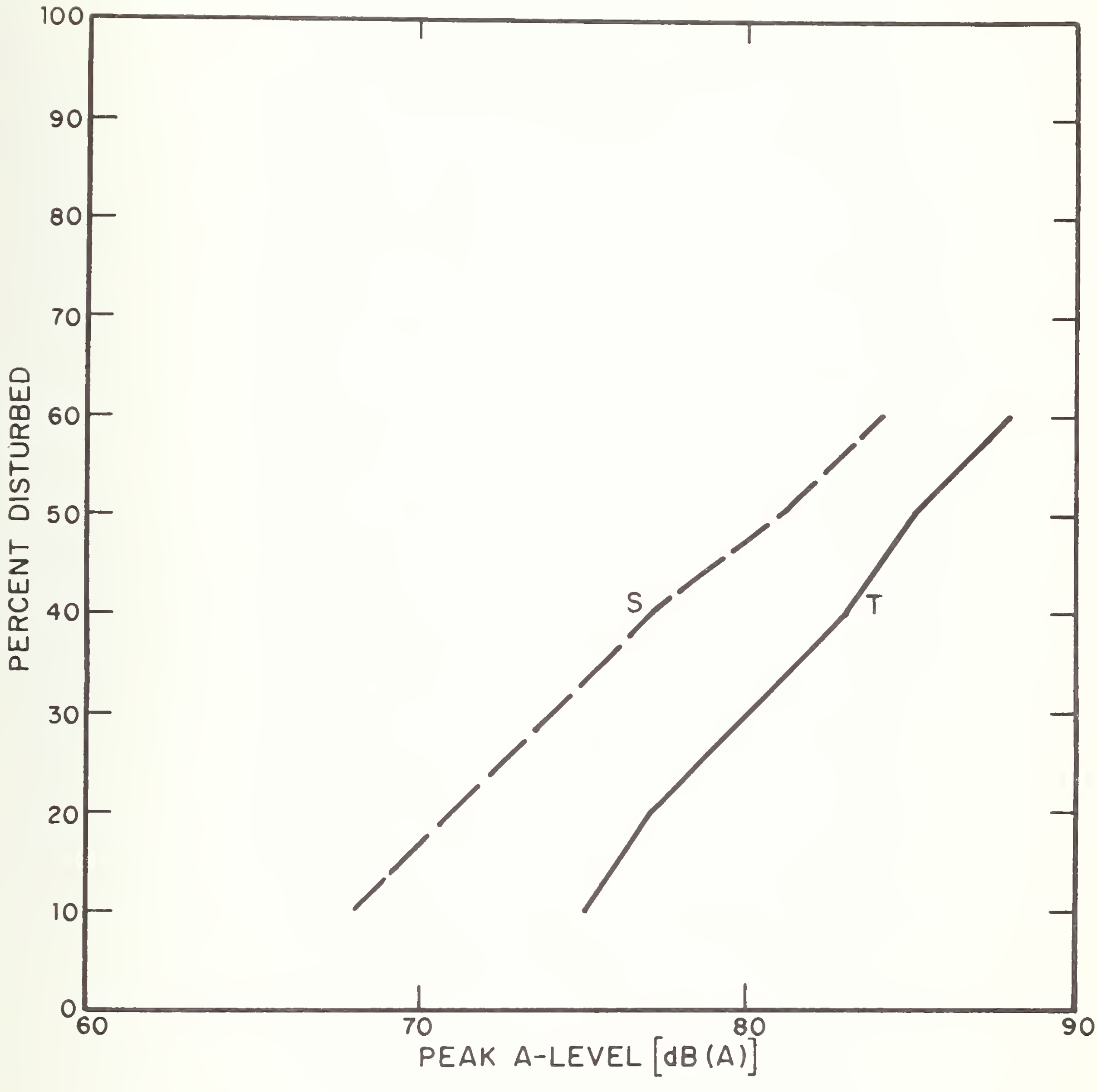

FIG. 12. STARTLE (35).

