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The Relative Effect of Noise at Different Times of Day

An Analysis of Existing Survey Data

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TABLE OF CONTENTS

TABLE OF CONTENTS
CONTINUED

SUMMARY

It is often hypothesized that the impact of noise is different at different times of day. This report examines survey evidence on the relative impact of noise at different times of day and assesses the survey methodology which produces that evidence. Two types of analyses are performed, analyses of the relationship between overall (24 hour) noise annoyance and time-period noise levels and analyses of time-period annoyance measures.

Analyses of overall (24 hour) noise annoyance are used to assess environmental noise indices. The importance of noise at different times of day is represented by a weight which is applied to noise occuring in the evening and/or the nighttime in such environmental noise indices as LDN (Day-Night Average Sound Level) and CNEL (Community Noise Exposure Level). Such a weight appears as a parameter in models of human reactions to noise. Analyses of the regression of overall (24-hour) annoyance on noise levels in different periods can provide direct estimates of the value of the parameters in these models. The analyses in this report are based on the original computer tapes containing the responses of 22,000 respondents from ten studies of response to noise in residential areas. The estimates derived from these analyses are found to be so inaccurate that they do not aid in choosing between the various time-of-day weighted noise indices or even between the weighted (eg. LDN) and the unweighted indices (eg. 24-hour LEQ). The estimates do not provide useful information for policy or scientific purposes. The possibility that the type of questionnaire item could be biasing the estimates of the time-of-day weightings is considered but not supported by the data. Two alternatives to the conventional noise reaction model (the adjusted energy model) are considered but not supported by the data. The inaccuracy in the estimates of the time-of-day weightings can be traced to the high correlation between nighttime and daytime noise levels in the surveyed residential areas.

The importance of noise at different times of day is also analyzed with survey questionnaire items about the amount of annoyance felt at different times of day. Severe problems in interpreting answers to these questions mean that the results of these analyses do not provide valid estimates of the time-of-day weightings.

It is concluded that existing survey data do not provide valid, satisfactorily accurate numerical estimates of the relative importance of noise at different times of day.

INTRODUCTION

Nighttime noise is often believed to have a greater impact on annoyance in residential areas than daytime noise of the same noise level. This common observation is partially based on the obvious point that a noise which is noticed during the daytime is less disturbing than a noise which is noticed and believed to have caused sleep disturbance during the night. Such conventional wisdom does not, however, provide enough evidence to determine the relative impact of noise at different times of day. This is partly because numerical estimates are needed and partly because the proportion of the routine noise events which are noticed may be different for nighttime and daytime.

Definition of the Time-of-Day Weighting Model

The importance of noise at different times of day is represented in environmental noise indices by a weight which is applied to noise occurring in the evening and/or nighttime. Such a weight appears as a parameter in models of human reaction to noise. The most widely accepted of these models is the adjusted energy model. (Two other infrequently used response models are also considered in the body of the report.) The adjusted energy model of human reactions is consistent with the model implied by such equivalent energy indices as LDN (Day-Night Average Sound Level), NEF (Noise Exposure Forcast), WECPNL (Weighted Equivalent Continuous Perceived Noise Level) and CNEL (Community Noise Exposure Level). In these noise indices and in the adjusted energy model generally the noise level in the nighttime (and sometimes evening) period is adjusted with a numerical weight before being combined with the noise level from the daytime period to make a 24-hour index (L_I). In this report that numerical weight is represented by a symbol "w_j" for the time period "j". This weight is then multiplied by the number of noise events or the relative pressure squared values of the sound levels. With these multiplicative weights the model for three time periods (day, evening and night) is written as:

$$L_I = q + c \bullet 10 \bullet \log_{10}\left(\sum_{i=1}^{N_d} 10^{L_{id}/10} + w_e \bullet \sum_{i=1}^{N_e} 10^{L_{ie}/10} + w_n \bullet \sum_{i=1}^{N_n} 10^{L_{in}/10}\right)$$

(The daytime weight is not explicitly represented in the model because it is understood to be set to one, $w_d=1$). The multiplicative time-of-day weight has a value of $w_e=3$ for evening noise in CNEL and a value of $w_n=10$ for nighttime noise in LDN and CNEL. This multiplicative weight can also be transformed and expressed as a decibel adjustment (D_{L_j}) which is added to the level of each noise event in a time period. In this case the model for two time periods is written:

$$L_I = a + c \bullet 10 \bullet \log_{10} \left(\sum_{i=1}^{N_d} 10^{L_{id}/10} + \sum_{i=1}^{N_n} 10^{(L_{in}+D_{L_n})/10} \right)/24$$

The D_{L_n} adjustment is the conventional weight of 10 in LDN, or 12.2 in CNR or NEF. the relationship between the two alternative expressions for the time-of-day weights is:

$$D_{L_j} = 10 \bullet \log_{10}(w_j)$$

One characteristic of the adjusted energy model is not immediately obvious. In many instances the logic of the adjusted energy model implies that response to noise is determined by the noise of only a single period. This occurs because response is related to the sum of the antilogs of the noise levels and these antilogs may often differ by several orders of magnitude. As a result the noise levels in both periods will affect annoyance only when they are approximately equal on a subjective basis. If for example there is a nighttime weighting of 10 (w_j=10, D_{L_n}=10) and the daytime noise levels exceed the nighttime noise levels by 20 decibels, then there is a subjective difference of approximately 10 decibels. In this case the model implies that further reductions in nighttime noise would have virtually no effect on reactions to the overall noise.

Review of Past Research

Two sets of findings from a recent review of over 30 time-of-day noise studies (Fields, 1985a) are of importance for this report: findings about the value of the time-of-day weight and findings about assumptions in the adjusted energy model.

While there had been considerable discussion about time-of-day weights, it was found that optimum, best-fit estimates of the time-of-day weights were not available from any of the published analyses. Instead most previous analyses compared only two weightings (w_n=1 in LEQ and w_n=10 in LDN). Such analyses could only conclude that the best estimate would either be above or below an intermediate value. As significance tests were usually not applied to this procedure, it is not even known whether or not the differences were statistically significant. When the results from the different studies were compared they did not consistently support a particular value for the time-of-day weighting.

The review also considered the published evidence on several assumptions which are implicit in the adjusted energy model. The data were not precise enough to definitely confirm or reject the assumptions. Once noise level was controlled in the analysis, the data did not reject the assumption that response to similiar noise levels would be the same during the entire nighttime period. No evidence was found for a more distinct threshold for nighttime than for daytime annoyance.

Some data did however raise questions about whether nighttime responses are closely related to nighttime noise levels. One survey around Los Angeles International airport compared reactions when there were 50 flights a night with the reactions following changes in flight procedures which resulted in only occasional flights at night (Fidell and Jones, 1975). No change in nighttime reactions was found. A more detailed discussion of these findings is available in the previously mentioned review. For the purposes of this paper, the important point is that there is some doubt about the relationship between nighttime noise levels and nighttime response. The implication is that the present analyses should attempt to demonstrate that the reactions during a particular time period are a function of noise levels during that period and not simply a function of correlated variables, the noise levels during other periods.

Objectives of this Report

The previously mentioned review summarized the information which was available from existing publications. The research in the present report turns to original data sets with new analysis techniques to attempt to provide new information about the time-of-day weighting. The objectives of these analyses are the following:

1. To obtain estimates of the values of the time-of-day weighting and their 95% confidence intervals from available survey data.

2. To identify methodological factors which affect the validity and reliability of estimates of time-of-day weights.

3. To identify the times of day during which noise causes the greatest annoyance.

4. To measure the differences between annoyance responses for different time periods in decibel units.

5. To evaluate the validity of using results from such time-period annoyance responses to estimate time-of-day weights.

The first section of this report describes the data base. Next estimates of the time-of-day weights and their 95% confidence intervals are provided from multiple regression analyses. In these analyses the overall (24-hour) annoyance response is predicted from noise levels during time periods. This section on direct estimates of time-of-day weights concludes with an assessment of the methodology.

The remainder of the paper considers a different type of annoyance measure, a measure of annoyance during each specific time period. Such period-specific annoyance measures do not directly indicate how noise in each time period contributes to an overall assessment of annoyance during the entire 24-hour day. The first analyses in this section do, however, provide information about the times which are reported to be most annoying. The next analyses measure the gaps between responses in different time periods and express these annoyance differences in decibels. Finally, an assessment is made of the validity of interpreting these decibel values as time-of-day weights.

SYMBOLS AND ABBREVIATIONS

More details for noise indices and scales for acoustical measurements can be found in general noise references (e.g., Bennett and Pearsons, 1981).

a,c,g,h,q	Constants used in time-of-day models
A_j	Annoyance for period j
A_O	Overall noise annoyance for the total 24-hour period
B	Partial regression coefficient for time period (j) or noise index (I)
CNEL	Community Noise Equivalent Level, dB
CNR	Composite Noise Rating
D_j	Regression coefficient for dummy variable for period j
LDN	Day-night Average Sound Level
LEQ_j	Equivalent continuous sound level for period j, dB
L_I	Noise level for noise index I, dB
L_{ij}	Sound level of noise event i in period j. (Unless otherwise specified this is normalized to a 24-hour period. Thus it is the 24-hr. LEQ value for event i in period j. The relative sound pressure squared is thus $10^{L_{ij}/10}$).
M	Dummy variable used in regression analysis (M=1 if the observation is in the category).
N	Number of noise events
NEF	Noise Exposure Forecast

NNI_{10}	A noise index which is the same as the Noise and Number Index except that the number weighting is k=10 rather rather than k=15. The units of this index are labeled "decibels" in this report. The decibel unit label is satisfactory in this case because the label is applied to only small differences between noise levels in different time periods.
t_j	Number of hours in period j
WECPNL	Weighted Equivalent Continuous Perceived Noise Level, dB

Additional Subscripts

d	Daytime period
e	Evening period
i	A single noise event
I	Noise index I
j	A time period
k	A person
L	Noise level L
n	Nighttime period
O	Overall, 24-hour period

Time-period Weight Symbols

ADJD	Additive adjustment in decibel difference model, dB
ADJP	Additive adjustment in independent effect model, dB
D_{L_j}	Decibel value to be added to the single event sound level or a single hour LEQ for time j before being summed, (decibel weight), dB
w_j	Weight to be multiplied by number of events (N) or relative sound pressure squared ($10^{(L_i/10)}$) (number weight)

DATA FOR THE ANALYSES

The data used in the analyses presented in this report are drawn from 25 surveys of residents' responses to environmental noise. The surveys use a wide range of different types of questions to measure people's responses to noise (appendix A). The full titles for the surveys are given in appendix B together with reference numbers which are keyed to a catalog of surveys which contains a description of each survey (Fields, 1981). The primary analyses for this report are based on ten of these surveys for which the complete data sets are available in the noise survey archive at the NASA Langley Research Center. These are the only surveys which could be used in analyses relating to the first study objective, the estimation of time-of-day weights and the appropriate confidence intervals.

The ten primary surveys are described in tables I and II. From table I it can be seen that the 10 surveys include interviews from 21,928 people drawn from four countries. Aircraft, road traffic and railway noise sources are considered. For six of the surveys, evening noise levels are available as well as the nighttime levels. The definitions of evening and nighttime periods for the physical noise data are given in table I.

Characteristics of the physical noise level data which relate to the study designs are presented in table II for the ten surveys. The most important characteristic of the noise environments is summarized in the last four columns. The noise levels in the various periods are highly correlated. In no case is the correlation lower than r=0.81. In half of the studies the correlations are above r=0.90. These correlations are all between noise levels measured in decibels, not between the logarithmically transformed quantities which enter into the adjusted energy model. Nonetheless, the high correlations provide an indication that problems in multicollinearity are likely. Measures of arithmetic differences between the noise levels in the various time-of-day periods provide a similar indicator in the center columns of table II.

ANALYSIS OF OVERALL ANNOYANCE TO PROVIDE DIRECT ESTIMATES OF TIME-OF-DAY WEIGHTS

Direct estimates of the time-of-day weights come from an evaluation of the relationships between residents' annoyance (24-hour summary noise assessments) and the noise levels at different times of day. The values of the time-of-day weights can then be found which provide the best prediction of annoyance responses. The "best" value is defined as one which minimizes the squared errors in predicting annoyance scores.

The form of the relationship between total annoyance and the period noise levels is specified by a model which combines the period noise levels. Though several models will be discussed in a later section of this report, the most often used model is the conventional model discussed in the next section, the adjusted energy model.

Estimates of Parameters in the Adjusted Energy Model

The regression equation for predicting overall annoyance can be expressed in the following familiar form which parallels the earlier definition of the adjusted energy model:

$$A_O = a + B_I \bullet 10 \bullet \log_{10}(B_d \bullet \sum_{i=1}^{N_d} 10^{L_{id}/10} + B_n \bullet \sum_{i=1}^{N_n} 10^{L_{in}/10})$$

(To simplify the presentation of the model, only two periods have been represented here. In the data analysis, however, three periods (i.e. including evening) will be considered.))

The objective of the analysis in this section is to estimate the time-of-day weight which is the ratio of two of the coefficients:

$$w_n = B_n / B_d$$

As now presented the model is over-identified. There are only two independent variables but three slopes are being estimated B_I, B_d, and B_n. A unique value can not be identified for each parameter. A unique solution can be obtained if one of the parameters (B_d) is eliminated. If the sum of two of the partial regression coefficients is set to one ($B_d + B_n = 1$), then the equation can be written in terms of the daytime noise level (which in set to have a coefficient of one) and the nighttime regression coefficient (B_n) which is applied to the difference between the nighttime and daytime noise (DIF). This difference between the two noise levels is defined as:

$$DIF = \sum_{i=1}^{Nn} 10^{Lin/10} - \sum_{i=1}^{Nd} 10^{Lid/10}$$

The regression equation can now be written as:

$$A_O = a + B_I \bullet 10 \bullet \log_{10} \quad B_n x DIF + \sum_{i=1}^{Nn} 10^{Lid/10} /24$$

The nighttime weighting is now:

$$w_n = B_n / (1 - B_n)$$

The adjusted energy model is not linear in its parameters, thus a nonlinear, iterative regression procedure is used to find values of the parameters which give a best fit. Most of the analyses are based on the use of the Marquardt minimization technique to find values of the parameters which minimize the residual sums of squares. This technique is incorporated in the NONLINEAR REGRESSION program in version 8.3 of the Statistical Package for the Social Sciences (SPSS.., 1981). Some results were compared with those obtained from a modified Gauss-Newton method which is used in the P3R program included in the BMDP package of programs (Dixon, 1983).

The results from the total annoyance regression analyses are presented in table III for the dichotomous time-period analyses (day and night) and in table IV for the three-period analyses (day, evening, night). The total annoyance scales are of two types. The "Verbal" scales come from questions which present a set of verbal descriptors to the respondent. The 1967 Heathrow survey question is a typical verbal scale with four scale points:

> Please look at this scale and tell me how much the noise of the aircraft bothers or annoys you.
>
> [4] Very much
> [3] Moderately
> [2] A little
> [1] Not at all
>
> [The numbers in the brackets are the values assigned to each category for the analysis. The respondents do not in fact see the numbers.]

The "Numeric" scales come from questions in which only the end points of the scale are given verbal labels. The scale from the London traffic survey is a numeric scale:

> I want to ask you how you feel about traffic noise here where you live. Looking at this card would you tell me which number best represents how you feel?
>
> Definitely satisfactory 1
> 2
> 3
> 4
> 5
> 6
> Definitely unsatisfactory 7

The values for the partial regression coefficients and the standard errors of those coefficients are presented in the first two columns of data in table III. All standard errors are calculated using the jackknife repeated replication technique (appendix C). The estimate of the nighttime weight is presented in the next-to-the-last column of table III. The 95% confidence interval for this weight is calculated by transforming values of the nighttime partial regression coefficient which are 1.96 standard deviations from the estimated value ($B_n \pm 1.96 \cdot \sigma B_n$). (The rationale for basing confidence intervals on the nighttime partial regression coefficient rather than on the nighttime weight is provided in appendix D.)

The standard errors of the partial regression coefficients for the total noise index indicate that this coefficient is generally precisely estimated and highly statistically significant ($p<0.01$). The estimates of the nighttime partial regression coefficient are not as precise. The effect of this imprecision is evident in the large 95% confidence intervals for the estimates of the nighttime weight (w_n) in table III.

The estimates of the nighttime weights are the chief items of interest in table III. These estimates vary from -1.0 (1967 Heathrow study) to plus infinity (French Expressway Survey). Thus, the surveys do not provide similar estimates. The individual survey estimates are not precise. The "+∞" indicator in the last column for every survey shows that none of the surveys could identify an upper limit for a confidence interval for the nighttime weighting. The lower limit for the confidence intervals is negative for nine of the fifteen estimates. A negative value for the weight implies that increasing the nighttime noise reduces annoyance. Thus, nine of the fifteen estimates do not provide useful values for the lower 95% confidence interval.

