Updating a dosage–effect relationship for the prevalence of annoyance due to general transportation noise

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More than a decade has passed since a relationship between community noise exposure and the prevalence of annoyance was synthesized by Schultz [T. J. Schultz, J. Acoust. Soc. Am. **64**, 377–405 (1978)] from the findings of a dozen social surveys. This quantitative dosage–effect relationship has been adopted as a standard means for predicting noise-induced annoyance in environmental assessment documents. The present effort updates the 1978 relationship with findings of social surveys conducted since its publication. Although the number of data points from which a new relationship was inferred more than tripled, the 1978 relationship still provides a reasonable fit to the data.

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INTRODUCTION

It has been more than a decade since Schultz (1978) synthesized a relationship between transportation noise exposure and the prevalence of annoyance in communities from the findings of a dozen social surveys. Although initially greeted with considerable controversy, the relationship has become a mainstay of assessments of the effects of noise exposure on communities, and has gained widespread currency as the most thorough and well-documented dosage–effect relationship available to environmental planners.

One concern expressed at the time of publication of Schultz's synthesis was that it might have a chilling effect on the conduct of further social surveys of noise-induced annoyance, since some believed that agencies which fund such studies might erroneously conclude that the synthesis represented a definitive solution to many of the problems of assessing effects of noise exposure on communities. The abundance of surveys conducted since preparation of the synthesis (cf. Borsky, 1985; Fidell *et al.*, 1985; Fields and Walker, 1982; Hall and Taylor, 1977; Hall *et al.*, 1981; Hede and Bullen, 1982; Rylander, 1977; Schomer, 1983b; Sorensen and Hammar, 1983, *inter alia*) demonstrates that such concerns were unfounded.

In fact, so many measurements have been made of the prevalence of noise-induced annoyance in various communities since publication of the synthesis paper that it is now worth reviewing the dosage–effect relationship derived in 1978 in the light of evidence published since.

I. METHOD

Table I lists 15 social surveys of the annoyance of transportation noise exposure published since the preparation of the 1978 Schultz synthesis paper that were judged sufficiently similar in design to those considered by Schultz to be comparable for present purposes. Five criteria for comparability were adopted: (1) At least one questionnaire item had to inquire directly about long-term annoyance *per se*, rather than activity interference or other noise effects from which annoyance might arguably be inferred; (2) the noise source under study had to be a transportation noise source, and actual acoustic measurements of noise exposure were strongly preferred; (3) acoustic measurements, if not reported in units of day–night average sound level (DNL), had to be convertible into such units with reasonable confidence; (4) sample sizes had to be adequate for estimating

TABLE I. Summary of social surveys reviewed.

Mnemonic	Authors(s)	No. of data points
1978 addenda, new surveys:		
(1) U. S. AIRBASE	Borsky, 1985	25
(2) ANTWERP STREET	Myncke *et al.*, 1977	31
(3) BRUSSELS STREET	Myncke *et al.*, 1977	23
(4) BURBANK AIRPORT	Fidell *et al.*, 1985	20
(5) CANADIAN ROAD	Hall and Taylor, 1977	14
(6) DANISH STREET	Relster, 1975	28
(7) BRITISH RAIL	Fields and Walker, 1982	11
(8) AIRCRAFT/ TRAFFIC	Hall *et al.*, 1977	21
(9) ORANGE COUNTY AIRPORT	Fidell *et al.*, 1985	12
(10) AUSTRALIAN AIRCRAFT	Hede and Bullen, 1982	42
(11) TRAMWAY/ TRAFFIC	Rylander, 1977	12
(12) DECATUR AIRPORT	Schomer, 1983	4
(13) SWEDISH RAILROAD	Sorensen and Hammar, 1983	15
(14) WESTCHESTER AIRPORT	Fidell *et al.*, 1985	8
(15) DANISH RAILROAD	Andersen *et al.*, 1982	26
	total:	292

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prevalence of annoyance with reasonable precision; and (5) the scale used for quantification of annoyance had to permit identification of numbers of respondents describing themselves as "highly annoyed" in a manner comparable to that devised by Schultz (1978).

Specifically excluded from present consideration were laboratory studies of noise-induced annoyance, field studies of community reaction to impulsive noise sources (gunfire, blasting, helicopters, sonic booms, etc.), and studies of community response to other nontransportation sources (e.g., construction).

A. Treatment of data from studies meeting selection criteria

Since the major goal of the present effort was to preserve comparability of analyses with those conducted by Schultz (1978), the conventions adopted by Schultz for deriving paired values of noise exposure and prevalence of annoyance were retained. For example, the definition of "highly annoyed" respondents adopted by Schultz (those respondents whose self-described annoyance fell within the upper 27%–29% of the response scale, except when category labels unambiguously dictated otherwise) was retained. Likewise, it was necessary to transform noise measurements reported in units other than $L_{\rm dn}$ to units of $L_{\rm dn}$ in several cases. Treatments of the data of individual studies are described below.

1. Australian aircraft (Hede and Bullen, 1982; 3575 interviews)

Hede and Bullen report a conventional social survey of the annoyance of aircraft noise. Noise levels were reported in units of $L_{\rm dn}$ for field measurements made at various locations around the commercial airports at Sydney, Perth, Adelaide, Melbourne, and the Royal Australian Air Force Base at Richmond. Personal interviews were conducted with 45 to 115 respondents per site. The physical measurements used in the present analysis are reported in Hede and Bullen's Tables 3.3 and D.9 and Fig. 6.4. Twenty-four-hour noise measurements were made for approximately 2 weeks per site. These values were then compared to existing noise exposure forecast (NEF) contours for accuracy.

The percentages of respondents highly annoyed were tabulated from responses to questionnaire item 36 by the authors (Bullen, 1988). The item was worded "How would you describe your 'general feelings' about the aircraft noise in this neighborhood?" Respondents were constrained to select one of the following categories: (1) highly annoyed, (2) considerably annoyed, (3) moderately annoyed, (4) slightly annoyed, or (5) not at all annoyed.

A total of 42 paired values of measured noise levels and percentages of respondents highly annoyed were available in this data set. Respondents describing themselves as "highly annoyed" were considered highly annoyed for present purposes to conform with the convention adopted by Schultz (1978, p. 381) for dealing with named response categories.

Ninety-five percent confidence intervals were calculated for the estimated percentages of respondents highly annoyed at each interviewing site by assuming that the self-reports of annoyance in the categories "highly annoyed" and all other categories were binomially distributed:

$$1.96(PQ/N)^{0.5}$$

where P is the proportion of respondents highly annoyed, Q is the proportion of respondents not highly annoyed, and N is the number of respondents per site. Figure 1 displays the 95% confidence intervals for the data points reported by Hede and Bullen in relation to the dose–response curve synthesized by Schultz (1978).

2. Aircraft–traffic comparison (Hall et al., 1981; 673 interviews)

This social survey compared the annoyance from aircraft noise to the annoyance of road traffic noise at nine sites around Toronto International Airport (Canada). Inter-

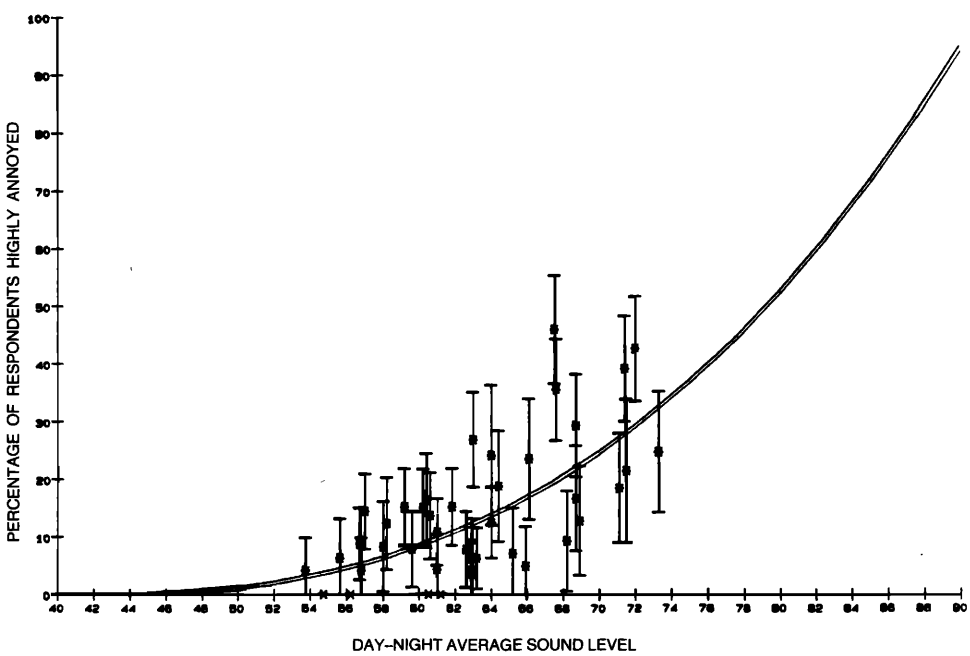

FIG. 1. Relationship of data from Australian Aircraft Study to 1978 synthesis curve.