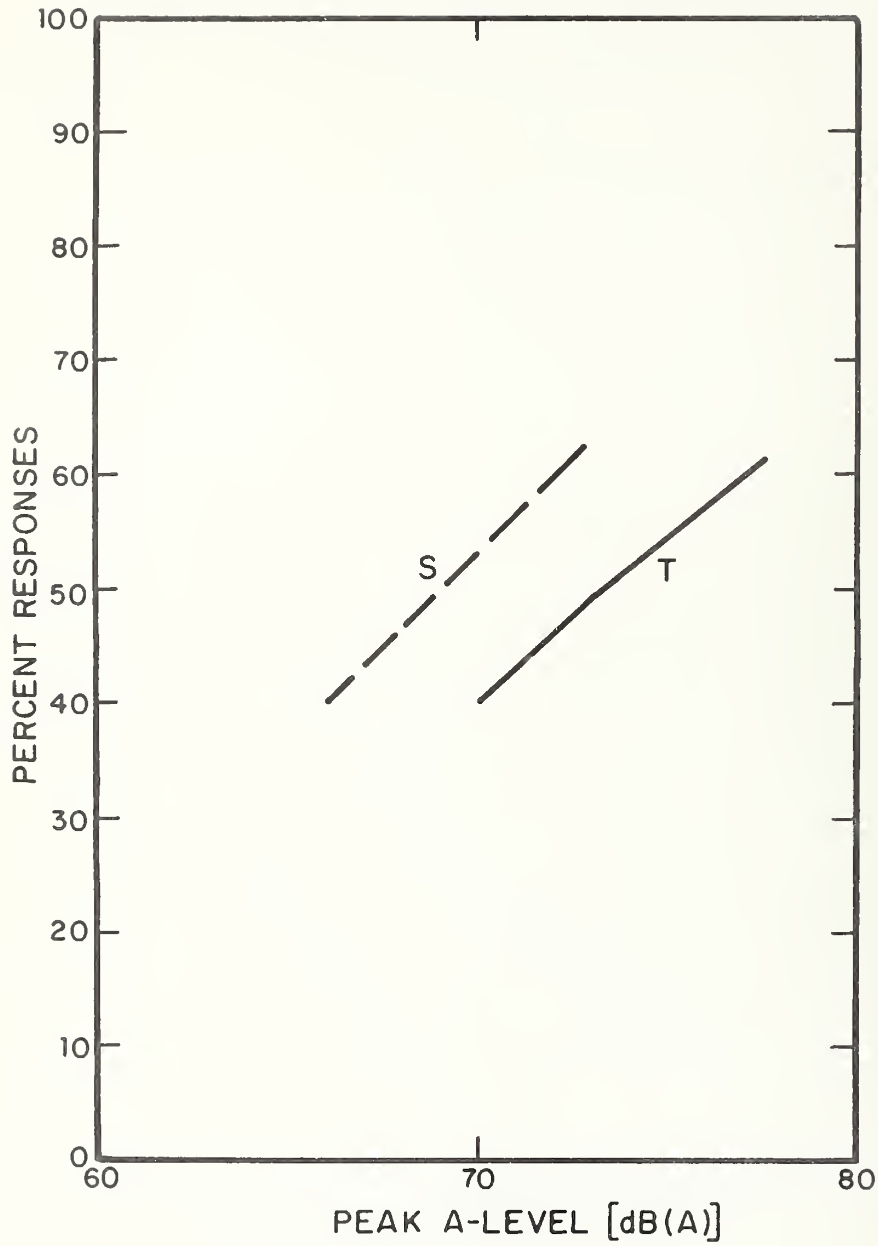

FIG. 13. ANNOYANCE.

At this same maximum level of 70 dB(A), near the Tokaido Line only about 13% were disturbed in conversations face-to-face and on the telephone, but 55% were disturbed listening to TV or radio (Figs. 8–10). Near the Sanyo Line more than twice as many (30%) were disturbed in conversations and telephone, but the interference with TV and radio is about the same (58%) as on the Tokaido Line. Also at a maximum level of 70 dB(A), the people near the Tokaido Line had apparently gotten over their startle reaction, but about 18% near the Sanyo Line had not (Fig. 12). Finally, at this maximum level of 70 dB(A), 40% of the people near the Tokaido Line and 52% near the Sanyo Line rated the noise of the trains above the middle of the seven-point noisiness scale (Fig. 13).

The coefficients of correlation between the maximum noise levels during train passages and the annoyance scores were $r = 0.531$ for the Sanyo Line and 0.552 for the Tokaido Line. Correlation coefficients of nearly the same magnitude were found between annoyance and distance from tracks.