The quality of the estimates of the nighttime weights can also be summarized with the coefficient of variation. The coefficient of variation is the standard deviation of a statistic divided by the statistic. Generally a coefficient of variation for the denominator of a ratio should be no greater than 0.1. The coefficients of variation in the last column of table III are in every case greater than 0.5. (The denominator of the ratio with which w_n is calculated was defined above as $1-B_n$. The standard deviation of $1-B_n$ is the same as for B_n.) The chief finding in table III is thus that no single survey provides a satisfactorily precise estimate of the nighttime weight.

The data which provide such poor estimates of the time-of-day weights are also being used to provide the estimates of the standard errors. Thus the estimates of the standard errors are also imprecise. It should thus be expected that such sampling errors will lead to occasional estimates of the standard errors which are much more or much less precise the estimates suggest. Given the similarity in the design of all the surveys, no particular survey estimate should be considered to be highly precise simply from the calculated value of the standard error. Thus it should not be assumed that the nighttime weight must be at least $w_n=4$ because one survey (Western Ontario) provides a lower confidence interval of $w_n=4$.

Estimates of evening weights are presented in table IV for the five surveys which calculated evening noise exposures. For these surveys the daytime period which was defined in table III has now been divided into two smaller periods, a daytime period and an evening period. The partial regression coefficients, time-of-day weights, standard errors and confidence intervals for these two periods are presented in the same form as in table III. The confidence intervals are so great in each case as to encompass both the estimate that response is totally controlled by the night (or evening) noise ($w_i=+\infty$) as well as the estimate that response is totally controlled by daytime noise ($w_i<0$). The sole positive value for the lower 95% confidence interval is only $w_i=0.5$ (British Railway Survey). The estimates from the individual surveys are thus again so inaccurate as to not be useful. The estimates do not provide a basis for determining whether there should be time-of-day weights. They do not help to determine whether evening or night is the more sensitive time period.

In an attempt to produce a useful summary of the study findings, the individual study estimates have been combined using six different methods in table V. The estimates of the nighttime weights come from nine of the weights, w_n, (first line of table V) is plus infinity because three of the studies in table III produced nighttime weight estimates of $w_n=+\infty$. The middle value (median) for the weights is $w_n=2.6$. The median, however, is only based on the middle value and does not take into account the pattern of dispersion about that central value.

The estimates of the nighttime weight in the remainder of table V are formed by averaging the nighttime regression coefficient (B_n) and then calculating the corresponding time-of-day weight from that average ($w_n = B_n/(1-B_n)$). This somewhat indirect approach has the advantage that averages are calculated on a statistic which has a relatively continuous distribution and a relatively normal sampling distribution (appendix D). The simple average of the 14 estimates of the partial regression coefficient provides an estimate of $w_n=1.6$. This estimate ignores the variation in the accuracies of the different study samples. A simple weighting by number of interviews gives an estimate of $w_n=2.8$, but still does not take into account any of the other study design factors which would affect the accuracy of the estimate. Conventionally, such factors can be accounted for by weighting study estimates by the accuracy of their estimates (the inverse of the variance). The next lines of table V show that this value depends on which variance is used to indicate accuracy. The variance of the partial regression coefficient ($\sigma^2 B_n$) provides a mean of 24.7. While the variance of the nighttime weights (σw_n) provides an estimate of $w_n=0.1$. (This is because the estimates of the parameters and their variances are not independent.) The inaccuracies in the estimates of these variances (noted earlier) mean that neither variance provides a good basis for weighting the study estimates.

All of the central tendency measures have deficiencies which are noted in the last column of table V. The range of estimates for mean values and the inaccuracies in the estimates from single studies (tables III and IV) suggest that the data do not provide any clear evidence about the value of the nighttime weighting.

Two possible methodological explanations for the inability to estimate the time-of-day weights will be examined in the next two sections. The possibility that other time-of-day models might more closely fit human responses will be explored first. The possibility that variations in the annoyance questions could be creating variations in the time-of-day weights will then be considered.

Comparisons with Alternative Models

Only the adjusted energy model has been used in noise regulations. Studies of residents' responses to noise have occasionally analyzed responses using either of two other models: the independent effect model or the decibel difference model. This work has been reviewed in an earlier publication (Fields, 1985).

With the first of these models, the independent effect model, it is assumed that the sensitivity to noise in any particular time period is unaffected by the noise levels in any other time periods. If there are differences in the sensitivity to the noise in two periods, this difference occurs because changes in noise levels in the sensitive period will have a greater impact on annoyance than changes in noise levels in the other period. The equation for predicting annoyance using this model is a simple linear multiple regression equation in which the noise levels for the periods are independent variables:

$$A_O = g + B_{L_d} \bullet L_d + B_{L_e} \bullet L_e + B_{L_n} \bullet L_n$$

A time-of-day adjustment for this model can be expressed in terms of the number of decibels in the daytime which would bring about the same change in annoyance as a single decibel in the evening or the night:

$$ADJP_e = \frac{B_{L_e}}{B_{L_d}} \qquad \text{and} \qquad ADJP_n = \frac{B_{L_n}}{B_{L_d}}$$

The second alternative to the adjusted energy model is the decibel difference model. In this model it is assumed that annoyance is independently affected by the noise level for the total 24-hour period (24-hour LEQ) and the number of decibels which separate the noise levels in the time periods. The model for two periods is the following:

$$A_O = h + B_{L_{24}} \bullet LEQ_{24} + B_{dn} \, (LEQ_d - LEQ_n)$$

A time-of-day adjustment for this model can be defined as the difference between the daytime and nighttime noise levels which is equivalent to a one-decibel effect of the 24-hour noise level (LEQ).

$$ADJD = \frac{B_{dn}}{B_{L_{24}}}$$

If the nighttime noise is more annoying, the adjustment would be negative. For this model an adjustment is subtracted from the 24-hour index (24-hour LEQ). The greatest adjustment is made when nighttime noise levels are low relative to the daytime levels.

The various nighttime models are compared in table VI. In the table the percentage of variance explained (R^2) by each of the models has been computed for 23 annoyance scales drawn from the ten surveys. As a point of reference, the results for LEQ and LDN are also presented. The value of the time-of-day adjustment which is appropriate for each model is found in brackets "[ ]" in each cell of the table.

The differences in the percentage of variance explained by the alternative models in table VI are small. For nine of the ten surveys the differences are less than one percent. Any weak patterns in the data do not support the alternatives to the adjusted energy model.

The time-of-day weights are fixed in LEQ and LDN. As a result in table VI the correlations for LEQ and LDN are slightly lower than for the remaining indices in which the time-of-day weighting is allowed to take on a value which is optimal for the particular data set. The independent effect model never produces the highest correlations with annoyance. The decibel difference and the adjusted energy models (two-period) perform equally well in table VI.

From table VI it is clear that the difficulties in estimating a time-of-day adjustment do not derive from the model; the adjusted energy model performs as well as the other proposed models.

Comparisons of Alternative Annoyance Questions

Estimates of the nighttime weights are compared for eight types of annoyance questions in table VII. The relevant comparisons in this table are between different types of questions for the same surveys.

An examination of the nighttime weights in table VII shows that there is not a relationship between the type of question and the estimate of the nighttime weight. This is true even when closely matched pairs of questions are compared in which one question explicitly refers to the daytime and the other explicitly refers to the nighttime (last four columns of table VII).

For example, though the 1967 Heathrow nighttime question yields a higher weight (w_n=2.6) than the daytime question (w_n=1.0), the England traffic survey displays exactly the opposite pattern in the next line: the question about sleep disturbance yields a lower nighttime weighting (w_n=2.6) than does a question about speech interference (w_n=3.0). Without a pattern for these explicit time-period questions it is understandable that no pattern emerged when the weights for the more standard "no time period implied" questions, the types of questions used in the previous analyses, were examined in the first three columns of table VII.

The results from table VII show that the estimates of the nighttime weighting presented earlier in this report have not been biased by the type of questionniare item or the division of the scales. A comparison of the estimates of the evening weightings in table IV leads to the same conclusion.

The fact that the explicit nighttime questions are not associated with high nighttime weightings is important. Since a question about nighttime annoyance does not lead to an index which heavily weights nighttime noise, then it should not be expected that a question about overall annoyance in the same study would be able to provide a satisfactory estimate of the weighting of nighttime noise.

Several explanations might be offered as to why a nighttime question does not elicit a high nighttime noise weighting. It may be that people are not sensitive to the amount of nighttime noise. This explanation can not, however, be tested because the large standard errors for the estimates of the nighttime weightings in the previous analyses have shown that the sensitivity of the population can not be established with the available data. There could could be important differences between responses to the different questions, but the standard errors of the statistics are so large that even quite large differences could not be reliably established with the existing data sets.

Sources of Inaccuracies in Estimates of Time-of-Day Weights

The standard errors of ratios of regression coefficients, such as the time-of-day weights, are a function of four broad categories of factors: human response characteristics, sample size, variation in the values of the independent variables (noise levels) and correlations between the independent variables. The first three factors have been present when parameters other than the time-of-day weighting have been successfully estimated by the surveys used in these analyses. The ability of all of the surveys to establish reliable relationships between overall noise levels and annoyance is demonstrated by the small standard errors for the total noise index partial regression coefficients in table III. In another publication several of the surveys provided relatively precise estimates of the relative effect of noise level and number of events (Fields, 1984).

One feature which sharply distinguishes these time-of-day analyses from other analyses is the high correlation between the independent variables. In table II it was seen that correlations between the independent variables (noise levels at different times of day) are as high as r=0.97 and never lower than r=0.82. The formula for estimating the standard errors of the time-of-day weights show that with such high intercorrelations it is impossible to create accurate estimates with economical sample sizes (Fields, 1985b: p.14).

The inaccuracy in the estimates has not been explicitly noted in previous survey publications because standard errors of estimates of time of day weights have not actually been calculated. Although an Australian study did attempt to determine whether the noise levels in each of the time periods had an independent effect on annoyance (Bullen and Hede, 1983), the study did not in fact test for the significance of the difference between different estimates (see discussion in appendix C).

The analyses presented up to this point show that direct estimates of time-of-day weights are not available from survey data. The remaining sections of the report examine the annoyance responses for particular time periods. The annoyance responses for the different periods are compared. The possibility of using these period responses as a basis for indirect estimates of time-of-day weights is explored.

ANALYSES OF MEASURES OF ANNOYANCE IN TIME PERIODS

People's feelings about noise in particular time periods can be measured with questions which ask them to either score or rank-order the annoyance felt during each period. Both types of questions refer to annoyance during specific time periods and thus differ from the questions examined in the previous section. In the previous section a single annoyance rating was obtained for the entire 24-hour period.

Initially, in this section, feelings about noise are examined to identify the times of day when people say they are most annoyed in residential areas, irrespective of noise level. Later sections introduce controls for noise levels and consider the conclusions which can be drawn from analyses of these time-period annoyance questions.

Rankings of Annoyance in Time Periods: No Control for Noise Level

In this section the presentations of annoyance responses without noise level make it possible to go beyond the 10 primary data sets at NASA to include data from additional surveys. Annoyance with noise during different times of day is presented for 21 questions drawn from 18 surveys in figures 1 to 6 and summarized in table VIII. The questions used in the 18 surveys vary considerably.

Key phrases from the questionniare items are used as labels to the left of each of the figures. The questionnaire items are reproduced verbatum in a separate section of appendix A.

Many of the most important differences between the questionnaire items are evident from the labels in the figures. When respondents are asked to rank the periods according to which period is worst (eg. 1961 Heathrow survey in figure 1(a)) the figures display the percentage of the sample which choose each time period as the most annoying. When respondents are asked to score each of the periods separately on a scale (eg. 1967 Heathrow survey in figure 1(b)) the figures display the average of the scores for each period.

The questions also differ in the number and definition of the periods which were presented to respondents. Two questions ask about only two periods (night and day) but the remainder ask about at least three periods. When information is available about hours which are to be included in the period, the hours are given below the figures (eg. 1961 Heathrow survey in figure 1(a)). If the periods are only defined by a verbal label then the labels are presented in quotation marks below a figure and the boundary between the periods is marked with a crooked line (eg. 1967 Heathrow survey in figure 1(b)). The numerical label is used as the figure label even if the time is only indicated in parenthetical instructions to the interviewer and may not have been read to each respondent.

The figures differ in whether or not percentages are presented for the number of respondents who say they are either never bothered by noise or always bothered. While noise conditions may have some marginal effect on the likelyhood of such responses, the major reason that the surveys differ is methodological. Some studies encourage such responses in the questionniare and report the results in publications while other studies may not make allowances for such responses in the questionnaire or may not report these responses separately.

It is not possible to determine exactly how respondents' answers are affected by the question wording or the number of time categories mentioned in the question. There is some indication that the restricted definition of night as the time when "you are trying to sleep" may reduce the number of people who select the nighttime period as the most annoying. Neither of the two surveys which used the "trying to sleep" definition had a plurality of respondents saying that nighttime was the most annoying period (1972 Heathrow and 1973 Los Angeles Nighttime).

The evidence also shows that the number of categories can affect ratings of periods. Figures 5(c) and 5(d) from the 1979 New York survey are based on questions about how people would allocate resources for noise control. The two questions differ only in the number of alternative time periods which was increased from two to three. While the definition of the nighttime period was unchanged in the two questions, the proportion of the resources respondents said they would want to allocate to nighttime noise decreased from 40% to 27%. This finding at least suggests the possibility that as a portion of the day is broken into smaller periods, the number of people who will choose some part of that portion as the "most annoying" period will increase.

From examining ratings of the most annoyed period in the figures, it is clear that respondents are not unanimous in their feelings about which period is worst or even about whether the periods differ from each other. In the 1961 Heathrow survey (fig. 1(a)) for example, there is a roughly even three-way split between those who say the evening is worse (25%), the night is worse (34%), and no time is bothersome (27%).

There is diversity between surveys in the time which is chosen as most annoying. When the 21 graphs in figures 1 to 6 are summarized in table VIII it is seen that in 5 cases the daytime is most annoying, in 8 cases evening is most annoying and in 7 cases the night is most annoying (there is one tie between evening and night). However, the five "daytime" cases include the only survey questions which do not offer an "evening" alternative (fig. 2.a, fig. 5.d), the only ones with the more restrictive "when you are trying to sleep" nighttime definition (fig. 1.c, fig. 2.a), and an open question which only asks about "times when you are disturbed most" without explicity mentioning the nighttime fig. 3.b). Of the remaining 15 surveys, in only one is the daytime period rated worst (fig. 4.c) and in the remaining 14 either the evening or nighttime is rated worst (two of these 14 are for "early morning"--0600 to 0900). There is thus some evidence that the evening and nighttime periods are rated worse than the daytime, but there is not a basis for choosing between the nighttime and evening periods.

One obvious explanation for the differences in annoyance rankings between surveys and between individuals within surveys is that the ranking of noise levels may differ. Nighttime noise might be relatively annoying in one survey because the noise levels were relatively high during the nighttime in that survey. This explanation will be the subject of the later analyses of period responses which include controls for noise level.

Difficulties in Interpreting Answers to Time-Period Annoyance Questions

A close consideration of the time-period annoyance questions reveals that the meaning of the "worst" periods which were identified above is not at all clear. Three questions drawn from the surveys in table VIII serve to illustrate the issues involved in interpreting the answers to time-period annoyance questions.

Q.#1 Do you find the aircraft bother you most during the morning (8-12), the afternoon (12-6), the evening

(6-11) or the night (11-8)?
[1961 Heathrow Survey]

Q.#2 When do you find the noise of an aircraft most disturbing around here: during the night when you are trying to sleep, during the evening, or during the daytime?
[1972 Heathrow Survey]

Q.#3 On this scale from 0 (not at all disturbed) to 10 (unbearably disturbed) how do you rate main road noise. . . indoors day/indoors evening/night. . . ?
[1978 Ontario Survey]

Difficulties in interpreting the answers to these questions occur partly because of ambiguities in the meaning of the questions and partly because of uncertainty about the factors which affect responses. Two ambiguities in the meaning of the questions will be discussed first.

Noise Entity The most serious ambiguity concerns the definition of the noise entity or unit which is being compared by the respondents. When a respondent is asked to compare the noise in two periods the comparison could be between any of the following five entities:

[Single event noise entities]

1) The single noise event which generated the worst reaction ever experienced during each period (ignore all other noise events).
2) The average noticed noise event in each period (ignore the number of noise events).

[Summed event noise-period entities]

3) The average hour during each period (ignore the length of the period).
4) The sum of the noise during each period (take into account the length of the period).
5) The sum of the noise for the portion of each period during which the respondent is normally at home.

Questions such as Q.#1 and Q.#3 could be interpreted in any of these five ways. The conventional wisdom, that nighttime noise which disturbs sleep is worse than daytime noise, is a statement about the two single-event types of noise entities. It seems likely that many people would make such an interpretation. These single event interpretations, however, do not provide information about how often annoyance is experienced or about the combined impact of all noise events during a period. It is only the later multiple event noise entities which are of direct interest for most policy purposes. Figures 1 to 6 only provide useful information about the period of day which generates the most annoyance if the respondents have interpreted the questions to refer to multiple event noise entities.