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views were conducted with 10 to 180 respondents per site. Noise levels were reported in units of L_{dn}. The data analyzed for present purposes are those reported in Table III (road traffic) and Table IV (aircraft) of Hall *et al.* (1981).

Data for road traffic noise were collected by automated equipment during 24-h periods during weekdays, at one location per site. Aircraft noise exposure was predicted by use of the Integrated Noise Model software. Control tower records for 1977 were used as the source of operational information for the predictions.

Hall *et al.* solicited judgments of the annoyance of transportation noise sources with a direct question ("How do you rate each of the sounds you have mentioned?") and a bipolar response scale composed of the following categories: (1) extremely agreeable, (2) moderately agreeable, (3) considerably agreeable, (4) slightly agreeable, (5) neutral, (6) slightly disturbing, (7) moderately disturbing, (8) considerably disturbing, and (9) extremely disturbing.

Nine data points for aircraft noise and 12 data points for traffic noise were reported. Hall *et al.* suggested that "... the appropriate cutoff point for high annoyance on the response scale is between moderately and considerably disturbing... ." This criterion represents the top two of the nine response categories of the bipolar scale. If the "neutral" category is considered to be equivalent to "not at all annoyed," however, Hall *et al.* in effect counted the top 40% of a five-point scale. Thus the authors' criterion overestimates the percentage of respondents highly annoyed relative to the percentages counted by the criteria adopted for the 12 clustering surveys. Figure 2 shows 95% confidence intervals for both the aircraft and traffic noise data.

3. Burbank Airport survey (Fidell et al., 1985; 5041 interviews)

Fidell *et al.* describe a social survey of aircraft noise annoyance involving multiple rounds of interviews in the vicinity of a mixed-use civil airport located in Southern California [reported as "study 1" in Fidell et al. (1985)] at which noise levels changed considerably over time due to changing runway use patterns. Noise levels were monitored continuously for a week prior to interviewing at multiple microphone positions within the boundaries of each site, and calibrated against exposure gradients from aircraft noise exposure contours. *De facto* panel samples of 220 to 330 respondents per site were interviewed five times in person or by telephone. Table II of Fidell *et al.* (1985) presents the annoyance and noise data for five rounds of interviews in four airport neighborhoods. The percentage of respondents highly annoyed was derived from responses to questionnaire item 4, which asked respondents if they had been (1) not at all annoyed, (2) slightly annoyed, (3) moderately annoyed, (4) very annoyed, or (5) extremely annoyed by the noise of aircraft over the past year.

Twenty data points resulted from this assessment of long-term noise exposure. (Another questionnaire item that solicited judgments of the annoyance of aircraft noise exposure over the past week was not considered for present purposes to preserve comparability with the time scales of other surveys.) Respondents describing themselves as "extremely annoyed" or "very annoyed" were considered to be highly annoyed. Figure 3 displays 95% confidence intervals for the data points.

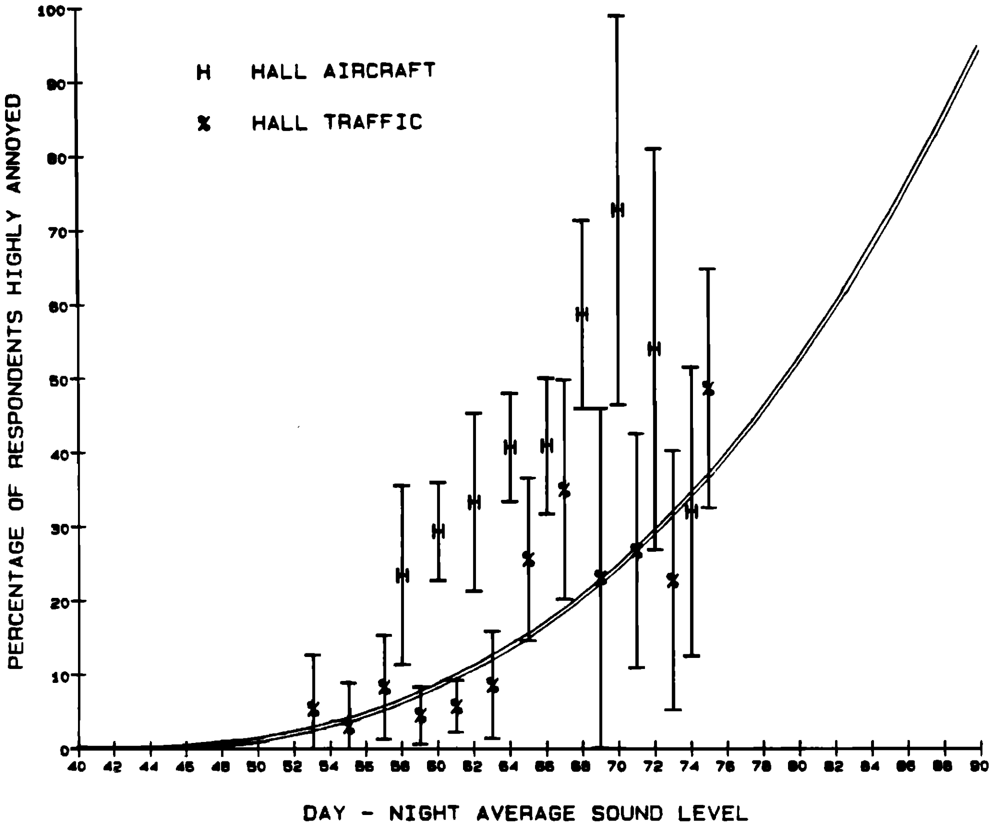

FIG. 2. Relationship of data from Aircraft–Traffic comparison to 1978 synthesis curve.

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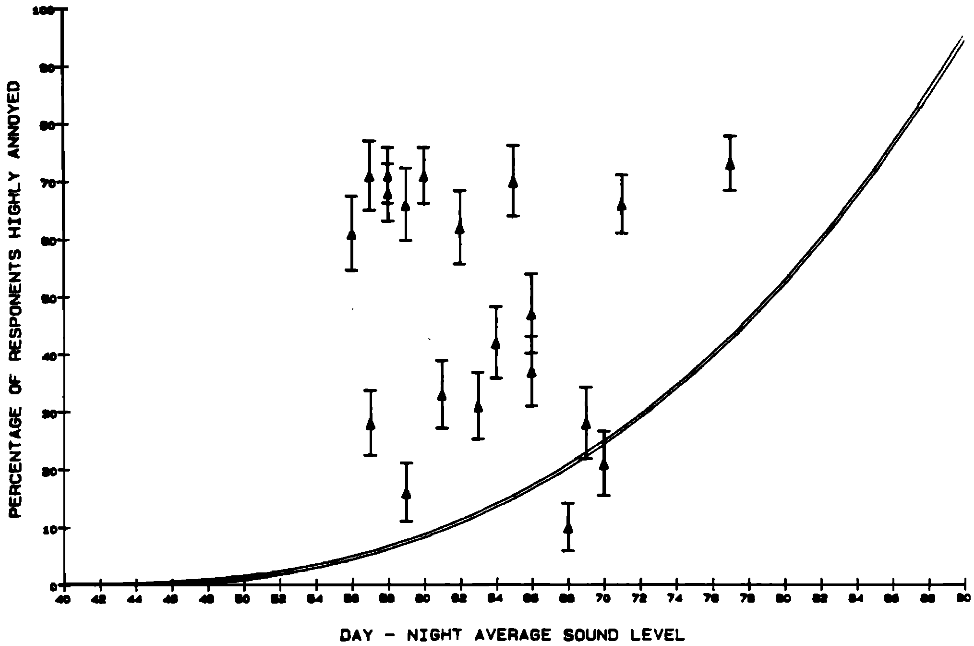

FIG. 3. Relationship of data from Burbank Airport Study to 1978 synthesis curve.