2.4.4 Effect of attitudes on annoyance

An analysis of the questionnaire responses by the Japanese researchers showed the following relationships:

1. No significant relationship between the annoyance and the type of house construction.

2. At the same noise level, the annoyance score of people facing the railroad tracks is larger than that of people living at the back of the house; however, since the noise level was always measured at the front of the house, the people living behind were shielded and actually were exposed to lower noise levels.

3. An informant with children of 6–10 years gave a slightly higher score.

4. No relationship to whether the informant owns or rents his house.

5. The relationship to period of residence was studied in detail only for the Tokaido Line, where no significant dependence was found in general. There was a tendency for the annoyance to be lower for people living there for longer periods, implying some adaptation; however, among the people who had lived there for more than two years, if they had been there since before the Tokaido Line began running (more than 8 yrs) their annoyance scored significantly higher.

There is no mistaking the difference in responses of people living near the older Tokaido and the new Sanyo Lines, *for the same noise level exposure;* stated alternatively, to elicit the same annoyance response the maximum train levels had to be 5–6 dB(A) higher on the Tokaido Line. (Since the number of trains on the Tokaido Line was about twice that on the Sanyo Line, this difference would even be 3 dB greater if the noise rating included a term like 10 log N to account for traffic volume!) Presumably this difference is largely due to some kind of "adaptation" of the people near the Tokaido Line in the 8 years of its operation. Since, according to the results above, the *individual* residents who had lived there before the operations began have *not* become habituated, it must mean that the *neighborhood* has adapted: that is, the sensitive people have moved away.

6. There is a significant correlation between the annoyance scores and the degree of general complaint against the neighborhood: the greater the complaint the greater the annoyance.

7. There is also a significant relation between annoyance and the attitude towards noise in general; for the same annoyance response, a shift of one attitude category (on a five-point scale)

in the unfavorable direction requires a 10 dB reduction in train noise.

8. Near the Tokaido Line no relationship was found between the period of residence and the attitude toward noise in general, reinforcing the conclusion that the noise-sensitive people have moved away.

2.4.5 Noise ratings taking traffic volume into account

The results of the survey were used to compare the annoyance scores against the Noise and Number Index (NNI) for the train noise. Also, the community response was estimated in terms of a rating called "NRN", though this rating was not described in the report; it appears to be something like the Community Noise Rating (CNR), with corrections for "repetition", "experience", and "type of district". Without further information not much can be learned from the NRN results.

As for the NNI, the activity interference scores for the two Japanese rail lines were plotted against the corresponding values of NNI, and these results were compared with those found for similar activities in the first London survey around Heathrow Airport. It was found that as the NNI increases, the adverse response to railroad noise increases much faster than that due to aircraft; again, this may be due to the "sensitive phrasing" of the questions in the railroad questionnaire.

Nothing was stated in the survey report to indicate whether the additional inclusion of the train traffic volume, as in the NNI noise rating, improved the correlation with annoyance over that with noise measures alone.

2.4.6 Train noise in relation to Japan's environmental standards

Environmental standards on noise levels were adopted in Japan following a cabinet decision in May 1971. The prescribed noise limits for an area where there are buildings for commercial and industrial use, as well as dwellings, facing a roadway with two or more lanes, are as follows: the median of the cumulative distribution of A-weighted sound pressure levels may not exceed 65 dB in the daytime or 60 dB at night. Most of the areas facing high-speed railway lines in urban areas were said to correspond to the same zone.

For the median levels of railway noise to be in the 60–65 dB(A) range, the *maximum* levels during train passages would have to be 70–75 dB(A), assuming 10 passages per hour. The summary of the survey, however, stated that the maximum levels from a newly established high-speed railway should lie around 60 dB(A) [*14*] (based on the NRN evaluations not tabulated here). In practice, the noise restrictions officially adopted by the Public Nuisance Abatement Council of the City of Sendai for the new Tohoku High-Speed Train Line, to be opened to traffic in 1976, were much more lenient:

> Maximum noise levels in dwelling areas during train passages: 75 dB(A) in the daytime or 70 dB(A) at night, at the time the new line opens.
>
> This noise level is to be reduced to 70 dB(A) for the entire day as soon as possible, within 2 or 3 years after the opening. It is believed that this level corresponds to 20–30% interference in the inhabitant's daily life.