Analyses in the next section will relate these time-period annoyance measures to noise levels. However, the ambiguity in the meaning of the questions means that it is not possible to know which noise index should be used in the analyses. If the single event interpretation were correct (Entities 1 or 2), then some measure of the mean of the single event noise levels would be appropriate. If the "average hour" interpretation (Entity 3) is correct then a measure of the value of LEQ for the periods would be appropriate. If the "sum of hours" interpretation (Entity 4) is correct, then a measure of the sum of the hourly values of LEQ would be appropriate. If the "sum of the hours exposed" interpretation is correct then the sum of the hourly values of LEQ would need to be adjusted for the amount of time a respondent was at home.

Researchers do not agree on the interpretations of these questions. Very similiar time-period questions are interpreted differently in two studies. In the published analyses of the 1972 JFK Survey it is assumed that an "average hour" entity is rated (a doubling of annoyance is related to a doubling of numbers of events per hour) (Borsky, 1976, p.21). However, in a 1961 Heathrow Survey publication it is assumed that a "sum of hours" entity is rated (annoyance is related to differences in the total numbers of events during the periods) Wilson, 1963; p.251).

Question Q#2 (1972 Heathrow survey) was designed to remove part of the noise entity ambiguity by attempting to specify single events with the word "an" before the word "aircraft". The author concluded that this was too subtle a wording change to remove the ambiguities (Ollerhead, 1978). This experience suggests that it may not be easy to design a question which will be easily understood by all respondents.

Acoustic Observer Frame of Reference While the intent of the researcher is to measure the respondents' feelings about noise, some respondents may take the role of the objective observer of physical noise levels. In this case the respondent attempts to help the researcher by reporting when there is the greatest amount of noise.

Contamination of Feelings The wordings of the questions suggest that the respondent should only report feelings towards the noise experienced in a single period. The analyses similarly require that the period responses be causally independent of one another (see next section of this report). Careful consideration of the annoyance responses, however, suggests that other factors are likely to be very important.

The high intercorrelations between all annoyance indices and general presence of "halo" effects suggest that people form an attitude toward very broadly defined objects. Given this general feeling, people tend to have a similiar undifferentiated attitude toward all other similiar objects. It thus seems highly likely that many people have a general feeling toward the noise from a source and do not have separately defined feelings towards the noise at each time of day. A person's attitude or experience with the noise in one period will almost certainly contaminate feelings and bias reported responses toward the noise in another period. Thus even when a respondent is primarily affected by noise in the evening, the respondent's feelings about the evening noise are almost certain to lead to an annoyed response for the other periods. Such a contamination of feelings between periods would mean that differences in the true impact of the noise in different periods could not be accurately measured by period annoyance responses.

Conventional Wisdom Reflex The predominant conventional wisdom is that a noise is worst when it occurs at night. This provides a convenient, easy response for a respondent who does not take the time to carefully consider the sum total of his feelings to noise at different times of day. The conventional wisdom response is also the convenient, easy response for the respondent who is unsure about his own feelings and thus automatically reporting this conventional, normal, socially acceptable response.

Conclusions The four difficulties in interpreting time-period annoyance responses limit the usefulness of the data presented in figures 1 to 6. Interpretations of the meaning of the data should be made with care. There is some indication that noise annoyance is concentrated more in the evening and nighttime periods than during the daytime periods. However, the lack of total agreement on a worst period, means that there is an important amount of annoyance in all periods.

The difficulties in interpreting the period responses mean that they can not be used to draw conclusions about the impact of reducing noise at selected times of day. The period responses may, however, provide some indication of the priority that people think should be assigned to reducing noise at different times of day. The comparison of figures 5(b) and 5(c) provide some support for this proposition. The data in figure 5(c) come from an unusual, but policy-relevant, question about how noise control resources should be distributed at different times of day (ie. How many of each hundred dollars of noise control money should be allocated to each time period). For this sample near JFK airport, the choice was to allocate 31% of the resources to the daytime, 42% to the evening and 27% to the night. In the previous question, respondents had been asked a rather more typical period response question about the time when they most wanted to "stop aircraft noise completely" (fig. 5b). The percentage distribution rather closely matches the dollar allocation question, 29% selected the daytime, approximately 40% selected the evening, and approximately 32% selected the night. (Slight differences in the period boundaries introduce the uncertainty in specifying the percentages). The comparison of these two questions from this same survey thus gives some confidence that the period response questions are related to at least one policy consideration, people's beliefs about how noise control resources and effort should be divided between different time periods. However, even this finding should be qualified by the findings in figure 5d. When the question about the allocation of dollars shifts from two periods (fig. 5c) to three periods (fig. 5d) the percentage of dollars allocated to the same 9-hour nighttime period decreases from 40% to 27%. The time period ranking data clearly provide only a broad indication of the timing of annoyance.

Differences Between Period Responses Measured in Decibels

In this section the time-period response data are related to time-period noise levels and differences between period responses are expressed in decibel units. Of the eighteen surveys in table VIII it is only possible to include four surveys in this analysis, the four surveys for which time-period noise data are available.

Two different methods can be used to provide estimates of decibel differences in annoyance responses. For the first method, period ratings are related to period noise levels and then the annoyance by noise level relationships from each period are compared (Period Comparison Method). For the second method, the proportion of respondents ranking one of a pair of periods as worse is related to the differences between the noise levels in the two periods (Annoyance Ranking Method).

Annoyance Comparison Method The annoyance comparison method is based on an analysis of the relationship between annoyance and noise level in each time period. These relationships are plotted in figure 7-10 for four surveys. The data points on the figures are in each case based on the average annoyance and average noise level for respondents within a noise category (usually a 5 dB category). The relationships are summarized with a logistic curve which is estimated using least squares criteria in a nonlinear regression. The curve for a single time period can be described with the following equation:

$$A = \frac{1}{1 + e^{-[(a + l_j) \bullet B_j]}}$$

The curve is a logistic curve which is based on a cumulative logarithmic distribution. The curve has a sigmoid shape and is symmetric around the midpoint of the annoyance scale. If the annoyance variable is scored so that it ranges from zero to one then the curve is symmetric about the A=0.5 point with the two tails being asymptotic to A=0 and A=1. The intercept parameter, "a", locates the noise level (-a) where the curve passes through the midpoint, A=0.5. The B parameter is related to the partial derivative of the curve at the point A=0.5.

The distance between the annoyance responses is based on the distance between the curve for the daytime and the curve for each of the other time periods. In figure 8, for example, the noise level is measured in decibels and thus the distance between the curves can be directly expressed in decibels. Since the values of the slope parameters are very similiar for each period, an analysis was performed which forced all of the periods to have a single slope. A single regression equation was defined to analyze the complete set of data points. Dummy variables were introduced to represent the different time periods. In this case the equation is written:

$$A_j = \frac{1}{1 + e^{-[(a+L_j + D_e \cdot M_e + D_n \cdot M_n) \cdot B_j]}}$$

In this equation the dummy regression coefficients give the decibel displacement for the evening curve ($-D_e$) and nighttime curve ($-D_n$) from the daytime curve. The data in figures 7 to 10 were analyzed with this technique. The values of the dummy regression coefficients are given in each figure in decibel units.

One of the advantages of describing the noise-annoyance relationship with a logistic rather than linear relationship is that the analysis directly provides an estimate of the decibel displacement of the two curves. The logistic form also allows both curves to approach but not cross the zero annoyance axis. The analyses were also repeated with standard multiple linear regression techniques. For the linear regression analysis, a decibel displacement was calculated from ratios of time-period dummy variable partial regression coefficients divided by the noise level partial regression coefficient. The estimates of the decibel displacement were almost the same for the logistic and the linear regression analysis (within a decibel of each other).

Even though all of the differences are expressed in decibels, the values for different studies can not be directly compared since they refer to different lengths of time periods. A comparative analysis of the studies is presented as part of the discussion about converting period differences into time-of-day weights.

Each of the studies provides a relatively precise estimate of the decibel displacement of the dose-response relationships. The values for the dummy regression coefficients (logistic analysis) are significant beyond the p=0.01 level with standard errors of no greater than 0.5 dB for the Ontario and 1967 Heathrow surveys. (Standard errors could not be computed for the other surveys as only aggregated results are available.) This degree of precision shows that after controlling for noise level, respondents are consistently rating the evening and nighttime period as worse than the daytime period. This finding is consistent with the hypothesis that there is a greater sensitivity at night as well as with the "conventional wisdom reflex" hypothesis. It is also consistent with the "contamination of feelings" hypothesis; if people's feelings toward noise in the different periods are not highly differentiated, then the controls for noise level mean that the low noise level periods appear to have relatively high annoyance ratings. The critical issue for both the "conventional wisdom" and "contamination of feelings" hypotheses is whether the reactions in one time period can be shown to be a function of the noise levels in that time period and not of the noise levels in other time periods.

The correlations between the annoyance reactions in each time period and the noise levels in all three time periods have been calculated for the 1967 Heathrow survey and the 1978 Ontario survey. In general the annoyance reactions for a specified time period are as highly correlated with the noise levels in other time periods as with the noise levels in the specified time period. This occurs because the noise levels from the three periods are highly correlated. As a result the data do not provide a basis for estimating the independent effects of different time periods on annoyance and it is not possible to reject the "conventional wisdom" or "contamination of feelings" hypotheses. The substantive significance of the decibel differences found in figures 7 to 10 thus remains in doubt.

Annoyance Ranking Method The ranking of the relative annoyance during two periods can be obtained in either of two ways. The respondents' scores on two period-annoyance questions (eg. the types of questions analyzed in the previous section) can be compared to indirectly determine which period is worse. Alternatively the respondents may have directly indicated which period is worse on a question such as the following (1961 Heathrow survey):

> Do you find the aircraft bother you most during the morning, the afternoon, the evening or the night?

The relative ranking of the annoyance in two periods can then be compared to the differences in the noise levels of the two periods.

In figure 11 the proportion of the respondents who rated nighttime noise as worse than daytime noise is related to the differences in the daytime and nighttime noise levels for the 1967 Heathrow survey. (Respondents who said the two periods are equally annoying are excluded from this particular analysis but included in a later analysis and in Figure 13.) The data points in figure 11 represent mean annoyance scores for respondents who live in environments with similar differences in daytime and nighttime noise levels. The trend in the data is consistent with the expectation that the proportion choosing nighttime noise as worse will increase as nighttime noise levels increase relative to daytime noise levels. The central tendency is estimated with a nonlinear regression equation which describes the best-fit logistic curve. The form of the equation is the same as was used earlier to describe the annoyance levels in each period.

Noise from the two periods is assumed to be equally annoying at the point where the sample is evenly divided concerning which period is worse. This is considered to be an equal annoyance point. It is labeled the "50%" point in figure 11. The difference in noise levels at this point is then the measurement, in decibels, of the difference in reactions to the two times of day.

For the 1967 Heathrow survey in figure 11, the 50% point is reached at 16 dB (NNI_{10}). The best fit line is based on an analysis of the individuals' annoyance data. Thus the line is somewhat above the two right-most data points, which represent only a small number of interviews, but passes through the middle of the remaining points which represent the vast majority of the interviews.

Figure 12 includes the results from two additional surveys with the appropriate best-fit lines. The 1978 Canadian survey data come from the same time-period rating questions which appeared previously in figure 8. The railway data come from a single question about the most annoying time period (appendix A) which is quite similar to the 1961 Heathrow survey question which was reproduced earlier in this section. The large proportion of the railway study sample (75%) which reported the same annoyance for all time periods was excluded from this analysis. The 50% annoyance point for these surveys is reached at 6 dB (Railway) and 8 dB (Ontario Traffic).

Individuals who give equal annoyance ratings to both periods have been excluded from the ranking analyses up to this point. However, these responses can also provide information about the point at which noises in two time periods are subjectively equal. The highest rate of reporting equal annoyance should occur when the two noise levels are subjectively equal. In figure 13 the proportion who report equal annoyance in the 1967 Heathrow survey is plotted by the difference between daytime and nighttime noise levels. There is a weak trend toward higher reports of equal annoyance as the daytime and nighttime noise levels become more equal. The best fit quadratic equation for the data describes the line which is plotted in figure 13. The point of maximum perception of equal annoyance is the point of inflection for the parabola described by this equation, in this case at 3 dB (NNI_{10}). Figure 13 thus serves to illustrate another technique for estimating decibel displacements of annoyance responses, but does not provide a valid estimate since the predicted value (3 dB) requires extrapolation beyond the range of the collected data.

The numerical values of the decibel differences can not be accurately estimated with the available data using the relative ranking method. The data set which should provide the best estimates is the 1967 Heathrow survey. This study includes the widest range of noise level differences (figure 12) and has the largest number of interviews. A 95% confidence interval for the estimate of the 50% annoyance point has been calculated on the basis of an optimistic assumption. (It is assumed that the responses and noise measurement errors in the 171 selected study sites in the

Heathrow area are independent of one another.) The resulting confidence interval for the regression line is plotted graphically in figure 14. With the optimistic assumption, there is a lower limit (13 dB) but no upper limit to the estimate of the 50% annoyance point. The slope of the regression line for the 1967 Heathrow survey is significantly greater than zero ($p<0.05$). For both the railway and Canadian surveys, however, the slopes are not significantly greater than zero and thus the estimates of the differences in responses are not significantly greater than zero.

A number of other relative ranking analyses were carried out but have not been described in detail because in each case the estimates were so inaccurate as to not be useful. The weak relationship in the 1967 Heathrow survey (fig. 13) between noise level differences and amount of reported equal period annoyance is not statistically significant. Similar analyses for the Canadian and railway surveys did not find significant relationships. Similar analyses of the relationship between day-evening noise level differences and the amount of reported equal period annoyance also provided highly inaccurate estimates which are not statistically significant. Relative rankings of daytime and evening noise were also examined. There were not significant relationships for either the railway or Canadian surveys.

The inaccuracy in the estimates which is observed for the relative annoyance ranking method has the same source as did the inaccuracy in the estimates from the total annoyance regression method, the high correlations between noise levels at different times of day. The high correlations create the small amount of variation in the range of day-night differences which is evident in table II and for two surveys in figure 12. This lack of variation is in turn the major explanation for the inaccurate estimates.

Difficulties in Converting Period Differences into Time-of-Day Weights

The difficulties in interpreting answers to time-period annoyance questions create difficulties in interpreting the meaning of the displacements of the time-period annoyance curves. The importance of these problems becomes clearer if the numerical results are expressed in terms of the time-of-day weighting parameters.

The results of all the period response analyses are summarized in table IX. Part A summarizes the results from the period response dummy regression analyses (figures 7 to 10). The dummy regression coefficients presented in these figures appear in brackets "[. . .]" in the first two columns of data. Part B of the table summarizes the results from the respondent ranking analyses (figure 12). The noise level difference at the 50% annoyance point is the decibel quantity which appears in brackets in the first two columns in Part B.

The figures in brackets in the first two columns of the tables can be interpreted as the decibel weights (D_{L_j}). The value of the number weight, w_j, appears in each cell of table IX (not in brackets). As was discussed earlier, the decibel weight is a simple transformation of the number weight (the logarithm of the number weight multiplied by ten).

The interpretation and in fact meaningfulness of these time-of-day weights is in doubt because of the ambiguities in the definition of the "noise entity" which the respondents were actually rating (see the earlier discussion of "noise entity" in the section on "Difficulties in Interpreting Answers to Time-Period Annoyance Questions"). If respondents were rating three of the five noise entities, then the present noise data are inadequate for deriving an estimate of the time-of-day weight. If the respondents were rating a single noise event or an average of the single events, then the time-of-day estimates in table IX are meaningless since these estimates are based on noise indices which include numbers of noise events as well as the levels of those events. Similar problems arise if the "noise entity" which the respondents were actually rating is the sum of the noise for only the portion of the day when the respondent is at home. Measures of noise exposure are not restricted to times when the respondent is at home, thus a weighting for this noise entity can also not be derived.

Estimates for time-of-day weights can, however, be formed for the remaining two of the five noise entities. If the "average hour" during each time period is being rated then the time-of-day weights are as presented in the first two columns of data in table IX. If, on the other hand, it is the "sum of the noise" which is being rated (ie. respondents consider the length of the time periods) then the time-of-day weights are as presented in the last two columns of data in table IX. In this case the differences in noise levels which were measured in terms of an average noise level during the periods (LEQ) must now be increased by a factor which reflects the relative length of the daytime and other time periods:

$$D_{L_j} = LEQ + 10 * \log_{10} (t_d/t_j)$$

(This issue is discussed in more detail in an earlier publication, Fields, 1985a). The values for the day or evening weights in the last two columns of table IX are always greater than those in the preceeding two columns, because the daytime period is longer than either of the other periods.