4. Orange County Airport (Fidell et al., 1985; 3103 interviews)

This social survey was reported as "study 2" in Fidell *et al.* (1985). Noise exposure measurements were made by the existing monitoring system installed at Orange County Airport located in Southern California. The data were energy-averaged over week-long intervals from six microphone positions and were compared with known aircraft noise contours to estimate area-weighted noise exposure levels. These sites were part of the airport's installed noise monitoring system. Face-to-face and telephone interviews were conducted with 200 to 330 respondents per site. Table IV of Fidell *et al.* (1985) summarizes the long-term annoyance data produced in four rounds of interviews in three interviewing areas in airport environs. The percentage of respondents highly annoyed was compiled from responses to questionnaire item 5, which asked respondents "While you've been at home over the past year, since last (season of year), have you been bothered or annoyed by the noise from larger airliners?" The named categories for the response scale were: (1) not at all annoyed, (2) slightly annoyed, (3) moderately annoyed, (4) very annoyed, or (5) extremely annoyed. Twelve paired values of percentages of respondents highly annoyed and measured sound levels were reported. These data points may be seen in Fig. 4.

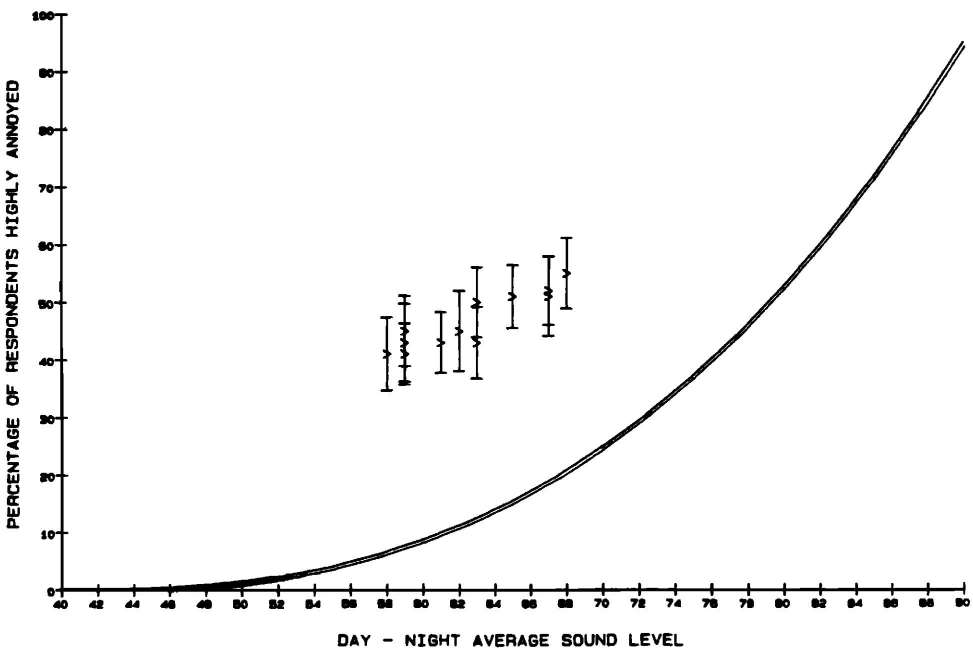

FIG. 4. Relationship of data from Orange County Airport Study to 1978 synthesis curve.

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5. Tramway and traffic survey (Rylander et al., 1977; 464 interviews)

Rylander *et al.* report a survey of differences in respondents' reactions to tramway and city traffic noise. Interviews were conducted with approximately 75 respondents at each of 12 sites in Gothenburg, Sweden, along streets supporting mixed motor vehicle and tramway traffic. Noise measurements were collected on tape recorders at 1-h intervals during afternoons, and were later analyzed using a statistical distribution analyzer. Specific details regarding the period of time over which these measurements were taken were not reported.

Noise levels reported in units of 24-h L_{eq} for both tramway and traffic noise were converted to L_{dn} values by taking the average of two different conversion procedures. The conversion equation for the first method (Galloway, 1977) was

$$L_{dn} = L_{eq(24)} + 3.38 \text{ dB}.$$

The conversion equation for the second method used by Schultz (1978) was

$$L_{dn} = 1.13 L_{eq(24)} - 4.9 \text{ dB}.$$

The differences between the conversions ranged from 0.3–0.8 dB.

Respondents were provided with three response categories from which to select an answer to the question "Are you annoyed by tramway or traffic noise?": (1) a little annoyed, (2) rather annoyed, and (3) very annoyed. Rylander *et al.* (1977) present the noise exposure and response data in Tables 1 and 2 for respondents who described themselves as "very annoyed." Respondents considered to be very annoyed by Rylander *et al.* (1977) were counted as highly annoyed for present purposes.

A total of 12 data points consisting of noise levels and percentages of respondents highly annoyed (six for tramway and six for traffic) were reported by Rylander *et al.* Figures 5 and 6 display 95% confidence intervals in relation to the Schultz Curve for both tramway and traffic noise respectively.

6. Decatur Airport (Schomer, 1983a,b; 231 interviews)

Schomer (1983b) reports a noise survey of attitudes toward aircraft noise conducted near Decatur, Illinois Airport. Noise measurements were made in units of L_{dn}. Field measurements of noise exposure were compared against exposure levels predicted by Integrated Noise Model Version 2.6. Details regarding the measurement methods were not specified. Personal interviews were conducted at four sites with 22 to 99 respondents per site.

Questionnaire item 7a inquired about noises heard at home that respondents preferred not to hear. For each undesired noise source heard in the home, questionnaire item 7f asked respondents to rate their annoyance using the following scale: (1) extremely annoyed, (2) very much annoyed, (3) moderately annoyed, or (4) slightly annoyed. Schomer considered respondents who described themselves as "very much" or "extremely" annoyed as highly annoyed. Schomer presents the noise source and response data in his Fig. 3 and Table IV for respondents he considered highly annoyed.

Respondents who spontaneously mentioned some type of noise annoyance were considered to be at least "slightly annoyed" by the noise source. It is assumed that respondents were "not at all annoyed" by noise sources that escaped mention, yielding a five-category response scale. Schomer's study yielded four paired observations of measured noise levels and percentages of respondents highly annoyed. These are plotted in Fig. 7.

7. British railroad (Fields and Walker, 1982; 1399 interviews)

Fields and Walker conducted an attitudinal survey of railroad noise in Great Britain. They made more than 2000 noise measurements at 403 locations in units of 24-h L_{eq}, noise and number index (NNI), community noise equivalent level (CNEL), and L_{dn}. Personal interviews were conducted with 45 to 220 respondents per site.