2.5 A Laboratory Study of the Noisiness of Trains

In connection with the Japanese social survey described in the previous section, a laboratory study was conducted in parallel, to try to define how the perceived noisiness (as opposed to expressed annoyance....though presumably there must be some relation between noisiness and annoyance!) depends on various parameters of the noise pattern during train passages [*15*]. The tests were carried out by presenting to trained observers a series of simulated and recorded train noises, having a variety of different peak levels, peak durations, rise and decay times, etc. These signals were alternated with a "Comparison Noise" whose level could be adjusted until the test noise and the comparison noise sounded equally loud.

It turned out that a satisfactory rating for the noisiness of train passages depends only on the maximum A-level during the train passage and the duration of the passage, thus lending support to the results of the survey. (However, despite the authors' claim that the noisiness is best predicted by the total energy in the noise of the passage,* it is not; indeed, this claim is somewhat difficult to understand, since they state: "The rate of noisiness change, however, differs according as [*sic*] the energy change is caused by a change of peak level of noise or by a change of its duration, even if the energy changes are equal in both cases."

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*They are *not* speaking of L_{eq}, the Equivalent Noise Level, but of the noise energy integrated over the duration of the train passage, with no division by the duration.

15. Shunichi, Kono, Toshio Sone and Tadamoto Nimura, "A Study on Noisiness of a Train Noise," *J. Acoust. Soc. Japan*, 29 (4), 225–?, April 1973.

The formula that successfully predicted the judged noisiness was:

$$N = L_{A_{max}} + \frac{\left(L_{A_{max}} - 20\right)}{10} \log_{10}(T_d) \qquad (2)$$

where $L_{A_{max}}$ is the maximum A-weighted sound level during the train passage and T_d is the time during which the noise level is within 10 dB of its maximum value. The duration *dependence* thus depends on the peak level, a relationship that hardly supports the claim that the noisiness of the train passage corresponds to the total sound energy in the event.

There is enough scatter in all survey results that this rather subtle dependence would likely be impossible to discover outside the laboratory.

3. CONCLUSIONS WITH RESPECT TO COMMUNITY NOISE IMPACT

The general conclusion from the four studies described above is that, as far as the noise impact itself is concerned....that is, leaving attitudes and dwelling exposure out of account....the best correlation with expressed annoyance is achieved when both the maximum noise level during train passages as well as the train traffic volume are taken into account; this can be done either explicitly, with separate terms for each variable (the NNI is an example, but not the best!), or by the use of L_{eq}, which embodies both variables. The prediction of annoyance is equally good either way.

For the specific purposes of the wheel/rail noise study, however, the most important parameter will be the maximum noise level during a train passage, since no attempt at trade-offs (with ambient noise, duration or traffic volume for example) is contemplated for most tests.

Based on all the information presently available, *the maximum A-weighted sound pressure level during a train passage* is the best choice for evaluating the efficiency of the various noise control measures to be studied in the wheel/rail noise project.* Of course, for diagnostic and analytical purposes, spectrum analyses of various degrees of refinement will be necessary. But the ultimate success of the noise control measure as it reflects impact of the wheel/rail noise on the community, can be assessed in terms of the reduction of maximum A levels during a train passage.

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*It is worth noting that the Draft International Standard 3095 (1972) "Measurement of Noise Emitted by Railbound Vehicles" of the International Standards Organization, Geneva, gives first priority to A-weighted sound levels for measuring the noise outside *all* kinds of railbound vehicles, with octave-band analysis permitted for diagnostic purposes.

In a more general context, such as weighing one kind of train noise against another in order to set noise abatement priorities, it will be necessary to include considerations other than simply the maximum level of the noise. This is somewhat complicated, as far as the impact of train noise on the community is concerned, because virtually no such general studies exist on which to base the comparison, and, moreover, the different kinds of train noise affect different parts of the community. Accordingly, the remaining conclusions of this section take a "common sense" approach, based on general acoustic consulting experience with a multitude of community noise problems. It is to be hoped that new research, specifically directed toward the "unknowns" of rapid transit noise impact, can be undertaken soon in the United States.