The results from the "period response" analyses in Part A in table IX can be compared with those from the "respondent ranking analyses" in Part B. Both the Heathrow and Canadian surveys appear in both parts of the table. The estimates of the time-of-day weights from the two analysis methods are quite similar, within two decibels, even though the comparison is complicated by the use of three time periods in Part A but only two periods in Part B of the table.

The estimates of the time-of-day weights in table IX are all positive. Thus, after the possible effect of period noise level differences are removed, respondents give a more annoyed rating to the noise level in these "sensitive" periods than to the daytime.

The estimates of the size of these positive time-of-day weights vary considerably, from a high of w_n=60 (D_{L_n}=18 dB) to a low of w_n=2 (D_{L_n}=3). This inconsistency is due to the uncertainties about the noise entities being rated and to differences between surveys.

The effects of uncertainties about the noise entities can be assessed by comparing the estimates of the weights in the last two columns of table IX with those in the preceeding two columns. To take the worst case, the value of the evening weight for the Canadian survey increases from an unimportant w_e=1 to an important w_e=7 (D_{L_e}=1 dB to D_{L_e}=8 dB) when it is assumed that respondents are considering the length of the time periods. The consideration of the noise entity also affects conclusions about the relative size of evening and nighttime weights. If respondents are only considering the average hour then nighttime is the more sensitive period. If, on the other hand, respondents are considering the length of the periods (sum of the exposures), then the evening is equally sensitive (Canadian survey) or more sensitive (Heathrow survey). In short, the unresolved ambiguity in the definition of the noise entity affects important conclusions.

The estimates of the time-of-day weights are also not consistent across surveys. The estimates of the nighttime weight in the last column (Part A), for example, vary from w_n=65 to w_n=4. The 1967 Heathrow survey estimates are substantially higher than those from the other four surveys. Neither set of estimates can be dismissed. The Heathrow results come from only a single survey, but it is the survey with design characteristics which should yield the best estimates (largest sample size and a wider range of noise level differences). The estimates from the other four surveys are rather similar to one another, but their individual estimates are based on weaker study designs.

CONCLUSIONS

The relative importance of noise at different times of day has been examined through analyses of the relationship between overall annoyance and time-period noise levels and through analyses of time-period annoyance measures. These analyses have led to the following conclusions about survey evidence on the relative importance of noise at different times of day.

1. Available social surverys do not provide valid, reliable estimates of the relative weighting for noise levels during different times of day which will best predict overall (24-hour) noise annoyance. The estimates from the surveys are so inaccurate that they do not aid in choosing between the various time-of-day weighted noise indices or even between the weighted (eg. LDN) and the unweighted indices (eg. 24-hour LEQ).

2. The estimates are highly unreliable because the day and night noise environments included in the studies are highly correlated. There is no evidence that these estimates are biased by the type of annoyance question used. There is no evidence that annoyance would be better explained by models other than the adjusted energy noise reaction model.

3. Analyses of time-period annoyance measures suggest that annoyance is greater in residential areas during evening and nighttime periods.

4. Evening and nighttime reactions are greater than daytime reactions to the same time-period noise level, but the estimates of the decibel equivalent of this difference in reactions are not found to be consistent in the different surveys. The estimated decibel equivalent of this time-period annoyance difference varies from 1 dB to 18 dB, depending on the survey. The relative importance of evening compared to nighttime noise can not be established.

5. Results from time-period annoyance analyses can not be used to derive valid estimates of time-of-day weights. The time-period annoyance measures can not provide direct evidence about the relationship between overall annoyance and time-period noise levels. The time period annoyance measures are also flawed by ambiguities in the definitions of the noise entity which is rated, by the possibility that some respondents report acoustical facts about noise rather than their feelings, by the contamination of feelings about one time-period by feelings in another time period, and by the possibility that the conventional wisdom about the importance of nighttime noise, rather than an equal feeling, is being reported.

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APPENDIX A:

ANNOYANCE SCALES

The annoyance scales are presented under three broad headings which parallel the three types of analyses used in this report: Overall Annoyance Scales, Period Annoyance Rating Questions, Annoyance Ranking Questions. All of the questions which appear in Figures 1 to 6 are presented in the Annoyance Ranking section. The numbers which appear in parentheses by each answer category are the values which are used in quantitative analyses.

OVERALL ANNOYANCE SCALES

Verbal Category Scales

1. (1967 Heathrow Survey)
"SHOW CARD A: Please look at this scale and tell me how much the noise of the aircraft bothers or annoys you (ORDINARY FLIGHTS NOT SONIC BOOM) (4) Very much, (3) Moderately, (2) A little, (1) Not at all."

2. (England Traffic Survey)
"Altogether, how much are you bothered or disturbed by the noise of road traffic when you are indoors at home? Does it bother you. . . (4) Very much, (3) quite a lot, (2) not very much, (1) or not at all."

3. (1975 South Ontario)
"How would rate the overall noise in this neighborhood? (1) Extremely Agreeable, (1) Considerably Agreeable, (1) Moderately Agreeable, (1) Slightly Agreeable, (1) Neutral, (2) Slightly Disturbing, (3) Moderately Disturbing, (4) Considerably Disturbing, (5) Extremely Disturbing." [The top two categories, "considerably" and " extremely", define high annoyance for the dichotomous high annoyance scale.]

4. (1976 South Ontario, and 1978 Ontario)
"Here is a list of common sounds (you have already mentioned some). Do you ever notice any of these (any of the others)? "How do you rate each of the sounds you have mentioned... main road traffic...? (1) Extremely Agreeable, (1) Considerable Agreeable, (1) Moderately Agreeable, (1) Slightly Agreeable, (1) Neutral, (2) Slightly Disturbing, (3) Moderately Disturbing, (4) Considerably Disturbing, (5) Extremely Disturbing". [The top two categories, "Considerable" and "Extremely", define the high annoyance for the dichotomous high annoyance scale.]

5. (French Expressway) English Translation
"Are you: (1) not at all disturbed, (2) hardly disturbed, (3) rather disturbed, (4) highly distubed, by the noise of the means of transportation?"

["Etes-vous : (1) pas du tout gene, (2) peu gene, (3) assez gene, (4) tres gene, par le bruit moyens de transport?]"

6. (British Railway Survey)
"Does the noise of the trains bother or annoy you: (4) Very much, (3) Moderately, (2) A little, (1) Not at all?"

Numeric Scales

1. (USA Nine Airport Survey)
This thermometer scale has labeled end points. "How much are you bothered or annoyed by aircraft noise?...Extremely 4 3 2 1 0 Not at all." [The top category is used to define annoyance for the two-category measure of high annoyance.]

2. (England Traffic Survey)
"...how do you feel about the amount of noise here <u>from cars or lorries or other road traffic</u>?...Definitely satisfactory 1 2 3 4 5 6 7 Definitely unsatisfactory?"

3. (1976 South Ontario)
"Please indicate the level of disturbance caused by the ... main road traffic noise ... by rating your disturbance on a scale of 0 to 10, where 0 indicates not at all disturbed, and 10 indicates unbearably disturbed. Please put your rating in the first box, marked overall."

4. (1978 Ontario Survey)
"On this scale from 0 (not at all distubed) to 10 (unbearably disturbed) how do you rate main road traffic noise and the overall noise?"

5. (Western Ontario Traffic)
How annoyed are you by. . . traffic noise. . . when you are home? (Card C)" [Card C has a format similar to the following]

Not at all Annoyed			Moderately Annoyed			Very Annoyed
1	2	3	4	5	6	7

6. (British Railway Survey)
"Please look at this scale and tell me how you feel about the amount of noise here from passenger, goods, and other trains?...Definitely Satisfactory 1 2 3 4 5 6 7 Definitely Unsatisfactory."

Indices Created From More Than One Question

1. Summed annoyance index (British Railway Survey)
This index is based on the average of a respondent's ratings

on two verbal category scales (including the one in this appendix) and three numerical rating scales (one is in this appendix). All refer to annoyance with railway noise generally. (Fields and Walker, 1982: p. 254)

2. Activity interference index (USA Nine Airport Survey)
This activity index is based on the sum of the annoyance expressed on nine activity items. Each item is scored from 0-4 depending on how much the person is annoyed by the particular interference (see numeric scale in this appendix). The nine items are the following: relaxing or resting inside, relaxing outside, sleeping, conversation, telephone conversation, listening to records or tapes, listening to radio or TV, reading or concentration, and eating. There are some differences in the sleep questions and TV questions between the three phases of this study but these are small enough that they should not have affected the way the total scale relates to annoyance at different times of day.

3. Activity interference index (1967 Heathrow Survey)
One point is scored for any annoyance on the verbal category scale and for each activity upon which a particular level of annoyance is reported.
Part 1: "Do the aircraft ever...(wake you up; interfere with listening to radio or TV; make the house vibrate or shake; interfere with conversation; interfere with or disturb any other activity or in any other way)?"
Part 2: "When they...how annoyed does this make you feel? Very, moderately, little, or not at all?"
(For wake you up and interfere with conversation, responses of "moderately" or "very" annoyed are scored "1". For each of the remaining activity interference questions any annoyance is scored "1".)

PERIOD ANNOYANCE RATING QUESTIONS

1. (1967 Heathrow Survey)
"I would like you to tell me at what times of the day you find you are usually most bothered by aircraft during the week. (SHOW CARD B) Let's take the morning first: please look at this scale and pick out the number which indicates how bothered or annoyed you feel during the morning.
And how about the afternoon? /Evening?/At night after you have gone to bed?...Very much bothered 7 6 5 4 3 2 1 Not at all bothered"

2. (1978 Ontario)
"On this scale from 0 (not at all disturbed) to 10 (unbearably disturbed) how do you rate main road traffic noise?...indoors day/indoors evening/night?"

3. (1978 Zurich Road Traffic Survey) <u>English translation</u>
"Let us assume that these are thermometers with which the

degree of disturbance can be measured. The number 10 means that you are almost unbearably disturbed, the number 0 that you are not disturbed at all.
We would now like to find the disturbance experienced by you. Please mark on the first thermometer the disturbance experienced by you during the day, on the second the one experienced during the night. (Please simply mark the corresponding number)." (10 = extremely annoying, 0 = not at all disturbing)

["Nehmen wir an, dies waren Themometer, mit denen man messen kann, wie stark man sich durch den Verkehrslarm gestort fuhlt. Die marke 10 bedeutet, dass man fast unertraglich gestort ist, die Marke 0, dass man uberhaupt nicht gestort ist.
Wir mochten nun die von Ihnen zu hause empfundene Storung erfassen. Wurden Sie bitte auf dem ersten Thermometer die von Ihnen tagsuber empfundene Storung eintragen, auf dem zweiten Thermometer diejenige Storung, die Sie in der Nacht empfinden. (Bitte einfach bei der entsprechenden Zahl ankreuzen)."(10 = stort unertraglich, 0 = stort kein bisschen)]

4. (1979 French Road Traffic Survey)
"At night (...During the daytime...) do you find the traffic noise is very annoying, fairly annoying, a little annoying or not at all annoying?"

["Dans la journee, estimez-vous que le bruit de la circulation est: tres genant, assez genant, peu genant, pas du tout genant?"]

["La nuit, trouvez-vous que le bruit de la circulation est: tres genant, assez genant, peu genant, pas genant du tout?"]

ANNOYANCE RANKING QUESTIONS (figures 1 to 6)

(The questions are identified by figure number and presented in the order in which they appear in the figures.)

Fig. 1a. 1961 Heathrow Aircraft Noise Survey
"Do you find the aircraft bother you most during the morning (6-12), the afternoon (12-6), the evening (6-11) or the night (11-8)?"

Fig. 1b. 1967 Heathrow Aircraft Noise Survey
(See Period Annoyance Rating Questions)

Fig. 1c. 1972 Heathrow Aircraft Noise Survey
"When do you find the noise of an aircraft most disturbing around here: during the night when you are trying to sleep, during the evening, or during the daytime?"

Fig. 1d. 1971 Gatwich Aircraft Noise Survey
"I would like you to tell me at what times of the day you find you are usually most bothered by Aircraft during the Week (Monday to Friday). (SHOW CARD B) Let's take the morning first...Please look at this scale and pick out the number which indicates how bothered or annoyed you feel during the Morning (6-12 am)/Afternoon (12-6 pm)/Evening (6-11 pm)/Night (11-6 am)...?

Very much bothered	7	6	5	4	3	2	1	Not at all bothered"

Fig. 2a. 1973 Los Angeles Airport Nighttime Study
"Does aircraft noise annoy you more when you are trying to sleep at night or does it annoy you more at other times during the day?"

Fig. 2b. 1970 USA Airport Survey (Two small airports)
"What times of the day do you particularly notice aircraft noise?...WEEKDAYS...Morning (6-9,9-12), Afternoon (12-3,3-6), Evening (6-9,9-12), Night (12-3,3-6)."

Fig. 2c. 1980 Australian Five Airport Survey
"Suppose you were able to have aircraft stopped from flying over in one of these 3-hour periods (SHOW CARD E), which one would you <u>most</u> like to have free from aircraft noise?"

Fig. 2d. 1972 JFK Airport Noise Survey
"During weekdays are you usually at home during most of the... (day from 7:00 am to 7:00 pm/evening from 7:00 to 11:00 pm/ night from 11:00 pm to 7:00 am) [If yes, Ask "A"]

A. Using the Degree Scale, could you tell me how much the noise from airplanes bothers or annoys you during the ...day/evening/night ...?Very much 4 3 2 1 Not at all"

Fig. 3a. 1975 Western Ontario Traffic Noise Survey
"Around this time of year, how annoyed are you by traffic noise during the following time periods <u>in the week</u> (Mon - Fri) when you are home?. . . [CARD C has a format similar to the following]

Not at all annoyed			Moderately annoyed			Very annoyed
1	2	3	4	5	6	7

Fig. 3b. 1967 Southern Ontario Traffic Noise Survey
"What days and times are you disturbed most? [Main Road Traffic Noise]"

Fig. 3c. 1978 Ontario Survey
On this scale from 0 (not at all disturbed) to 10 (unbearably disturbed) how do you rate main road noise...indoors day/indoors evening/night?

Fig. 3d. 1974 USA 24-Community Survey
"Is noise in your neighborhood more annoying at one time of day than another? [Morning, Afternoon, Evening, Night]"

Fig. 4a. 1971 Swiss Three City Airport Survey English translation
"At what time during day or night does airplane noise bother you most? In early morning (0600 to 0800 am), During forenoon (0800 to 1200), During noon (1200 am to 1400 pm), In the afternoon (1400 to 1800 pm), In the evening (1800 to 2200 pm), At night (2200 pm to 0600 am), Always the same, I don't know."

["Zu Welcher Tages- Oder Nachtzeit Stort Sie Der Fluglarm Besonders? Am Morgen (06-08h), Am Vormittag (06-12h), Am Mittag (12-14h), Am Nachmittag (14-18h), Am Abend (18-22h), In der Nacht (22-06h), Immer gleich, Weiss nicht"]

Fig. 4b, 4c. 1977 Zurich Street Traffic Noise Survey,
1976 Zurich Street Traffic Noise Survey
English Translation
"You know that may people today are disturbed by traffic noise. How is your situation, are you bothered at home by traffic noise?...frequently, occasionally, seldom, never. If "frequently", "occasionally" or "seldom", at what time does traffic noise disturb you the most? (only one entry, please) in the morning (6-9), during the day (9-19), evenings (19-22), nights (22-6). (Note: the division between evening is 2300 in 1976)."

["Sie wissen ja, dass heute viele Leute durch Verkehrslarm gestort werden. Wie steht es bei Ihnen, Werden Sie zu Hause durch Verkehrslarm gestort?...haufig, gelegentlich, selten, nie."

["Wenn "haufig", "gelegentlich" oder "selten", zu welcher Zeit stort Sie der Verkehrslarm am meisten? (Bitte nur eine Nennung) vormittags (6-9), tagsuber (9-19), abends (19-22), nachts (22-6).]"

Fig. 4d. 1978 Zurich Time-of-day Road Traffic Noise Survey
"At what time of the day or night do you experience the disturbance by traffic the most? When next to most? (Please only one mark each)...early in the morning (04-06), in the morning (06-08), during the day (08-19), early in the evening (19-22), late in the evening (22-24), at night (24-04), always the same,...the most, next to most!"

["Zu welcher Tages-oder Nachtzeit empfinden Sie die Storung durch den Verkehrslarm am meisten? Zu welcher am zweitmeisten? (Bitte je nur eine Nennung)... am fruhen Morgen (04-06), am Morgen (06-08), tagsuber (08-19), am fruhen Abend (19-22), am spaten Abend (22-24), nachts (24-04), immer gleich"]

Fig. 5a. JFK Questionnaire Development Survey (Annoyance measured hourly with 20 point scale)
"Now I would like you to tell me in a different way about the times during which you are [usually annoyed by airplane noise]. SHOW CATEGORY SCALE. This line (POINT) represents a twenty-four hour period. The line is divided into one hour periods, and for convenience we have marked the positions of 6 AM, noon, 6 PM and midnight. the vertical line of the left (POINT) represents your degree of annoyance. I would like you to tell me how annoyed you usually are by airplane noise during each hour of the day and night. for each one hour period I would like you to draw vertical line whose length indicates the degree of annoyance during that hour. Use the scale on the left as your reference. For example, in order to indicate your annoyance during the periods from 10-11 AM, you would draw a line starting at the 10 AM mark. The length of the line represents your degree of annoyance during that hour. A line going all the way to the top represents the maximum degree of annoyance. this line (show line) represents a medium degree of annoyance. If you are not usually annoyed by airplane noise during a particular hour, then you would draw no line at that hour. that would indicate zero degree of annoyance. Do you have any questions?"