The authors tabulated percentages of respondents high-

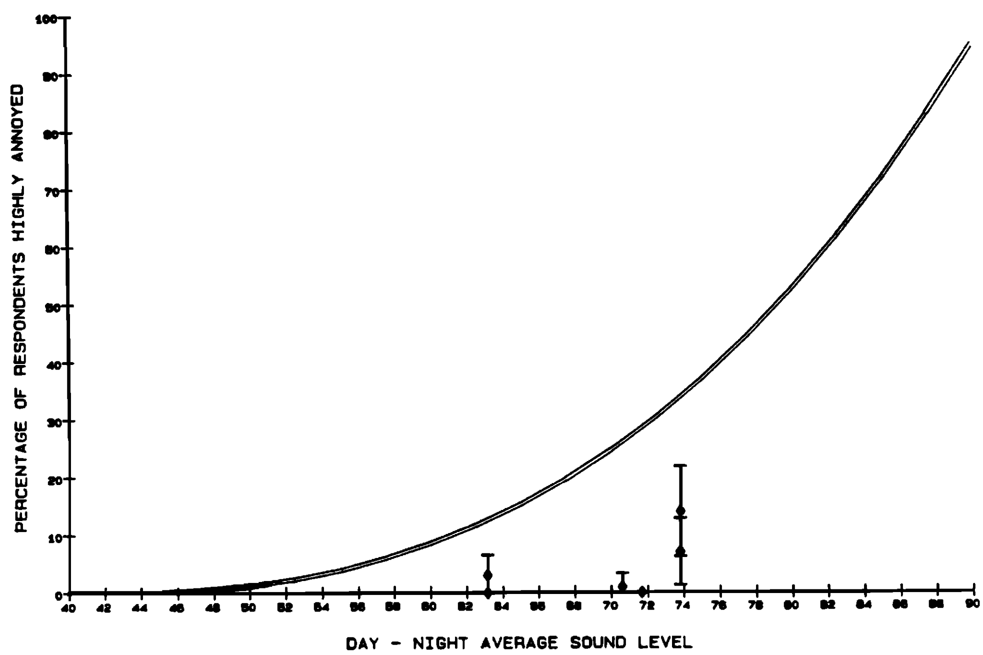

FIG. 5. Relationship of tramway data from Tramway and Traffic Study to 1978 synthesis curve.

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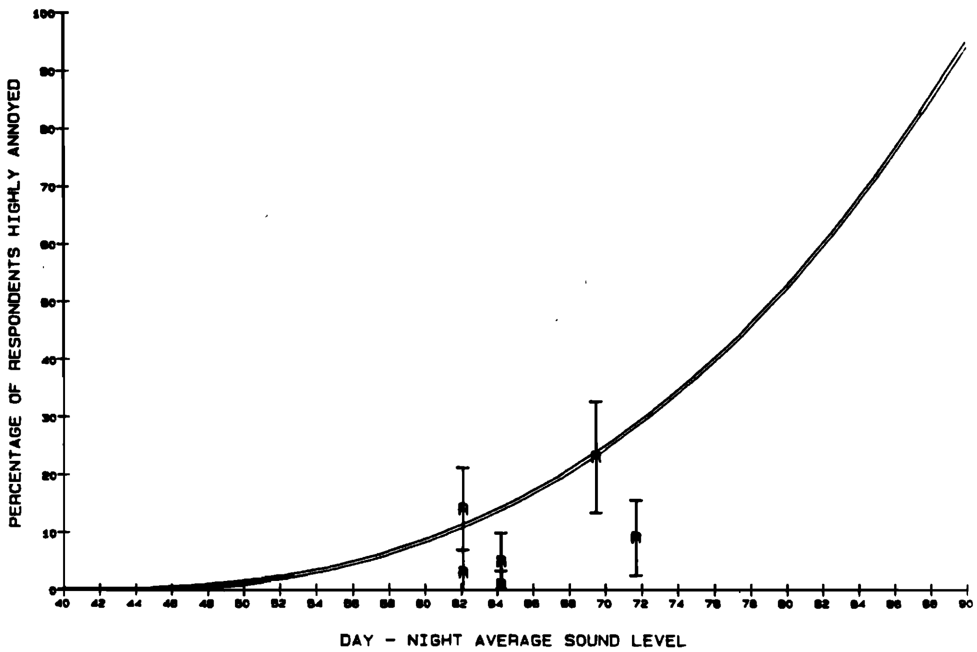

FIG. 6. Relationship of traffic data from Tramway and Traffic Study to 1978 synthesis curve.

ly annoyed to a direct question (questionnaire item 17b) worded as follows: "Does the noise of trains bother or annoy you: (1) very much, (2) moderately, (3) a little, or (4) not at all." Respondents describing themselves as "very much" annoyed by train noise were considered to be highly annoyed for current purposes. Figure 8 shows 95% confidence intervals for the British Railroad data.

8. Swedish railroad (Sorensen and Hammar, 1983; 1125 interviews)

Sorensen and Hammar report an investigation performed during 1978–1980 of reactions to railroad train noise in areas surrounding the cities of Malmo and Stockholm. The authors interviewed 50 to 100 respondents at each of 15 sites. Noise was measured in units of 24-h L_{eq} for each passing train. The conversion from the reported units of L_{eq} to L_{dn} was performed as described for the Rylander (1977) survey.

The data used in the present analysis are found in Fig. 1 of Sorensen and Hammar (1983). Since the data were not tabulated, a grid was overlaid on Sorensen and Hammar's Fig. 1 to estimate values of pairs of noise exposure levels and percentages of highly annoyed respondents.

Sorensen and Hammar did not report the labels of response categories used for eliciting annoyance judgments. They did, however, claim close similarity of annoyance measurement techniques with an earlier survey (Rylander *et al.*,

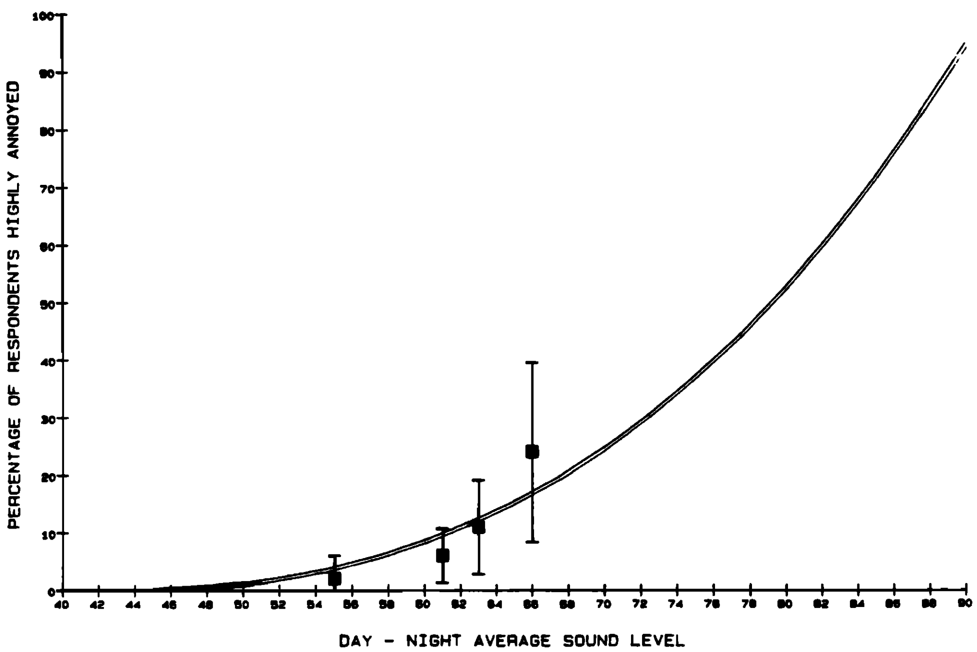

FIG. 7. Relationship of data from Decatur Airport Study to 1978 synthesis curve.