The wheel roar and the rail-joint impacts that dominate high-speed train noise over most of the route affect the greatest number of people. These two kinds of noise affect the same people for the same period of time, and in assessing annoyance it is both impractical and unnecessary to distinguish between them; together they make up the noise of a high-speed train passage. As for the *intensity* of their impact on the community, it is to be rated by the *maximum A-weighted noise level during the train passage*. Whichever one of these two components....the roar or the rail joint impacts....dominates the maximum A-level is to be given priority in noise abatement in each case.

As for the *cumulation* of the noise impact, this should be accounted for by adding to the maximum A-level a term that deals with total duration: namely, 10 log T,* where T is the total

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*The constant 10 in this term is common in ratings for many kinds of intermittent noise. By comparison, the level-dependent number of seconds during the 24-hour day, on the average, for which the train noise is within 10 dB of its maximum value during each train passage. (For high-speed train noise, according to the survey results reviewed earlier, it would be just as suitable to use the *number* of train passages as to use the duration of train passages; but since we will sometimes wish to compare this noise component with other quite different phenomena, such as wheel squeal, we use duration.)

The squeal of wheels interacting with the rails on curves, on the other hand, is mostly a low-speed phenomenon that affects a different part of the community. Whereas the noise of roar and rail-joint impacts moves with the train, the squeal noise is confined to the neighborhood of curves of relatively short radius of curvature. People living here seldom hear roar or rail-joint impacts, but they hear wheel squeal from nearly every train that passes.

Despite the intermittency and the high noise levels typical of wheel squeal, it is suggested that a correction for "startle" is NOT appropriate for rating this component of train noise, simply because it does not come as a surprise for people living in the impacted areas; they know to expect this noise with every train that passes.

However, a correction for the piercing, pure-tone character of the squeal is necessary in comparing the impact of this component of noise with others. It is common practice to account for

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Continuation of preceding footnote

multiplier found in the Japanese laboratory study (the second term of Eq. 2) would be 8, if the peak A-level were around 100 dB, which is typical of both high-speed and rapid transit trains at about 30 ft.

the increased annoyance of noises containing pure-tone components by adding 5 dB to the A-weighted sound pressure level [*1*]. For this reason, we recommend that the maximum A-level of the wheel squeal should be increased by 5 dB for such comparisons. The duration of the wheel squeal is to be rated by adding a 10 log T term, where T is the total number of seconds of duration of wheel squeal "sequences" in an average 24-hour day. A "sequence" corresponds to the squeal period for one passage. For passengers inside the cars, the duration of such a sequence would be the time for one car to pass the curved section of track; for people in the community, it would be comparable to the whole train passage time.

Some train noises are not relevant to a study of wheel/rail noise, such as the engine noise of the locomotives (or other traction units), the noise of warning signals (whistles, horns, bells, etc.) and the noise of shunting in the yards. Practically no study has been done on the effects of these noises, by themselves, on the community. And even for some wheel/rail interaction noises, such as flange impacts, passage over switches, etc., almost nothing quantitative is known. In the absence of any better idea, however, it is suggested that these noises may also be handled with a sum of a maximum A-level and a 10 log T term for duration of "sequences".

No attempt is made here to account for the fact that *more* people are typically impacted by the high-speed components of train noise than by, say, wheel squeal. Such an evaluation, and the consequent noise abatement priority decisions, are beyond the scope of the present report, for they invoke matters of policy, economics and politics.

4. NOISE AFFECTING THE TRAIN PASSENGERS

For train passengers waiting on the platforms or in stations, the same noise *rating* (namely annoyance, as measured by A-levels) should apply as for the nearby community, even though the *criterion of acceptability* might be chosen to be less stringent because of the limited duration of their exposure. Again, the recommended rating is the maximum A-level, with a 10 log T correction for duration.

We consider now the impact of the wheel/rail noise on passengers inside the train.

For passengers riding in *airplanes*, it has been the custom, almost without exception, to specify the acoustical quality of the ride in terms of the Speech Interference Level (SIL). This is because of the great importance attached to being able to converse comfortably with ones seat partner (and also, in part, because the extreme difficulty of applying effective noise control measures at low frequencies in airplanes makes the aircraft manufacturer reluctant to promise low low-frequency noise levels!). There has been much less consistency in describing the acoustical quality inside *trains:* sometimes the Noise Criterion (NC or NCA) curve is specified; sometimes the Speech Interference Level, sometimes an idealized spectrum shape approximating the spectra actually measured in comfortable railroad cars [*16*].*

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*A range of acceptable interior noise levels is sometimes given, the upper value being chosen so that the passenger can carry on conversations with nearby neighbors without difficulty, and the lower value chosen to guarantee enough ambient noise that his privacy is not impaired, since he ordinarily does not want to talk or listen to *all* the other passengers.