Fig. 5b. (Annoyance measured in top priority for eliminating noise)
"Here is a list of 12 two-hour periods. HAND LIST. Imagine that the aircraft noise in this neighborhood could be stopped completely for a single two-hour period. In every other respect, the amount of noise would be unchanged. Pick the period which you would want most of all to be quiet. OBTAIN RESPONSE. Put a '1' next to that period on the sheet. Now suppose aircraft noise couldn't be stopped during that period. What period would you choose instead? Put a '2' next to that period on the sheet. OBTAIN RESPONSE. Now continue with this through the remainder of the list, ranking of periods in the order in which you would most like them to be free of noise."

Fig. 5c. (Annoyance measured in $100 to reduce noise (two periods))
"Q. Now let us imagine that someone were to spend money on reducing aircraft noise in this community. Out of every $100.00, how much would you want spent on reducing noise between 10 PM and 7 AM and how much would you want spent on noise between 7 AM and 10 PM?"

Fig. 5d. (Annoyance measured in allocation of $100 to reduce noise (3 periods))
"Q. Now divide the day into three periods: 7 AM - 7 PM, 7 PM - 10 PM, 10 PM - 7 AM. How would you divide 100 dollars?"

Fig. 6 1975 British National Railway Noise Survey
Q A "Do you find the train noise is more annoying at certain times of the day or is it always the same?

IF MORE ANNOYING AT CERTAIN TIMES

Q B "At what time do you find the train noise <u>most</u> annoying? (Morning 8-12 am, Afternoon 12-6, Evening 6-11 pm, Night 11-8, All equally, Evening and night)"

APPENDIX B:

LIST OF SURVEYS USED IN ANALYSES

[The six digit identification number preceeding each survey title is the identification number used in a catalog of social surveys of noise annoyance (Fields, 1981).]

UKD-008	1961 Heathrow Aircraft Noise Survey (First Heathrow Survey)
USA-022	1967 U.S.A. Four Airport Survey (Phase I of TRACOR Survey)
UKD-024	1967 Heathrow Aircraft Noise Study (2nd Heathrow Survey)
USA-032	1969 U.S.A. Three Airport Survey (Phase II TRACOR Survey)
USA-044	1970 U.S.A. Small City Airports (Small City TRACOR Survey)
UKD-052	1971 Gatwick Airport Noise Survey
SWI-053	1971 Three City Swiss Noise Survey
USA-059	1972 JFK Airport Noise Survey
UKD-061	1972 Heathrow Airport Noise Pilot Survey
UKD-071	1972 B.R.S. London Traffic Noise Survey
UKD-072	1972 English Road Traffic Survey
USA-082	1973 Los Angeles Airport Night Study
FRA-092	1973 French 10 City Traffic Noise Survey
USA-102	1974 U.S.A. 24 Site Community Noise Survey
UKD-116	1975 British National Railway Noise Survey
CAN-120	1975 Western Ontario University Traffic Noise Survey
CAN-121	1975 Southern Ontario Community Survey
CAN-121	1976 Southern Ontario Community Survey
SWI-133	1976 Zurich Street Traffic Noise (Apartments) Survey
SWI-158	1977 Zurich Pilot Traffic Noise Survey
CAN-168	1978 Canadian Four Airport Survey
SWI-173	1978 Zurich Time-of-Day Survey
FRA-197	1979 French Behavioral Effects of Road Noise Study
AUL-210	1980 Australian Five Airport Study [Not in 1981 catalog]
XXX-820	JFK Time-of-Day Annoyance Measurement Development Study [This survey is not included in the 1981 catalog]

APPENDIX C:

SAMPLING ERROR COMPUTATIONS

All of the surveys described in this report are based on area samples in which there is a clustering of respondents into areas. Some of the samples are probability samples and some are purposive samples of different types of areas. All studies have multiple selections within each selected study area. Previous publications have reported that after the effects of noise level are removed, there is evidence that area of residence affects response (Fields and Walker, 1982; Fields, 1982; Fields, 1984: p. 462). Sampling error calculations must take into account that clustering of responses. In this report all estimates of sampling errors are based on a pseudo-replication technique, jackknife repeated replication. The technique is described by Kish and Frankel (1974). For the studies in this report each study is assumed to be independently selected. Estimates of the sampling variance are thus based on the extent to which estimates of a parameter vary when whole study areas are excluded from the sample.

None of the previous studies have calculated standard errors of estimates for estimated time-of-day weights. The report on the Australian study did however identify the difficulties which occur when the noise levels in different time periods are higly correlated (Bullen and Hede 1983). The analysis techniques which were used do not, however, provide estimates of the significance of the differences between different weightings. The text of that article refers to the significance of differences between indices which have different daytime and nighttime weightings. However, the appendix to the article indicates that the only tests were for the significance of the partial regression coefficients (ie. whether the partial regression coefficient is significantly different from zero). Thus there is not a direct comparison of differences between the predictive powers of different indices.

The Australian analysis also is based on simple random sampling assumptions. The analyses reported in the first paragraph of this appendix indicate however that simple random sampling assumptions are not justified because responses and the residuals of annoyance responses are found to cluster by sampling areas (e.g. airports or study areas). The part of the Australian report which calculates sampling errors on simple random sampling assumptions thus provides unrealistically precise estimates of the sampling errors. The true sampling errors are likely to be very high because, as the authors of the report state, the effects of airports are confounded with the effects of noise level:

> ". . .in controlling for airport, one would also be 'controlling out' most of the variation in time-of-day exposure, so that the analysis would become extremely insensitive." (Bullen and Hede, 1983: p. 1627)

In other words, when the possibility of area effects are considered the estimates of time-of-day effects become quite inaccurate, just as has been reported in the body of the present report.

APPENDIX D:

INTERVAL ESTIMATES OF THE PARAMETERS OF THE ADJUSTED ENERGY MODEL

The "Adjusted Energy Summation Model" is based on the following model for the relationship between annoyance, as a dependent variable, and daytime and nighttime noise levels as predictor variables:

$$(1) \quad A = \beta_o + \beta_I \bullet \log_{10}[(\beta_d \Sigma \log_{10}{}^{-1}(Leq_d/10) + \beta_n \Sigma \log_{10}{}^{-1}(Leq_n/10))/24] + \varepsilon,$$

where, β_o is the intercept, β_I is the slope for the equation relating annoyance to the weighted noise level, and ε is a random disturbance term. The parameters β_d and β_n reflect the relative importance of the daytime and nighttime components of the overall noise exposure.

The model can be re-parameterized in terms of the ratio of the two noise coefficients, w_n, sometimes referred to as the nighttime weighting:

$$(2) \quad w_n = \beta_n/\beta_d,$$

in such a way as to make the parameters unique. This is achieved by dividing both β_n and β_d by the constant, βd. This results in the following expression for the model:

$$(3) \quad A= \beta_o + \beta_I \bullet \log_{10}[(\Sigma \log_{10}{}^{-1}(Leq_d/10) + w_n \Sigma \log_{10}{}^{-1}(Leq_n/10))/24] + \varepsilon,$$

where the intercept, β_o has also been re-defined appropriately.

Model (3) is non-linear multiple regression model. Least squares estimates of the parameters of this model can be achieved via iterative algorithms. See, for example, Neter, Wasserman and Kutner (1984: Chapter 14).

Estimates of model parameters obtained using the iterative techniques described by Neter, et.al. have asymptotically normal sampling distributions. This allows for the formation of interval estimates using normal theory and jackknife estimates of standard errors. However, these intervals are valid asymptotically as the sample size gets large. Since one never has an infinite sample, it is necessary to check the validity of the normal approximation for the sampling distribution in the finite case. To this end, a small simulation study was conducted.

First, 200 observations were generated for a set of two predictor variables, referred to here as DAY and NIGHT. These were generated using the random number generator within the TRAN paragraph of BMDP. The goal was to mimic, as much as possible, the distribution of the Leq/10 scores in existing studies. The resulting distribution of these two variables was approximately bivariate normal, with means 5.70 and 5.28 and standard deviations 0.92 and 1.17 for DAY and NIGHT, respectively. The correlation between these scores was -0.096. To mimic the model given in equation (1), dependent variables, A_i were generated using the following model:

$$(4) \quad A_i = \beta_o + \beta_L \bullet \log_{10}[\beta_n\ 10^{NIGHT_i} + 10^{DAY_i}] + \varepsilon_i, \text{ where}$$

$$\beta_o = -2.7,\ \beta_L = 0.67,\ \beta_n = 2.33, \text{ and } \varepsilon_i \sim \text{Normal } (0, \sigma_\varepsilon = 1.75).$$

Note that the simulation model described in equation (4) is of the same form as that described in equation (2), with independent variables, NIGHT and DAY defined in the obvious manner. Twenty independent observations of the dependent variable A_i were generated for each of the 200 pairs of independent variables described above. Thus, there were 20 independent replications of model (4) based on the same joint distribution of independent variables.

Each of the 20 independent replications were analyzed using the nonlinear regression procedure in BMDP, program 'P3R' (Dixon, 1983). The results are presented in the table below:

TABLE OF ESTIMATES

Rep. no.	$\widehat{w_n}$	$\widehat{\beta_n}$
1	1.758	0.637
2	4.338	0.813
3	0.483	0.326
4	1.303	0.566
5	7.187	0.878
6	0.423	0.297
7	0.845	0.458
8	2.419	0.708
9	3.131	0.758
10	23.435	0.959
11	2.565	0.719
12	1.986	0.665
13	4.865	0.829
14	2.930	0.746
15	6.896	0.873
16	1.468	0.595
17	3.359	0.771
18	4.009	0.800
19	2.569	0.720
20	8.729	0.897
Mean	3.998	0.690
Std.Dev.	5.077	0.178

The column labelled $\widehat{w_n}$ representes the estimates of the nighttime weight, w produced by the non-linear BMDP program. Notice that the distribution is quite skewed to the right and is not at all normal. For this reason, the standard deviation of the 20 replicate estimates is quite large. Obviously, sample sizes of 200 are not sufficiently large to yield a normal sampling distribution in this case.

The column labelled β_n contains a transformed version of the parameter estimates. This is the partial regression coefficient for nighttime noise ($\hat{\beta}_n$) which is directly estimated in the regression analyses in this report. Notice that the distribution of these estimates is much more nearly normal. For that reason, one can form symetric confidence intervals using these transformed estimates. For example, an approximate 95% confidence interval for the transformed parameter, β_n could be obtained by usual normal theory as:

$$0.690 \pm 2 \times 0.178/\sqrt{20} = 0.690 \pm 0.080 = (0.610, 0.770)$$

This interval can be the tranformed back to the scale of the parameter w_n by inverting the transformation: $w_n = \beta_n/(1-\beta_n)$, yielding the following approximate 95% confidence interval:

$$(0.610/0.390, 0.770/0.230) = (1.56, 3.35)$$

Notice that this interval contains the known, true value for w_n, 2.33.

In conclusion, it is recommended that jackknife estimates of variance be based on the transformed parameter estimates, β_n. Normal theory confidence intervals should be formed for the transformed parameter. Finally, confidence intervals for the original parameter, w_n, should then be obtained by inverting the transformation for the limits of these confidence intervals as outlined above.

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TABLE I: DESCRIPTION OF TEN SURVEYS

Study title (Main reference)	Number of interviews	Definition of time period (e=evening,n=night)	Noise Metric	Method for determining noise levels
PART A: AIRCRAFT SURVEYS				
USA nine airport (Connor and Patterson, 1976)	8225	n=22:00-07:00	CNR	Measurements and interpolation
1967 Heathrow (Second...1971)	3755[a]	e=19:00-23:00[b] n=23:00-07:00	NNI_{10}[c]	Model based on measurements at Heathrow
PART B: ROAD TRAFFIC SURVEYS				
England traffic (Morton-Williams, et al., 1978)	1195	n=22:30-07:30[d]	L10	Measurements and interpolation
London traffic (Langdon and Buller, 1977)	2903	n=22:00-06:00[e]	L10	Measurements
1975 South Ontario (Hall, et al., 1977)	560	e=19:00-23:00 n=23:00-07:00	LEQ	Measurements
1976 South Ontario (Hall, et al., 1977)	850	e=19:00-23:00 n=23:00-07:00	LEQ	Measurements
1978 Ontario (Hall, et al., 1981)	912	e=19:00-22:00 n=22:00-07:00	LEQ	Measurements
Western Ontario (Bradley and Jonah, 1979)	1100[f]	n=22:00-07:00	LEQ	Measurements
French expressway (Vallet, et al., 1978)	975	e=20:00-24:00 n=24:00-08:00	LEQ	Measurements
PART C: RAILWAY SURVEY				
British railway (Fields and Walker, 1982	1453	e=19:00-21:00 n=21:00-07:00	LEQ	Measurements

a Although 4655 interviews are present in the data set, only 3755 have noise data for both daytime and nighttime. For the remaining interviews, the average peak level of the flights during at least one period was less than the conventional definition of an aircraft noise event for NNI (80 PNdB).

b The definition of the end of the evening period is not reported in the study publications. It is assumed to be 23:00 in accord with the definition of the beginning of the nighttime period for flight regulations.

c NNI_{10} is equivalent to the conventional British NNI index except that the weighting for the number of noise events is 10 rather than 15.

d Daytime noise levels are based on measurements over the 06:00 to 24:00 period.

e Daytime noise levels are based on measurements over the 08:00 to 20:00 period.

f One hundred interviews from the original data set are excluded which were obtained on repeated visits to two sites.

TABLE II: DESCRIPTION OF TIME-PERIOD NOISE DATA FOR 10 STUDIES

Study title (Noise metric)	Noise level 24-hr (dB)		Difference between metrics (1st period - 2nd period) in dB for: (σ =standard deviation of difference)								Correlations for:			
			Two period division		Three time-period division of 24 hrs.						Two per- iods	Three time-period division		
			Day-night		Day-night		Day-evening		Evening-night		r_{dn}	r_{dn}	r_{de}	r_{en}
	Mean	σ	Mean	σ	Mean	σ	Mean	σ	Mean	σ				
PART A: AIRCRAFT SURVEYS														
USA nine airport (CNR)	108	10.9	6.2	3.2	No Evening Noise Data						.96	No Evening Noise Data		
1967 Heathrow (NNI_{10})	92	6.8	9.1	2.4	9.9	2.5	8.4	4.3	1.5	3.6	.94	.94	.82	.87
PART B: ROAD TRAFFIC SURVEYS														
England (L10)	59	10.5	10.9	5.7	No Evening Noise Data						.86	No Evening Noise Data		
London (LEQ)	73	4.0	8.6	4.0	No Evening Noise Data						.86	No Evening Noise Data		
1975 Ontario (LEQ)	61	7.0	4.4	4.4	4.5	4.7	1.3	3.0	3.1	4.0	.88	.85	.91	.91
1976 Ontario (LEQ)	66	4.7	6.1	3.0	6.5	2.9	2.2	2.7	4.2	3.7	.88	.89	.85	.81
1978 Ontario (LEQ)	57	5.5	5.1	2.4	4.9	2.4	-0.2	2.5	5.1	3.1	.91	.92	.90	.86
Western Ontario (LEQ)	58	7.2	5.7	1.5	No Evening Noise Data						.98	No Evening Noise Data		
French (LEQ)	66	4.4	4.0	1.7	4.8	1.8	4.4	1.1	0.4	1.4	.93	.92	.97	.95
PART C: RAILWAY SURVEY														
British railway (LEQ)	56	10.7	3.7	4.9	3.7	5.0	0.8	3.8	2.9	2.8	.91	.90	.94	.97