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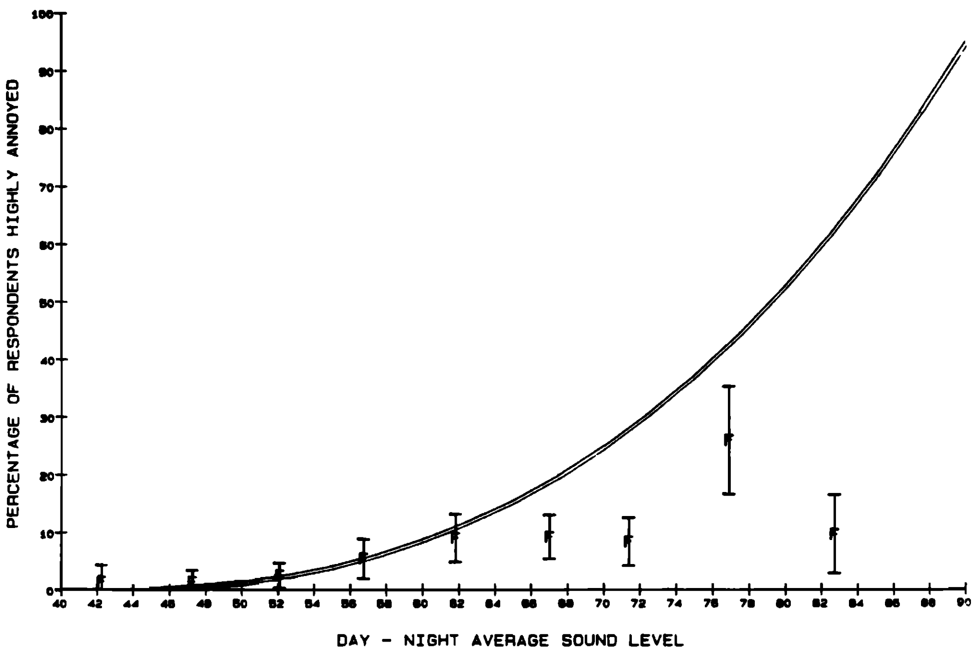

FIG. 8. Relationship of data from British Railroad Study to 1978 synthesis curve.

1980), which used four named response categories: (1) not annoyed, (2) a little annoyed, (3) rather annoyed, and (4) very annoyed. In the present analysis, "very annoyed" was used to describe high annoyance. Figure 9 shows 95% confidence intervals for the 15 data points from this study.

9. U.S. Airbase (Borsky, 1983, 1985; 874 interviews)

Personal interviews were conducted with 27 to 45 respondents per site at 25 sites near seven U.S. Air Force bases. Borsky used automatic equipment to measure exposure in units of L_{dn} for approximately 10 days per site. A threshold of 65 dBA was used for these measurements. It is unclear how levels of exposure lower than this threshold value were estimated.

The data used in the present analysis are based on a questionnaire item that asked "How much does noise from aircraft disturb, bother, or annoy you?" Respondents selected a response category from an "opinion thermometer" composed of ten gradations with named end points, as follows:

"not at all 0 1 2 3 4 5 6 7 8 9 extremely"

Respondents were considered highly annoyed for present purposes if they selected categories 7, 8, or 9 (30% of the response scale). Figure 10 shows the 95% confidence intervals calculated for the 25 sites.

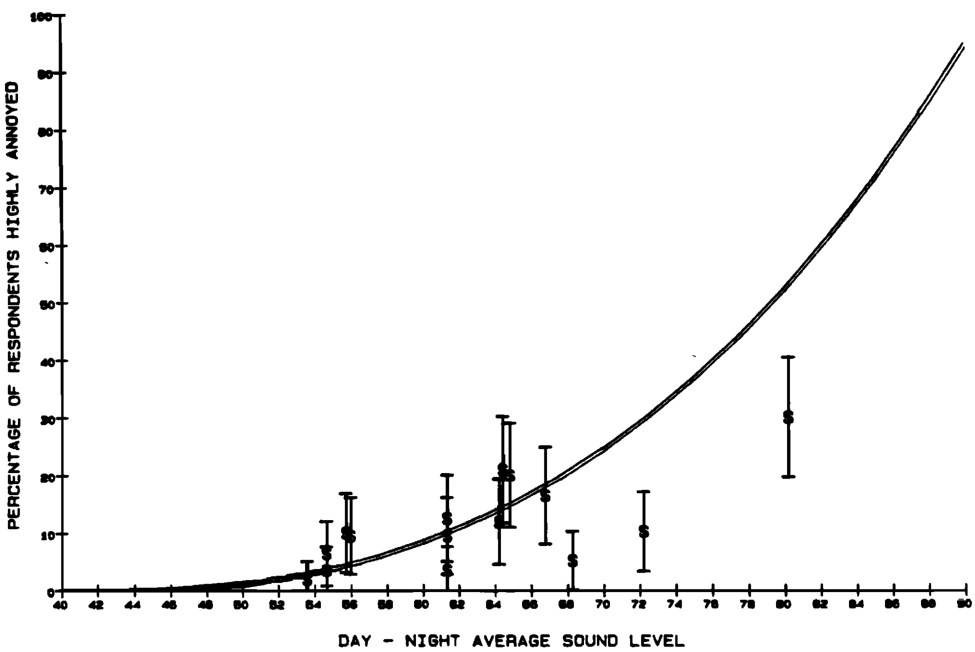

FIG. 9. Relationship of data from Swedish Railroad Study to 1978 synthesis curve.

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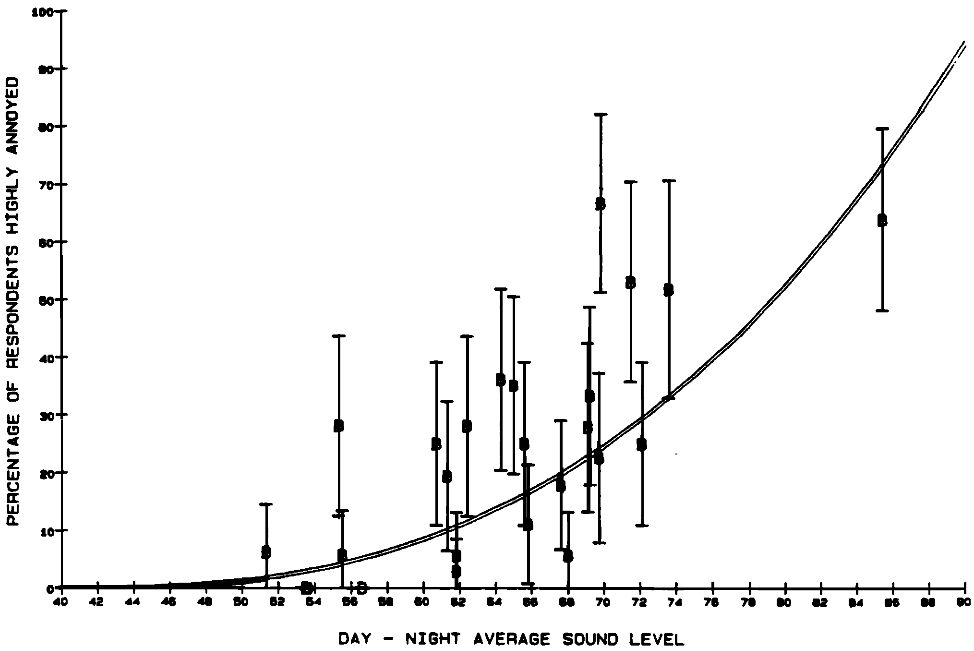

FIG. 10. Relationship of data from U. S. Airbase Study to 1978 synthesis curve.

10. Westchester County Airport (Fidell et al., 1985; 1465 interviews)

Fidell *et al.* report a social survey of the annoyance of aircraft noise at four sites around Westchester County Airport located in New York state. Both personal and telephone interviews were conducted twice with samples of 100 to 250 respondents per site. Noise measurements were made by automatic equipment at multiple microphone locations within each site for a week prior to interviewing, and were reported in units of L_{dn}.

Table VI of Fidell *et al.* (1985) summarizes the percentage of respondents highly annoyed and measured noise levels. Questionnaire item 4 asked respondents "And how about this past (season of year): Have you been bothered or annoyed by noise from airplanes while you've been at home during these months?" Respondents were allowed to choose one of the following categories: (1) not at all annoyed, (2) slightly annoyed, (3) moderately annoyed, (4) very annoyed, or (5) extremely annoyed. Respondents describing themselves as either "very" or "extremely" annoyed were considered highly annoyed for current purposes. Figure 11 presents the 95% confidence intervals for the eight data points reported by Fidell *et al.* in relation to the dose–response curve generated by Schultz (1978).