16. Theodore J. Schultz, "Noise and Vibration Criteria for the Northeast Corridor Trains", Report No. 1276, Bolt Beranek and Newman Inc., 15 December 1965.

It is well-established, however, that even for a fairly wide range of noise spectrum shapes, there is a very high correlation between such noise ratings as NC,SIL and the A-weighted sound level.[*1*] For example, in comparisons involving almost 1000 quite dissimilar noise spectra, the correlation coefficient between A-levels and SIL was 0.983, with a standard deviation of 2.9 dB; between A-levels and NC the coefficient was 0.995, with a standard deviation of 1.0 dB; and between A-levels and annoyance level rank (similar to the idealized spectrum shape mentioned above) the coefficient was 0.989, with a standard deviation of 0.3 of a rank, or about 1.5 dB [*17*]. It is clear that any of these interior noise criteria can be expressed equally well and with negligible error as A-weighted sound pressure levels; and for consistency with the evaluation of community noise impact it is desirable to do so. Thus, as far as the train passengers are concerned, the success of noise control measures on wheel/rail noise should be assessed in terms of A-level reduction of the noise.

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17. Botsford, J. H., "Using Sound Levels to Gauge Human Response to Noise," *Sound and Vibration* 3 (10), 16-28 (October 1969)

5. NOISE AFFECTING THE OPERATORS

As far as the comfort of the train operators is concerned, the impact of the train noise on them is like that on the passengers riding in the cars, and is suitably assessed by the A-level of the noise to which they are exposed. Their ability to communicate readily among themselves in carrying out their duties can also be evaluated as well in terms of A-levels as by SIL, as noted above in Sec. 4.

To the extent that the train operators may be exposed to noise levels high enough to raise the question of hearing damage risk, the impact of this noise should also be assessed in terms of A-levels, since the U.S. Occupational Safety and Health Administration and the U. S. Department of Labor have already formulated hearing protection policy by setting maximum permissible occupational noise exposure in terms of A-levels.

6. CONCLUSIONS

Although the criteria that apply to different groups of people affected by urban transit noise are different:

- annoyance at the property line, for the community;
- speech interference, for the passengers;
- speech interference and general long-term comfort for the operators;

nevertheless, the choice of noise rating is the same. We recommend for all monitoring of train noise, and for assessing the effectiveness of noise control measures in the wheel/rail noise program, that A-weighted sound pressure levels be used to rate the noise and that A-level reductions be used to assess the merit of the noise control measures.

We recommend that the relevant international or national draft standard be used for carrying out such evaluations, as follows:

For the exterior noise generated by the train as a whole or by individual cars or other items of rolling stock:

(a) ISO Draft International Standard 3095 (1973) "Acoustics-Measurement of Noise Emitted by Railbound Vehicles"

For the interior noise, affecting both passengers and operators, generated by the train as a whole or by individual cars or other items of rolling stock:

(b) "Revised Draft Proposal for Measurement of Noise Inside Railbound Vehicles", ISO/TC 43/SCI (Haag-4) 158E.

For the noise of individual items of equipment detached and isolated from the train:

(c) "Methods for the Determination of Sound Power Levels of Small Sources in Reverberation Rooms" American National Standard S1.21 - 1972.

For special tests, these procedures may have to be modified or adapted to special situations; whenever this is the case, the fact should be clearly noted in the test report, and the nature of the modification or departure from the standard test procedure should be carefully described.

In comparing one kind of train noise against the others, the duration of the noise intrusion is to be accounted for by the addition of a 10 log T term, where T is the typical duration in seconds of the intrusion of that noise component on any single location, in the course of a 24-hour day. For wheel squeal, the maximum observed A-level is to be increased 5 dB to account for the pure-tone character of this sound; no correction for "startle" or intermittency (other than 10 log T) is to be used in evaluating wheel squeal.

No attempt is made in this report to assess the trade-off between the level of the train noise and the number of people affected.

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