TABLE III: ESTIMATES OF NIGHTTIME WEIGHTING FROM REGRESSIONS ON OVERALL ANNOYANCE

Study	Annoyance scale[a] (number of scale points)	Partial regression coefficient for [b]: Total noise index B_I (σ_{B_I})	Partial regression coefficient for [b]: Nighttime sum[c] of rel. p^2 B_n (σ_{B_n})	Nighttime weight (w_n)[d]: Lower 95% confidence limit	Nighttime weight (w_n)[d]: Estimate of w_n	Nighttime weight (w_n)[d]: Upper 95% confidence limit	Coefficient of variation for $1-B_n$
PART A: AIRCRAFT SURVEYS							
USA nine airport	Numeric (5)	0.069* (0.007)*	0.90 (0.75)	-0.4	9.2	+∞[d]	7.5
1967 Heathrow	Verbal (4)	0.053* (.003)	>-120.92[e] (>239.9)	-1.0	-1.0	+∞	0.5
PART B: ROAD TRAFFIC SURVEYS							
England traffic	Verbal (4)	0.035* (0.003)	0.57 (0.54)	-0.3	1.3	+∞	1.3
	Numeric (7)	0.115* (0.007)	0.38 (0.34)	-0.2	0.6	+∞	0.5
London traffic	Numeric (7)	0.080* (0.027)	0.81 (0.81)	-0.4	4.2	+∞	4.3
1975 South Ontario	Verbal (5)	0.071* (0.009)	-0.70 (1.14)	-0.8	-0.4	+∞	0.7
1976 South Ontario	Verbal (5)	0.035 (0.019)	0.95* (0.17)	1.7	21.8	+∞	3.4
	Numeric (11)	0.062 (0.034)	1.01* (0.15)	2.6	+∞	+∞	15.0
1978 Ontario	Verbal (5)	0.080* (0.010)	0.57 (0.42)	-0.2	1.3	+∞	1.0
	Numeric (11)	0.240* (0.025)	0.10 (0.87)	-0.6	0.1	+∞	1.0
Western Ontario	Numeric (7)	0.121* (0.014)	1.02* (0.11)	4.0	+∞	+∞	6.0
French expressway	Verbal (4)	0.065* (>0.010)	1.04* (>0.08)	<7.6[f]	+∞	+∞	2.0
PART C: RAILWAY SURVEY							
British railway	Verbal (4)	0.029* (0.004)	0.48 (0.51)	-0.3	0.9	+∞	1.0
	Numeric (7)	0.067* (0.009)	0.72* (0.34)	0.1	2.6	+∞	1.2
	Index (11)	0.111* (0.015)	0.74* (0.24)	0.4	2.9	+∞	0.9

Footnotes for table III

* P<.05

a Annoyance scales are reproduced in appendix A.

b The definitions of the partial regression coefficients and the method for estimating them is given in the text in the section on "Estimates of Parameters in the Adjusted Energy Model". The method for calculating all standard errors and confidence intervals which takes into account the clustered sample design is discussed in that section and in Appendix C.

c As discussed in the text the partial regression coefficients for the nighttime and daytime noise (expressed in relative pressure squared units) are set to sum to 1.0.

d The symbol "+∞" indicates that the value of the nighttime regression coefficient is greater than 1.00 and thus that the daytime noise levels would be estimated to have a negative coefficient (ie. increasing the daytime noise decreases annoyance). This suggests that the relative increase in annoyance associated with the two variables is infinitely greater for the nighttime noise.

e This estimate for the nighttime partial regression coefficient does not converge even after 50 iterations. The value of B_n continues to become a larger and larger negative number. This means that the value of the weight (w_n) approaches $w_n = -1.0$. The lack of convergence may be due to the high correlation between the noise variables.

f The "<" symbol indicates that the lower confidence interval is almost certainly less than 7.6. The value of the standard error in this case could only be calculated on the basis of 8 of the ten jackknife pseduo-replicates. The other two replicates did not provide estimates of w_n.

TABLE IV: ESTIMATES OF NIGHTTIME AND EVENING WEIGHTINGS FROM REGRESSIONS ON TOTAL ANNOYANCE[a]

Study	Annoyance scale[a] (number of scale points)	Partial regression coefficient for sum of rel. p^2 for: Day B_d (σB_d)	Evening B_e (σB_e)	Nighttime B_n (σB_n)	Confidence intervals and weights: Evening Lower 95% limit	Evening Est. w_e	Evening Upper 95% limit	Nighttime Lower 95% limit	Nighttime Est. w_n	Nighttime Upper 95% limit
PART A: AIRCRAFT SURVEY										
1967 Heathrow[d]	Verbal (4)	233.24	325.28	92.04	d	-1.4	+∞	d	0.4	+∞
PART B: TRAFFIC SURVEYS										
1975 South Ontario	Verbal (4)	0.13	1.08	-0.21	-0.5	8.1	+∞	-0.3	-1.6	+∞
		.67	(0.60)	(0.41)						
1976 South Ontario	Verbal (5)	-0.02	0.42	0.59	-10.3	+∞	+∞	-5.6	+∞	+∞
		(0.3)	(0.39)	(0.38)						
	Numeric (11)	-0.03	0.34	0.69	-94.3	+∞	+∞	-68.0	+∞	+∞
		(0.2)	(0.78)	(0.76)						
1978 Ontario	Verbal (5)	0.41	0.18	0.41	-0.3	0.4	+∞	-0.5	1.0	+∞
		(0.33)	(0.25)	(0.42)						
	Numeric (11)	0.64	0.34	0.01	-0.3	0.5	+∞	-0.7	0.0	+∞
		(0.48)	(0.35)	(0.54)						
PART C: RAILWAY SURVEY										
British Railway	Verbal (4)	0.11	0.79	0.10	0.5	7.3	+∞	-1.0	1.0	+∞
		(0.16)	(0.27)	(0.21)						
	Numeric (7)	0.08	0.66	0.27	-1.1	8.4	+∞	-1.7	3.4	+∞
		(0.12)	(0.42)	(0.36)						

a Annoyance scales are reproduced in appendix A.

b The day, evening and nighttime noise data are represented in relative pressure squared units in the regressions. The sum of the regression coefficients is set to 1.00 ($B_d+B_e+B_n=1$).

c The 95% confidence interval is set using the Bonferonni inequality. It is conservatively assumed that the standard errors of the partial regression coefficients are independent. Using this technique the $p = \alpha$ confidence interval for a ratio is set by finding the $p= \alpha /4$ confidence interval for each of the terms in the ratio. The $p= \alpha$ confidence interval for the ratio is set by the two most extreme ratios of the two terms.

d The estimates for the partial regression coefficients do not converge even after 50 interations . The values of all coefficients become larger positive or negative numbers with each iteration. Thus, the value for the evening weight approaches $w_e=-1$ and for the night weight approaches $w_n=1$. No attempt is made to describe a lower confidence interval.

TABLE V: SUMMARIES OF NIGHTTIME WEIGHTS USING SIX METHODS TO COMBINE THE ESTIMATES FROM 9 STUDIES[a]

Method for combining study estimates		Estimate of nighttime:		
Statistic	Relative weight given to each study	Partial regression coefficient (B_n)	Weight[b] (w_n)	Problems with the method of measuring the central tendency
Mean of weights (w_n)	Equal importance	0.61	$+\infty$	Three studies with a negative weighting ($w_n = +\infty$ dominate estimates)
Median	Equal importance	0.72	2.6	Median does not account for dispersion in estimate
Mean of partial regression coefficient (B_n)	Equal importance	0.61	1.6	Ignores all aspects of differential reliability of estimates.
	Number of interviews	0.74	2.8	Only consider one aspect of reliability.
	Inverse of variance of B_n	0.96	24.7	Estimates of reliability are (1) biased by estimates of B_n or w_n (2) highly inaccurate.
	Inverse of variance of w_n	0.07	0.1	

a Each of the fifteen estimates in table III is treated as a separate estimate. the central conclusions about the variability in the estimates is not affected if a single estimate is taken from each study.

b The means for the last four entries are computed from an average of the partial regression coefficients which are then transformed into the nighttime weight.

$$w_n = B_n/(1-B_n)$$

TABLE VI: PROPORTION OF THE VARIANCE IN ANNOYANCE SCORES EXPLAINED BY ALTERNATIVE TIME-OF-DAY RESPONSE MODELS

Study	Annoyance question	Squared multiple correlation coefficient (R^2) for:					
		Energy summation models				Independent effects models[a]	
		LEQ	LDN	Study determined weight for:		Independent period effect	Incremental decibel difference
		(w_{n_0})	($w_{n_{10}}$)	Night [w_n]	Evening [w_e]	[$ADJP_n$=]	[$-ADJD_n$=]
PART A: AIRCRAFT SURVEYS							
USA nine airport	Numeric	0.212	0.212	0.212 [9.2]	No evening data	0.209 [1.7]	0.212 [0.5]
1967 Heathrow	Verbal	.163	.168	.168 [36.3]	-b-	.163 [4.6]	.169 [0.6]
PART B: ROAD TRAFFIC SURVEYS							
England traffic	Verbal	.193	.190	.193 [1.3]	No evening noise data	.186 [0.3]	.194 [0.1]
	Very	.058	.056	.058 [0.9]		.053 [0.2]	.058 [0.0]
	Numeric	.314	.306	.315 [0.6]		.307 [0.3]	.315 [0.1]
London traffic	Numeric	.033	.033	.034 [4.2]	No evening data	.033 [0.1]	.033 [0.0]
1975 South Ontario	Verbal	.213	.192	.224 [-0.4]	.231 [8.1,-1.6]	.213 [0.1]	.213 [-0.1]
	Considerably	.140	.122	.151 [-0.5]	.159 [17.6,-3.2]	.140 [0.0]	.142 [-0.2]
1976 South Ontario	Verbal	.032	.034	.034 [21.8]	.038 [-24.4,-34.4]	.032 [1.4]	.034 [0.5]
	Considerably	.021	.022	.022 [10.1]	.025 [-34.8,-17.0]	.021 [1.0]	.022 [0.4]
	Numeric	.021	.022	.024 [+∞]	.027 [-12.3,-24.9]	.021 [3.3]	.023 [0.7]
1978 Ontario	Verbal	.189	.181	.189 [1.3]	.189 [0.4,1.0]	.188 [0.2]	.189 [0.0]
	Considerably	.106	.103	.107 [1.8]	.107 [1.1,1.8]	.106 [0.3]	.170 [0.1]
	Numeric	.269	.249	.270 [0.1]	.271 [0.5,0.0]	.270 [0.0]	.270 [-0.2]

TABLE VI: (CONTINUED)

Study	Annoyance question	Squared multiple correlation coefficient (R^2) for:					
		Energy summation models				Independent effects models[a]	
		LEQ	LDN	Study determined weight for:		Independent period effect	Incremental decibel difference
		$(w_{n_0}=)$	$(w_{n_{10}}=)$	Night $[w_n]$	Evening $[w_e]$	$[ADJP_n=]$	$[-ADJD_n=]$
Western Ontario	Numeric	.173	.176	.177 [+∞]	No evening noise data	.177 [10.0]	.177 [0.8]
French expressway	Verbal	.068	.081	.086 [+∞]	b	.087 [3.1]	.088 [1.3]
	Very	.055	.066	.071 [+∞]	b	.072 [+∞]	.073 [1.4]
PART C: RAILWAY SURVEY							
British railway	Verbal	.103	.100	.103 [0.9]	.103 [7.3,1.0]	.103 [0.2]	.103 [0.0]
	Very	.032	.031	.032 [0.2]	b	.032 [0.2]	.032 [0.1]
	Numeric	.144	.143	.145 [2.6]	.145 [8.4,3.4]	.145 [0.4]	.145 [0.2]
	Index	.179	.178	.179 [2.9]	.179 [3.1,3.0]	.178 [0.3]	.179 [0.1]

a Models are defined by equations in the text.

b No estimate obtained from non-linear programs.

c The high annoyance measures come from dichotomizing the verbal annoyance scale at the most extreme of four of five catagories ("very" or "considerably").

TABLE VII: NIGHTTIME WEIGHTING (w_n) FOR EIGHT TYPES OF ANNOYANCE QUESTIONNAIRE ITEMS

Study	Type of annoyance questionnaire item[a]							
	No time period implied			Time period defined or implied:				
				Activity interference Index	Reference is to:[b]			
	Numeric	Verbal	Very/ Considerably		Daytime (Numeric)	Speech	Nighttime (Numeric)	Waking up
PART A: AIRCRAFT SURVEYS								
USA nine airports	9.2		36.3	9.1				
1976 Heathrow		-1.0	4.6	-1.0	-1.0		3.1	
PART B: ROAD TRAFFIC SURVEYS								
England traffic	0.6	1.3	0.9			3.0		2.6
1975 South Ontario		-0.4	-0.5					
1976 South Ontario	+∞	21.8	10.1					
1978 Ontario	0.1	1.3	1.8		-0.5		0.0	
French expressway		+∞	+∞					
PART C: RAILWAY SURVEY								
British railway	2.6	0.9	0.2			2.2		-0.5

a Annoyance scales are reproduced in appendix A.

b The speech and sleep interference questions are all dichotomized according to whether or not the interference is reported.

TABLE VIII: SUMMARY OF INFORMATION ABOUT TIME OF DAY WHEN MOST ANNOYED
(18 SURVEYS IN FIGURES 1 TO 6)

Study (Catalog ID Number [a])	Time when most annoyed by the noise occurs in the:[b]			Number of time periods used	Are the periods defined in hrs?[c]	Comment
	Day	Even-ing	Night			
STUDIES FROM FIGURE 1: ENGLISH AIRCRAFT SURVEYS						
1961 Heathrow (UKD-008)			X	4	YES	
1967 Heathrow (UKD-024)		X		4	NO	
1972 Heathrow (UKD-061)	X			3	NO	Night is when "trying to sleep"
1971 Gatwick (UKD-052)		=	=	4	YES	
STUDIES FROM FIGURE 2: US AND AUSTRALIAN AIRCRAFT SURVEYS						
1973 Los Angeles airport nighttime (USA-082)	X	not asked		2	NO	Night is when "trying to sleep"
1970 USA two small airport (USA-044)		X		8	YES	Asks about weekdays
1980 Australia five airport (AUS-210)		X		8	YES	Excludes "not bothered"
1972 JFK airport (USA-059)			X	3	YES	Includes only those home during all periods
STUDIES FROM FIGURE 3: CANADIAN AND UNITED STATES ROAD TRAFFIC NOISE						
1975 West Ontario (CAN-120)		X		6	YES	
1976 South Ontario (CAN-121)	X rush hour			6	NO	Asks about weekdays
1978 Ontario (CAN-168)			X	3	NO	Asks about indoors
1974 USA 24-Community (USA-102)			X	4	NO	54% "never bothered"

TABLE VIII: (CONTINUED)

Study (Catalog ID Number [a])	Time when most annoyed by the noise occurs in the:[b]			Number of time periods used	Are the periods defined in hrs?[c]	Comment
	Day	Evening	Night			
STUDIES FROM FIGURE 4: SWISS STUDIES OF AIRCRAFT AND OF ROAD TRAFFIC IN ZURICH						
1971 Swiss 3 airport (SWI-053)		X		6	YES	May choose several periods
1976 Zurich SWI-133)			X 6-9am	4	YES	Excludes not bothered
1977 Zurich (SWI-158)	X			4	YES	Excludes not bothered
1978 Zurich Time-of-day (SWI-173)			X 6-9am	6	YES	
STUDY FROM FIGURE 5: JFK AIRCRAFT STUDY						
1979 New York (XXX-220) (Period rating)		X		24	YES	
(period ranking)		X		12	YES	
(Distribute money- 3 periods)		X		3	YES	
(Distribute money- 2 periods)	X	not asked		2	YES	
STUDY FROM FIGURE 6: BRITISH RAILWAY SURVEY						
1975 British railway (UKD-116)			X	4	YES	

a This identification number is the number used in a catalog of 200 noise surveys (Fields, 1981) and is the key to the full title for the survey presented in appendix C.

b An equals sign "=" indicates that the two periods were ranked equally. "Not asked" indicates that only the daytime and nighttime periods (not evening period) were asked about.

c Studies which do not have the periods defined in hours generally ask about "morning, evening, night", but provide no specific boundaries for these periods.

TABLE IX: ESTIMATES OF TIME-OF-DAY WEIGHTS (w_n) FROM ANALYSES OF MEASURES OF ANNOYANCE IN TIME PERIODS

Study [a] (Reference, if not in table I)	Noise Source	Estimate if respondents consider:[b] Only mean level (period length ignored)		Sum of all period exposures (no. of hours considered)[a]	
		w_e [DL_e]	w_n [DL_n]	w_e [DL_e]	w_n [DL_n]
PART A: PERIOD RESPONSE ANALYSES					
1967 Heathrow	Aircraft	32 [15 dB]	40 [16 dB]	95 [20 dB]	60 [18 dB]
1978 Ontario	Road traffic	1 [1 dB]	4 [6 dB]	7 [8 dB]	7 [8 dB]
1978 Zurich[d] (Wehrli et al., 1978)	Road traffic	—	2 [3 dB]	—	4 [6 dB]
1979 French[d] (Lambert et al.,)	Road traffic	—	4 [6 dB]	—	6 [7 dB]
PART B: RESPONDENT RANKING ANALYSES (ONLY DAY-NIGHT COMPARISONS)					
1967 Heathrow	Aircraft	—	44 [16 dB]	—	65 [18 dB]
1978 Ontario	Road traffic	—	6 [8 dB]	—	8 [9 dB]
British railway	Railway	—	4 [6 dB]	—	5 [7 dB]

a Annoyance scales are reproduced in appendix A.

b A dash indicates that information was not available for the evening period.

c On the basis of the available documentation the period length defined for respondents in each survey is as follows: 1967 Heathrow, t_d = 12, t_e = 4, t_n = 8; 1978 Ontario, t_d = 12, t_e = 3, t_n = 9; 1978 Zurich, t_d = 16, t_n = 8; 1979 French, t_d = 14, t_n = 10.

d For the 1978 Zurich and 1979 French surveys individual data were not available for the analysis.