11. Danish railroad (Andersen et al., 1983; 615 interviews)

Andersen *et al.* report a survey conducted near seven Danish railways with traffic volumes ranging from 30–300

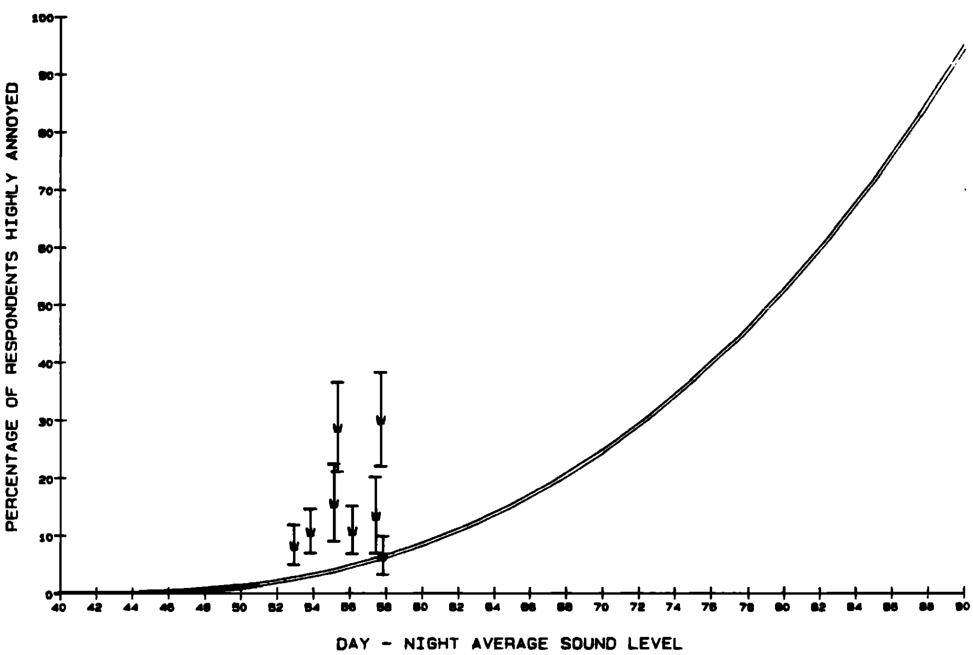

FIG. 11. Relationship of data from Westchester County Airport Study to 1978 synthesis curve.

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trains per hour. Numbers of respondents ranged from 1–55 at each of 26 sites. Noise measurements were reported by Andersen *et al.* in units of L_{eq} and were converted to L_{dn} by using the method described for the Rylander (1977) survey.

Andersen *et al.* directly asked respondents "Does railway noise annoy [you]?" Respondents indicated that they were (1) strongly annoyed, (2) somewhat annoyed, (3) slightly annoyed, (4) very little annoyed, or (5) not annoyed at all. Respondents rating themselves as "strongly annoyed" were considered to be highly annoyed for present purposes. This represents 20% of the response scale, slightly underestimating high annoyance as defined by the 27%–29% criteria.

A grid was overlaid on Figure 1 of Andersen *et al.* (1983) to estimate values of pairs of noise exposure levels and percentages of highly annoyed respondents. Figure 12 shows 95% confidence intervals for the 26 points from this study.

12. Other studies

Data from the following studies [considered as part of the original clustering surveys or four addenda by Schultz (1978)] are included in the present analysis as well. The reader is referred to Schultz (1978) for a detailed explanation of the treatment accorded the data of these studies.

French Aircraft (Alexandre, 1970)
Second Heathrow Airport (MIL Research, 1971)
First Heathrow Airport (McKennell, 1963)
London Traffic (Langdon, 1976)
Munich Airport (Rohrman *et al.*, 1974)
Paris Street (Aubree *et al.*, 1971)
French Rail (Aubree, 1975)
Swedish Aircraft (Rylånder *et al.*, 1972)
Swiss Road (Grandjean *et al.*, 1973)
Swiss Aircraft (Grandjean *et al.*, 1973)
USA 24 Site (Fidell, 1978)
Los Angeles Airport (LAX 2 SITE) (Fidell and Jones, 1975)
Antwerp Street (Myncke *et al.*, 1977)
Brussels Street (Myncke *et al.*, 1977)
Canadian Road (Hall and Taylor, 1977)
Danish Street (Relster, 1975)

B. Derivation of a fitting function

The studies summarized above yielded a total of 292 new data points. Figure 13 combines the data from the individual studies described above into a single plot, along with the 161 data points from the clustering surveys of Schultz (1978). A least-squares quadratic fit to the data points is also shown.

Figure 14 compares the third-order polynomial function Schultz chose to fit the data of the 1978 synthesis with a second-order fitting function for all 453 data points. As can be seen, the quadratic fit to the new data points is several decibels higher (about 4 dB higher at an L_{dn} value of 57.5 dB, and about 1.5 dB higher at an L_{dn} value of 70 dB), indicating greater annoyance than the 1978 synthesis over a large part of the range of interest for most purposes.

II. DISCUSSION

A. Relationship between third-order polynomial and least-squares quadratic fit

Schultz (1978) selected a third-order polynomial forced to predict zero prevalence of high annoyance at an L_{dn} value of 45 dB for the 1978 dosage–effect relationship. Figure 15 compares the 1978 dosage–effect relationship with (1) the (unconstrained) least-squares quadratic fitting function shown in the previous figures and (2) with quadrat-

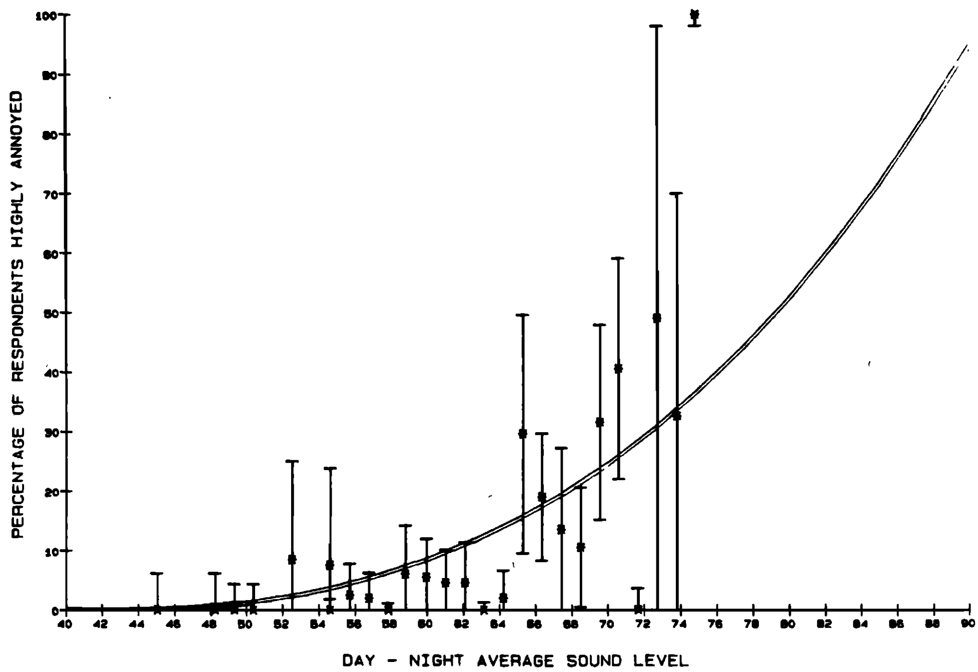

FIG. 12. Relationship of data from Danish Railroad Study to 1978 synthesis curve.