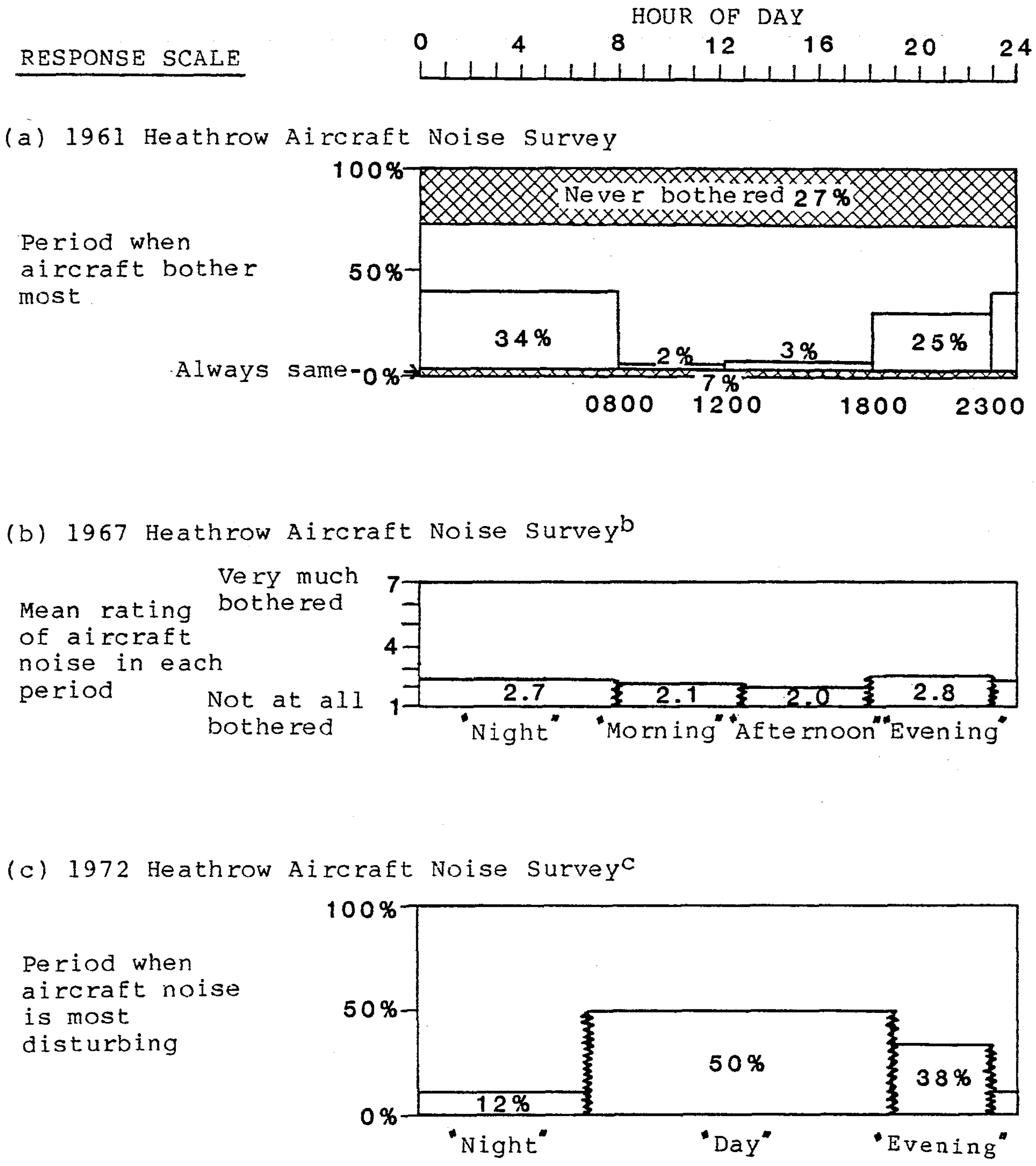
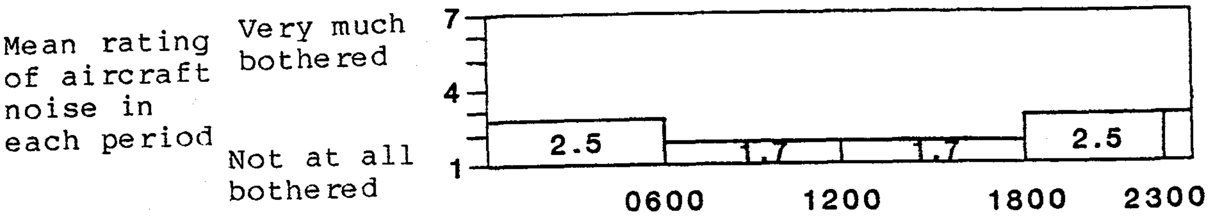


Figure 1.- Noise Annoyance by Time-of-day in Four English Aircraft Surveys[a]

(d) 1971 Gatwick Aircraft Noise Survey



Sources: Fig. 1a, McKennell, 1963: Appendix P, p. 11.
Fig. 1b, Analysis at NASA performed on original data set obtained from the ESRC data archive.
Fig. 1c, Ollerhead, 1978: p. 76.
Fig. 1d, Ollerhead and Cousins, 1975: p. 98.

[a]The questions used in the figure can be found in Appendix A.
[b]Respondents who answer "don't know" are excluded from the analysis. Those saying they do not hear aircraft are given a score of "1".
[c]Respondents are excluded from the figure who answered "don't know", "not disturbed" or "do not hear" the aircraft.

Figure 1. - concluded

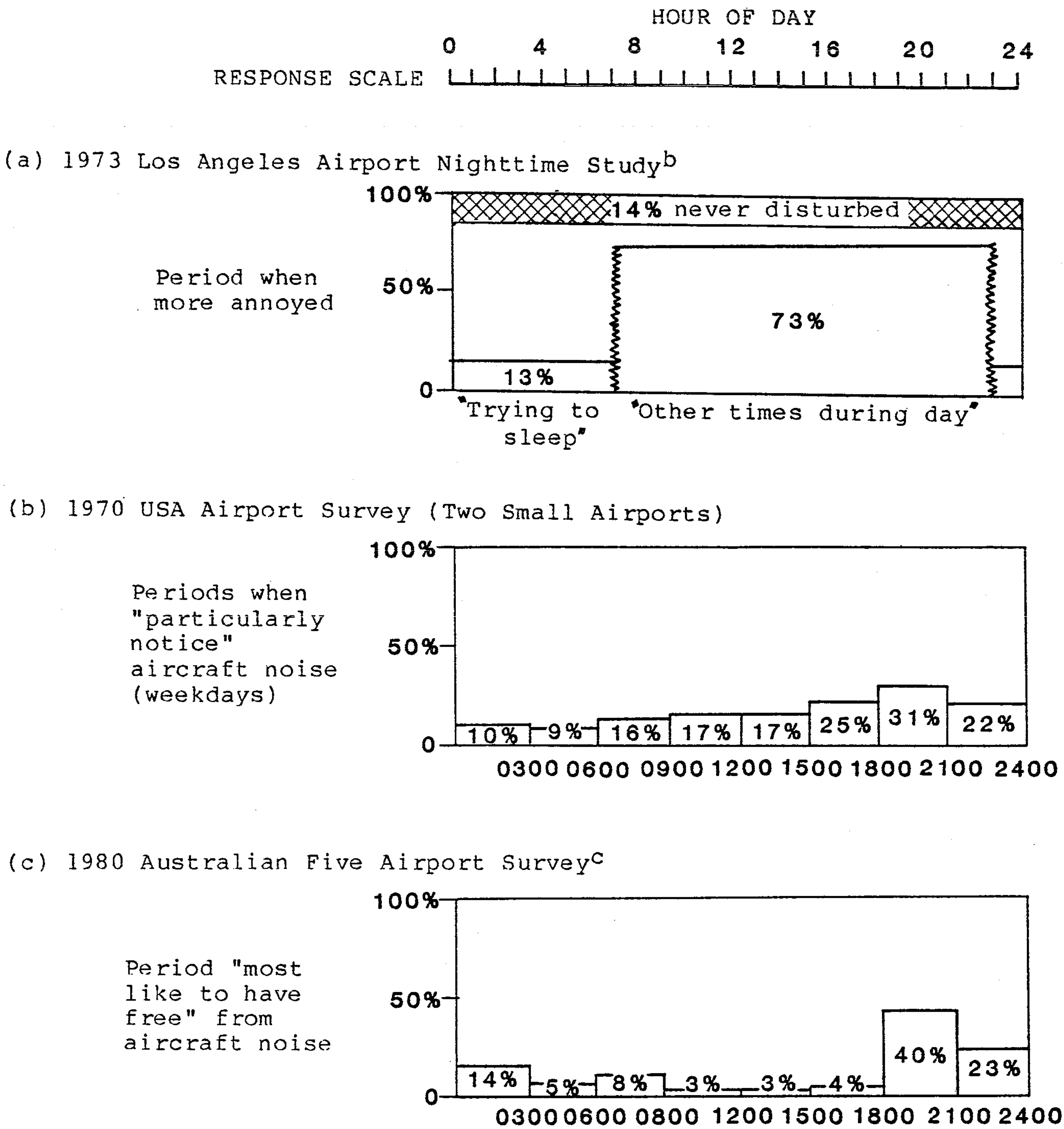
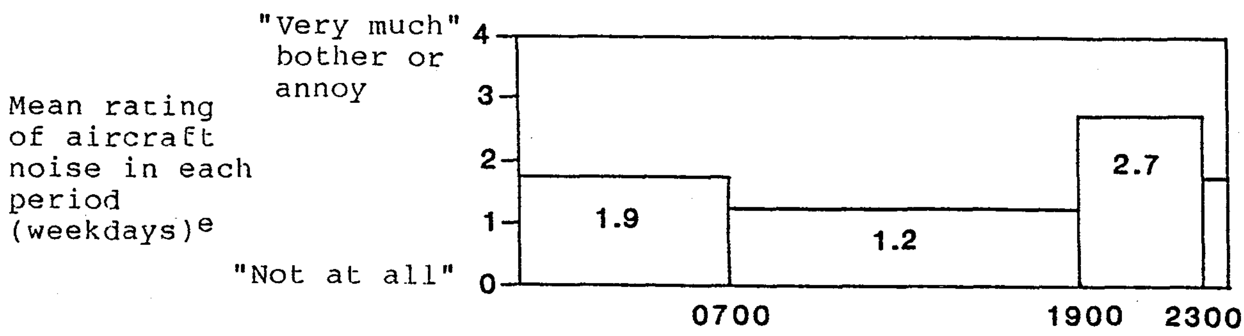


Figure 2. - Noise Annoyance by Time of Day in USA and Australia Aircraft Surveys[a]

(d) 1972 JFK Airport Noise Survey[d]



Sources: Figs. 2a,2b, Analysis at NASA performed on original data set obtained from ESRC data archive.
Fig. 2c, Bullen and Hede, 1983: p. 1629.
Fig. 2d, Borsky, 1976: p. 20.

[a]The questions used in the figure can be found in Appendix A.
[b]Respondents who answered "don't know" are excluded. The study was conducted in three waves which have been combined here since the time of the interview do not appear to affect the responses.
[c]Respondents who answered "don't know" or "not bothered" by aircraft noise have been excluded.
[d]Only people "usually at home during" most of all three time periods are included.

Figure 2. - concluded

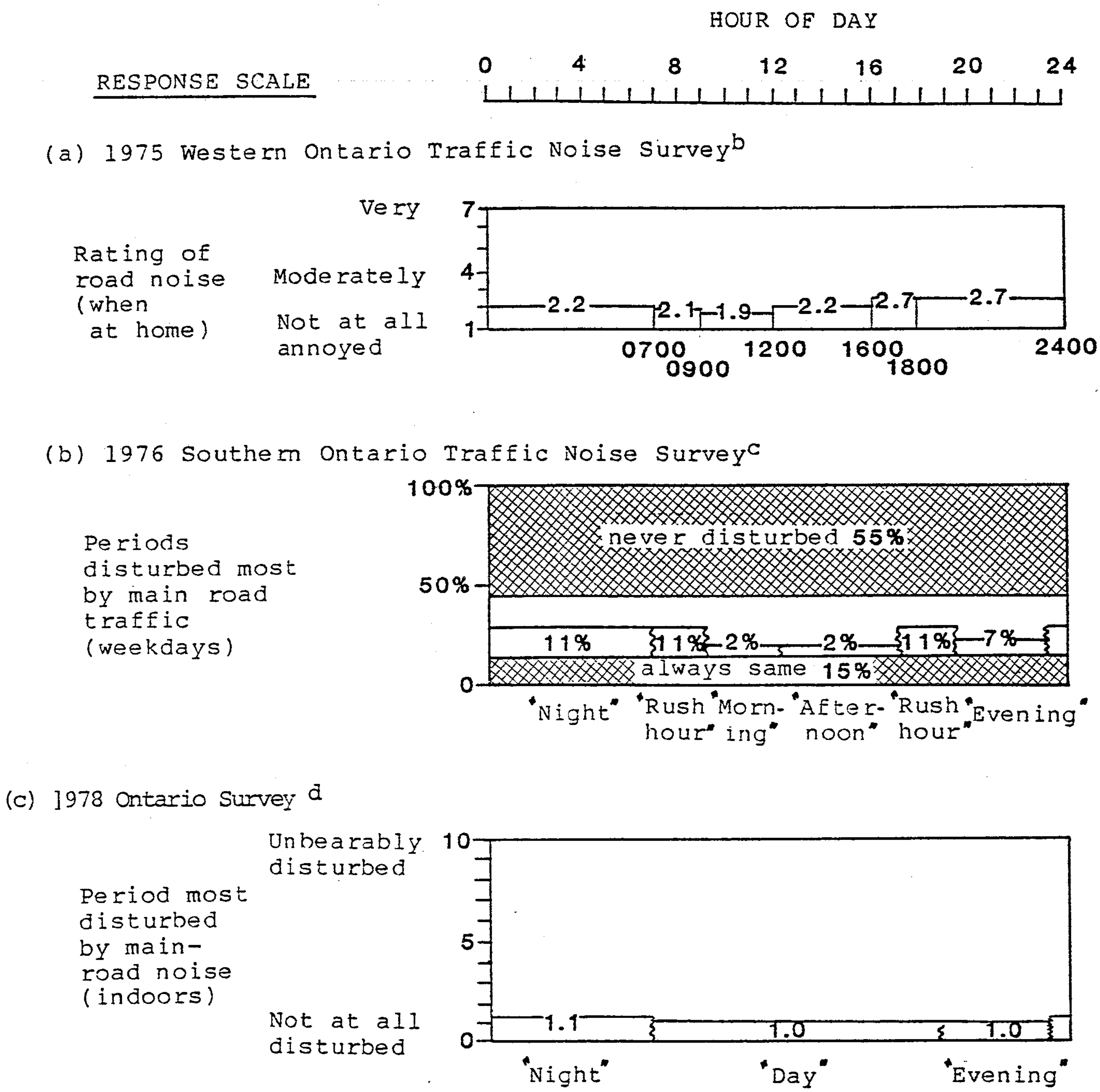
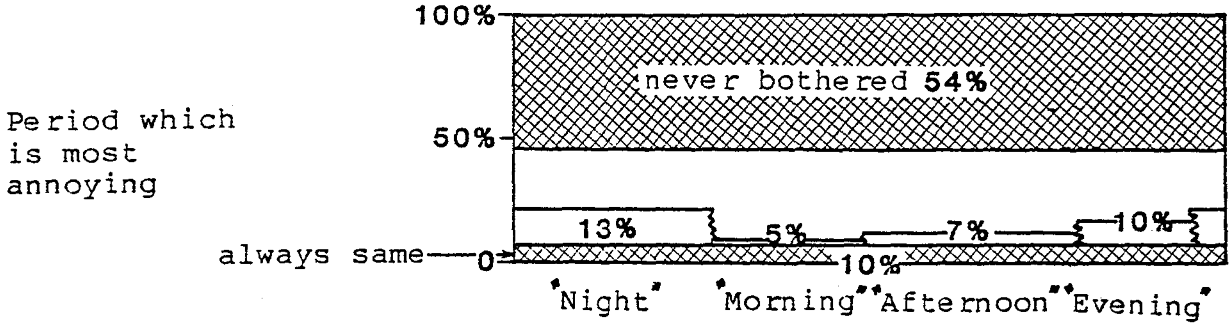


Figure 3.- Noise Annoyance by Time-of-day in Four Road Traffic Surveys[a]

(d) 1974 USA 24-community Survey



Sources: Analysis at NASA performed on original data set obtained from ESRC data archive.