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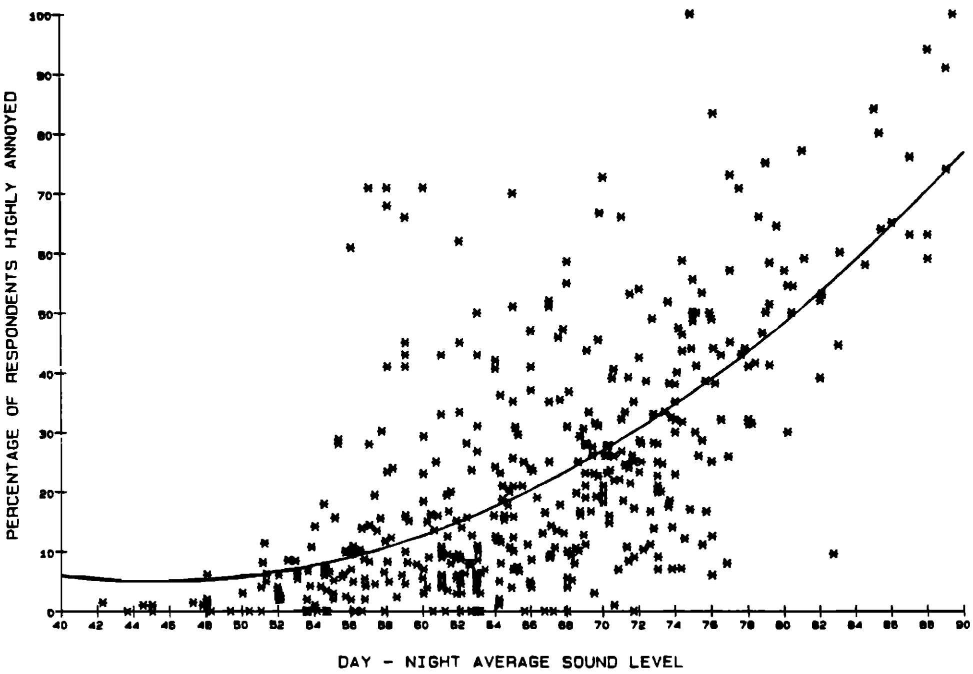

FIG. 13. Quadratic fit to all 453 data points.

ic least-squares fits to the upper and lower boundaries of the 95% confidence intervals for all data points. Note that the 1978 relationship lies within these limits over virtually all of its range.

The equation of the quadratic fitting function is

$$\%HA = 0.0360L_{\rm dn}^2 - 3.2645L_{\rm dn} + 78.9181.$$

The quadratic fit accounts for 44% of the variance in the data points. Since the best-fitting (least-squares criterion) cubic relationship accounts for only 1% more variance, and in the absence of any theoretical imperative in favor of either one, the quadratic is preferred over the cubic fit for reasons of parsimony.

The information on which both the 1978 and the quadratic fitting functions are based is not error-free. Indeed, there is uncertainty in quantification of both the dependent and independent variables of the dosage–effect relationship. Influences of errors of several types on the relationship are discussed briefly here, and from a different perspective, by Green and Fidell (1991).

B. Bias errors in definitions of high annoyance

One obvious influence on the shape of the fitting function is the definition adopted for high annoyance in each of the data sets. Table II compares the percentages of the response alternatives included in the definition of "high annoyance" in the 11 studies not considered in the 1978 synth-

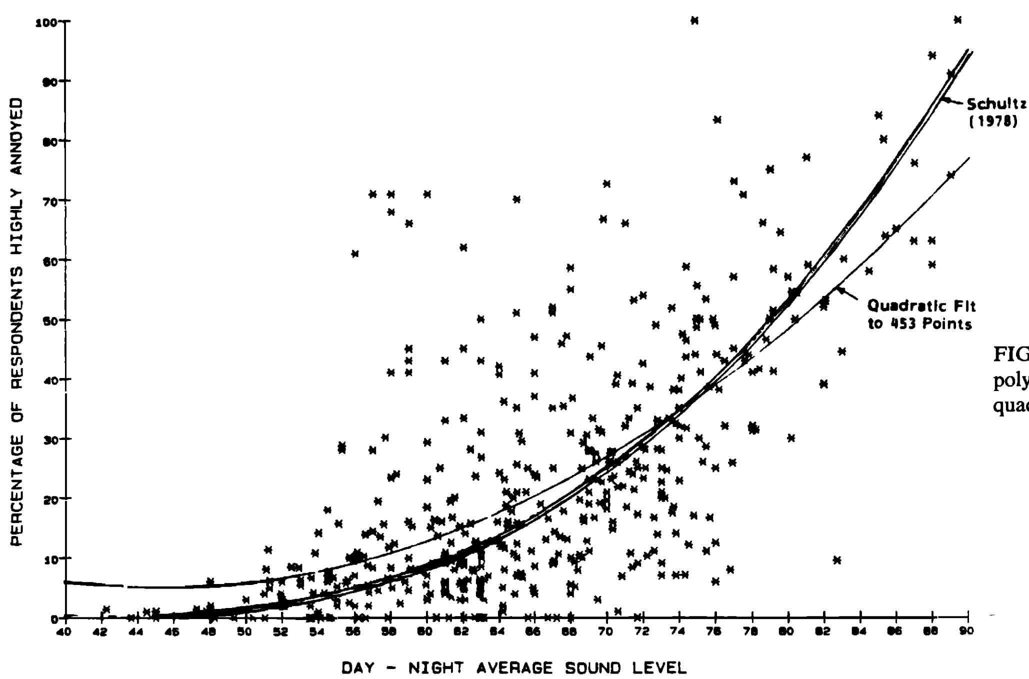

FIG. 14. Comparison of 1978 third-order polynomial fitting function with present quadratic fit to 453 data points.

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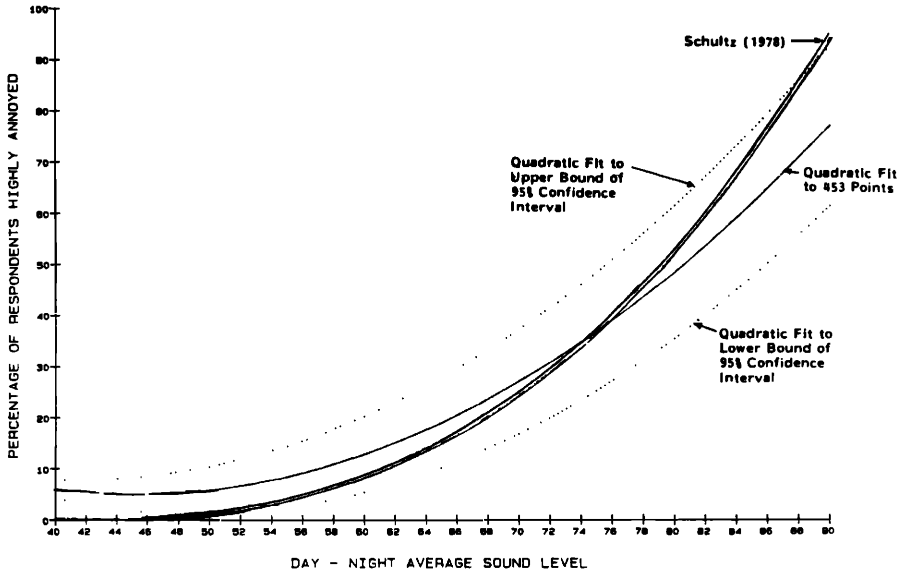

FIG. 15. Comparison of third-order polynomial and quadratic fitting functions sources of error in data.

esis.On average, self-reports of annoyance in the upper 31.4% of the response alternatives in these studies were considered to meet criteria for "high annoyance." This figure is slightly higher than the 27%–29% average for the 12 clustering surveys on which the 1978 dosage–effect relationship is based. About half (45.5%) of the data points underestimate "high annoyance" by 5%, while 54.5% of the data points overestimate "high annoyance" by 10.3%. Even these figures do not suggest the extent to which the dosage–effect relationship is sensitive to the definition of high annoyance in separate surveys. Because the present data set of 453 points is composed of a relatively large number of surveys each contributing a relatively small number of data points, changing the definition of high annoyance adopted in any one survey is unlikely to produce a meaningful change in the dosage–effect relationship.

For example, changing the definition of high annoyance adopted for the Burbank Airport data points from 40% of the response scale to 30% of the response scale as shown in Fig. 16 changes the quadratic fit hardly at all.

C. Uncertainty in measurements of percentages of respondents highly annoyed

Table III displays the sizes of the average estimated 95% confidence intervals for percentages of highly annoyed respondents for each of the 29 data sets. When published reports contained sufficient information, these estimates were made by calculating confidence intervals for each interviewing site and averaging them within studies. When the published reports indicated only total numbers of respondents and interviewing sites, the estimates were made by assuming equal numbers of respondents per site. As can be seen, there is considerable uncertainty in some of the survey data about percentages of respondents highly annoyed. The average width of the estimated 95% confidence intervals of the 29 studies is 16.5%. Given that the slope of the 1978 dosage–effect relationship is about 2%–3% highly annoyed per decibel of noise exposure through much of its range, the uncertainty in the original survey data corresponds to a change in noise exposure of nearly an order of magnitude.

TABLE II. Percentage of response alternatives considered "highly annoying" in surveys not considered in the 1978 synthesis.

Survey	% of response scale considered "highly annoying"	Comparison of percentages % of total data points	% of new data points
Australian Aircraft	20%	9.3%	21.4%
Aircraft/Traffic	40%	4.6%	10.7%
Burbank Airport	40%	4.4%	10.2%
Orange County Airport	40%	2.7%	6.1%
Tramway/Traffic	25%	2.7%	6.1%
Decatur Airport	40%	0.9%	2.0%
British Railroad	25%	2.4%	5.6%
Swedish Railroad	25%	3.3%	7.7%
U.S. Airbase	30%	5.5%	12.8%
Westchester Airport	40%	1.8%	4.1%
Danish Railroad	20%	5.7%	13.3%

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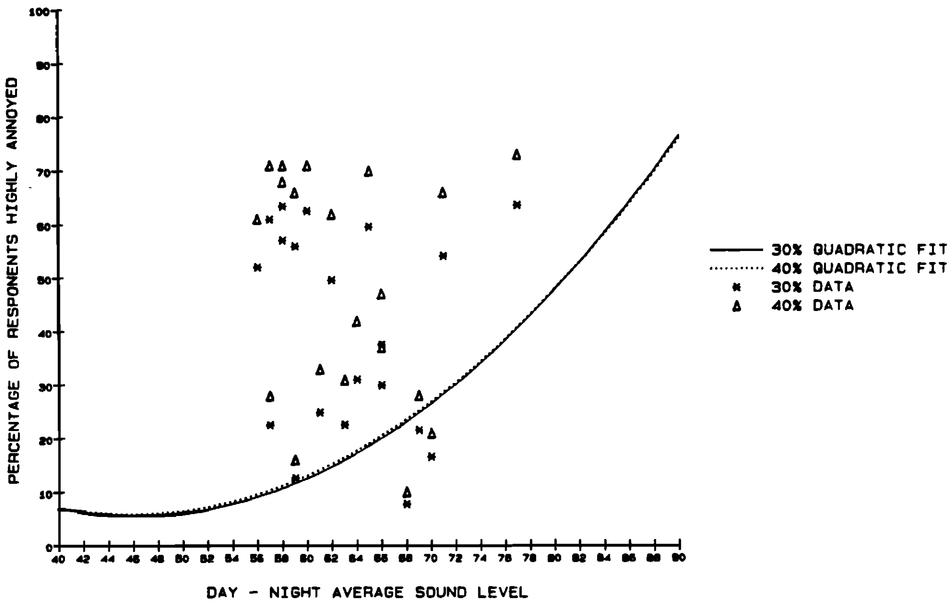

FIG. 16. Effect of changing definition of high annoyance for Burbank data.

Since this uncertainty represents the fundamental level of precision of measurement on the ordinate of the dosage–effect relationship, it is unproductive to seek explanations for smaller differences among potential fitting functions for these data.

TABLE III. Ninety-five confidence intervals for determinations of percentages of respondents highly annoyed.

Rank ordering of studies by average estimated confidence intervals Width of 95% confidence interval (%)	Study
7.1	Swiss Aircraft (Grandjean *et al.*, 1973)
7.2	Traffic/Tramway (Traffic only, Rylander, 1977)
7.4	Second Heathrow Airport (MIL Research, 1971)
7.5	British Rail (Fields and Walker, 1982)
7.6	French Aircraft (Alexandre, 1970)
9.0	Swiss Road (Grandjean *et al.*, 1973)
10.9	First Heathrow Airport (McKennel, 1963)
10.9	Westchester Airport (Fidell *et al.*, 1985)
11.3	Burbank Airport (Fidell *et al.*, 1985)
11.4	Traffic/Tramway (Tramway only, Rylander, 1977)
12.3	Orange County Airport (Fidell *et al.*, 1985)
12.5	Los Angeles Airport (Fidell and Jones, 1975)
13.5	Swedish Rail (Sorensen and Hammar, 1983)
14.3	Australian Aircraft (Hede and Bullen, 1982)
14.5	Brussels Street (Myncke *et al.*, 1977)
14.8	USA 24 Site (Fidell, 1978)
16.3	Antwerp Street (Myncke *et al.*, 1977)
16.3	Decatur Airport (Schomer, 1983)
17.3	French Rail (Aubree, 1975)
18.7	Paris Street (Aubree, *et al.*, 1971)
20.2	Danish Railroad (Andersen *et al.*, 1982)
22.1	Traffic/Aircraft Comparison (Traffic only, Hall *et al.*, 1977)
22.4	Canadian Road (Hall and Taylor, 1977)
23.4	U.S. Airbase (Borsky, 1985)
23.9	Danish Street (Relster, 1975)
24.4	London Traffic (Langdon, 1976)
29.5	Traffic/Aircraft Comparison (Aircraft only, Hall *et al.*, 1977)
32.0	Munich Airport (Rohrman *et al.*,1974)
40.3	Swedish Aircraft (Rylander *et al.*, 1972)

D. Errors in estimating noise exposure

A more difficult matter to address is uncertainty in reported measurements of noise exposure. Few of the studies reviewed provide sufficient detail to permit estimation of confidence intervals for such measurements. In general, the numbers of microphone locations, durations of measurement, calibration of measurements against other information, and homogeneity of exposure across interviewing sites are not well reported.

One exception is the measurements made at Burbank Airport. In this case, noise measurements were made at five locations within each interviewing site for a full week prior to interviewing, and the obtained measurements were calibrated against noise exposure gradients derived from aircraft noise contouring software. Even in this case, however, exposure varied by about ± 2.5 dB within interviewing sites. This figure is probably close to the greatest precision of physical measurement of any of the studies in the present data set. Thus the position of any fitting function developed for this data set probably cannot withstand any closer scrutiny of its relationship to the abscissa than 3 dB.

E. Reliability of dosage–effect relationship

One major implication of the preceding discussion of sources of error in the data set is that the relatively small differences between the current dosage–effect relationship and the one synthesized in 1978 should not be overinterpreted. The differences are minor ones that could be attributed as persuasively to errors of measurement of various sorts as to substantive effects. Another implication is that more sophisticated curve fitting procedures could be employed to deal with uncertainty on both axes of the relationship. For example, if the goal were to weight the salience of each data point by the magnitude of its likely errors of both physical and psychological measurement, a dosage–effect relationship with a rather different shape might well emerge.

Another limitation of both the 1978 polynomial approximation and the current quadratic fitting function is that

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they are both simply convenient data fitting functions, devoid of physical meaning. Both functions are positively accelerated within the range of DNL values of greatest interest, and both are nonmonotonic. Care is therefore necessary to avoid using these relationships outside their intended ranges. Common sense strongly suggests that in reality the function relating exposure to annoyance must be a sigmoid asymptotic to values of the prevalence of annoyance in the vicinity of 0% and 100%.

The next article in this issue develops a theoretically based alternative approach to the purely empirical curve fitting described above.

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