[a]The questions used in the figure can be found in Appendix A.
[b]Respondents were not asked about periods when they were not usually home on weekdays. Thus the same respondents do not provide ratings during all periods.
[c]Respondents were asked when they were most disturbed in an open question. Thus they could use verbal descriptors for time periods (e.g., "morning rush hour") which were not presented in other studies. Multiple designations of "worst" periods were permitted.
[d]Respondents are scored zero if they had previously said they were not disturbed.

Figure 3. - concluded

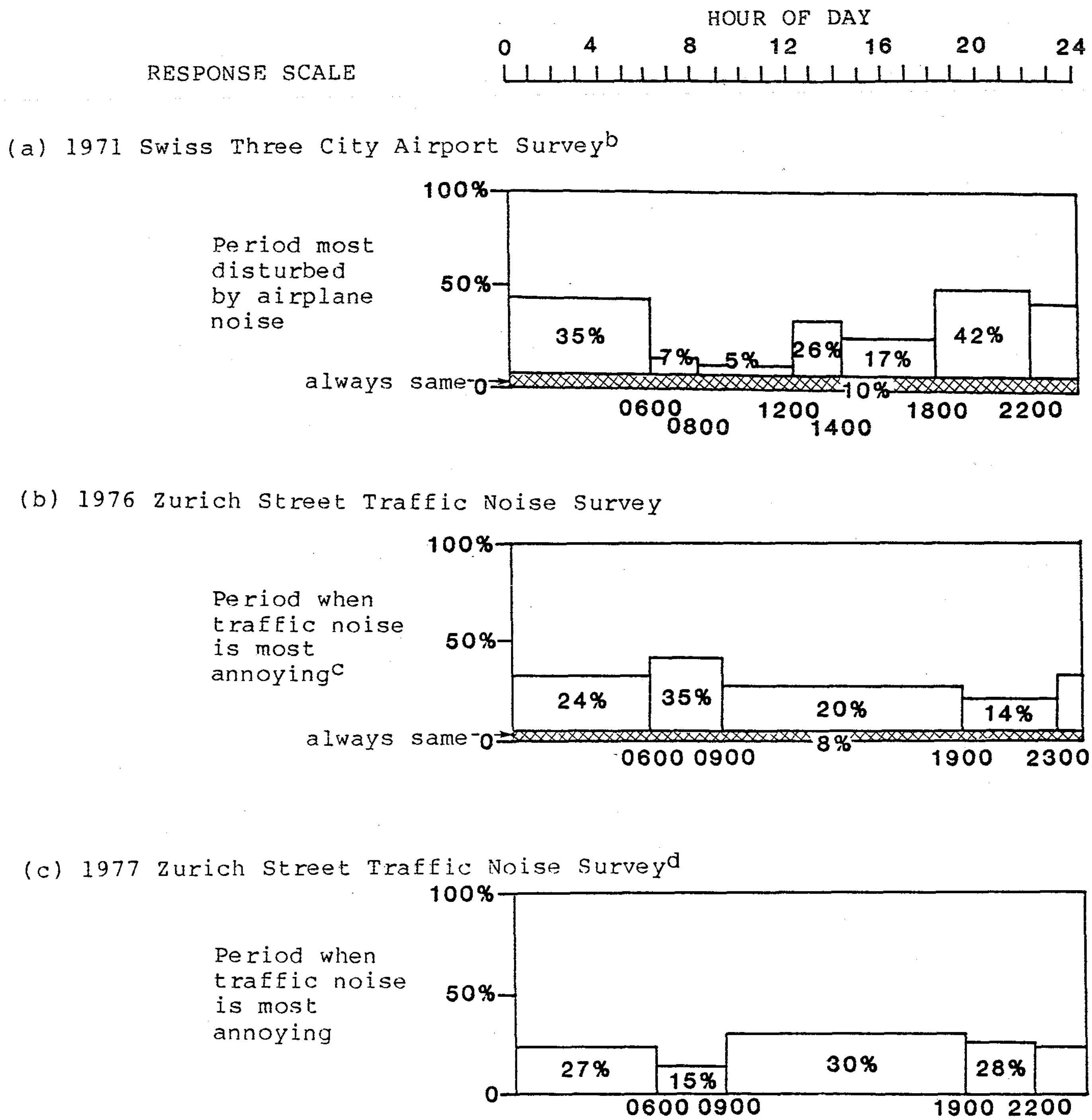
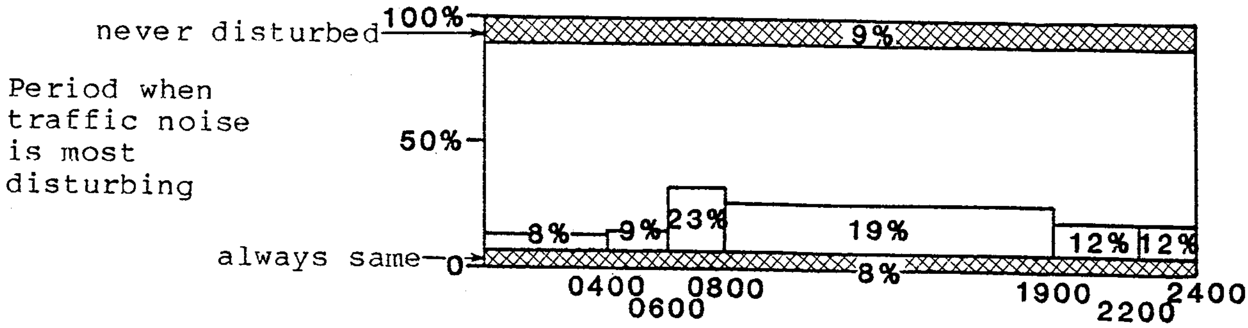


Figure 4.- Noise Annoyance by Time-of-day in Four Swiss Surveys[a]

(d) 1978 Zurich Time-of-day Road Traffic Noise Survey



Sources: Fig. 4a, Graf, et.al., 1974: p. 51.
Figs. 4b,4c, Wanner, et.al., 1977: p. 701.
Fig. 4d, Analysis at NASA performed on original data set obtained from the ESRC data archive.

[a]The questions used in the figure can be found in Appendix A.

[b]Multiple designations of the "most disturbed" periods were permitted.

[c]Respondents are excluded who reported they were never bothered by traffic noise.

[d]Respondents are excluded who reported they were never bothered by traffic noise. The question did not include a response category for being bothered the same amount during all periods.

Figure 4. - concluded

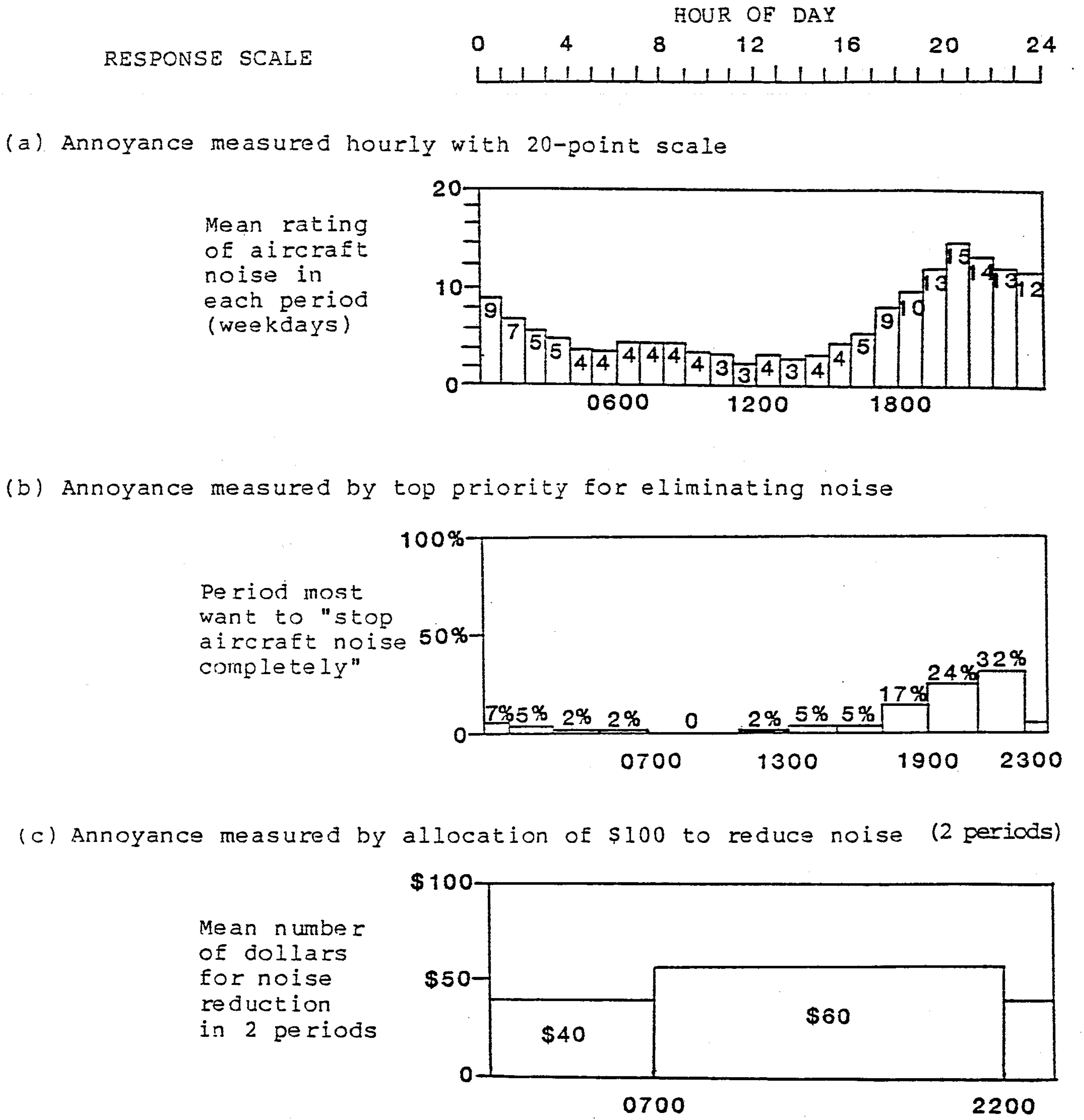
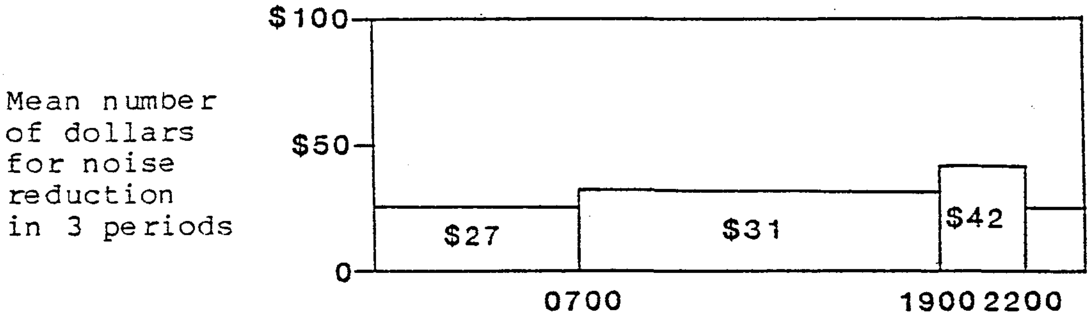


Figure 5.- Noise Annoyance by Time-of-day in JFK (New York) Questionnaire Development Study: Four Questionnaire Items[a]

(d) Annoyance measured by allocation of $100 to reduce noise (3 periods)



Source: Analysis of NASA data come from an unpublished study by Eugene Galanter, Columbia University, New York. The study was conducted to examine alternative questions for time of day surveys. The forty respondents were drawn from two neighborhoods.

Figure 5. - concluded

1975 British National Railway Noise Survey

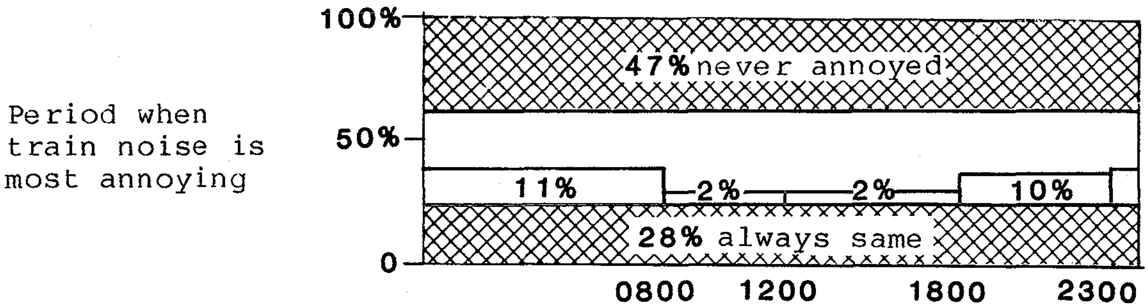


Figure 6.: Noise Annoyance by Time of Day in British Railway Survey (Source: Analysis at NASA of the original data set).

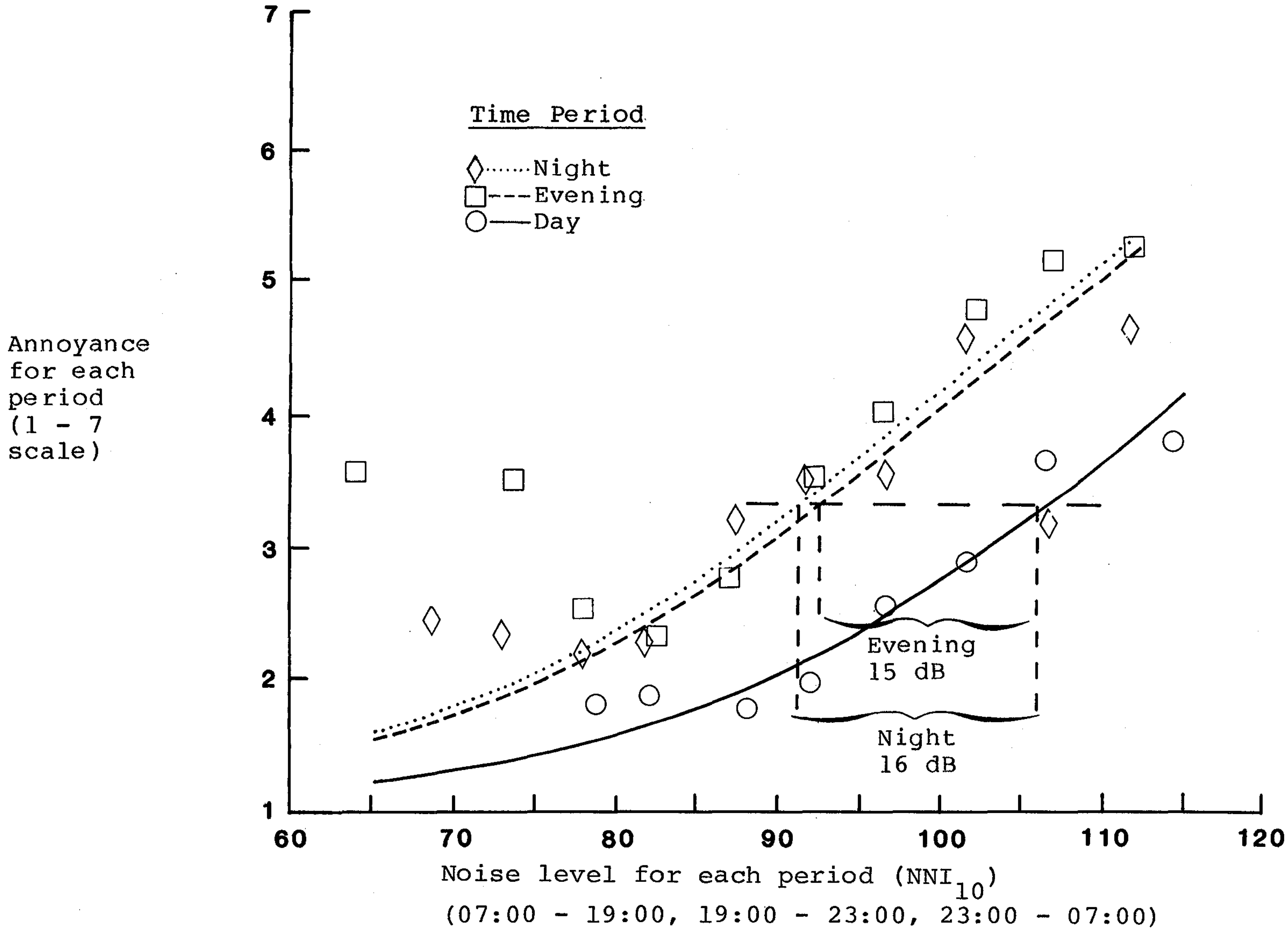


Figure 7. - Relationship between annoyance and noise level in three time periods (1967 Heathrow)

(Source: Analyses at NASA performed on the original data set obtained from the ESRC data archive)

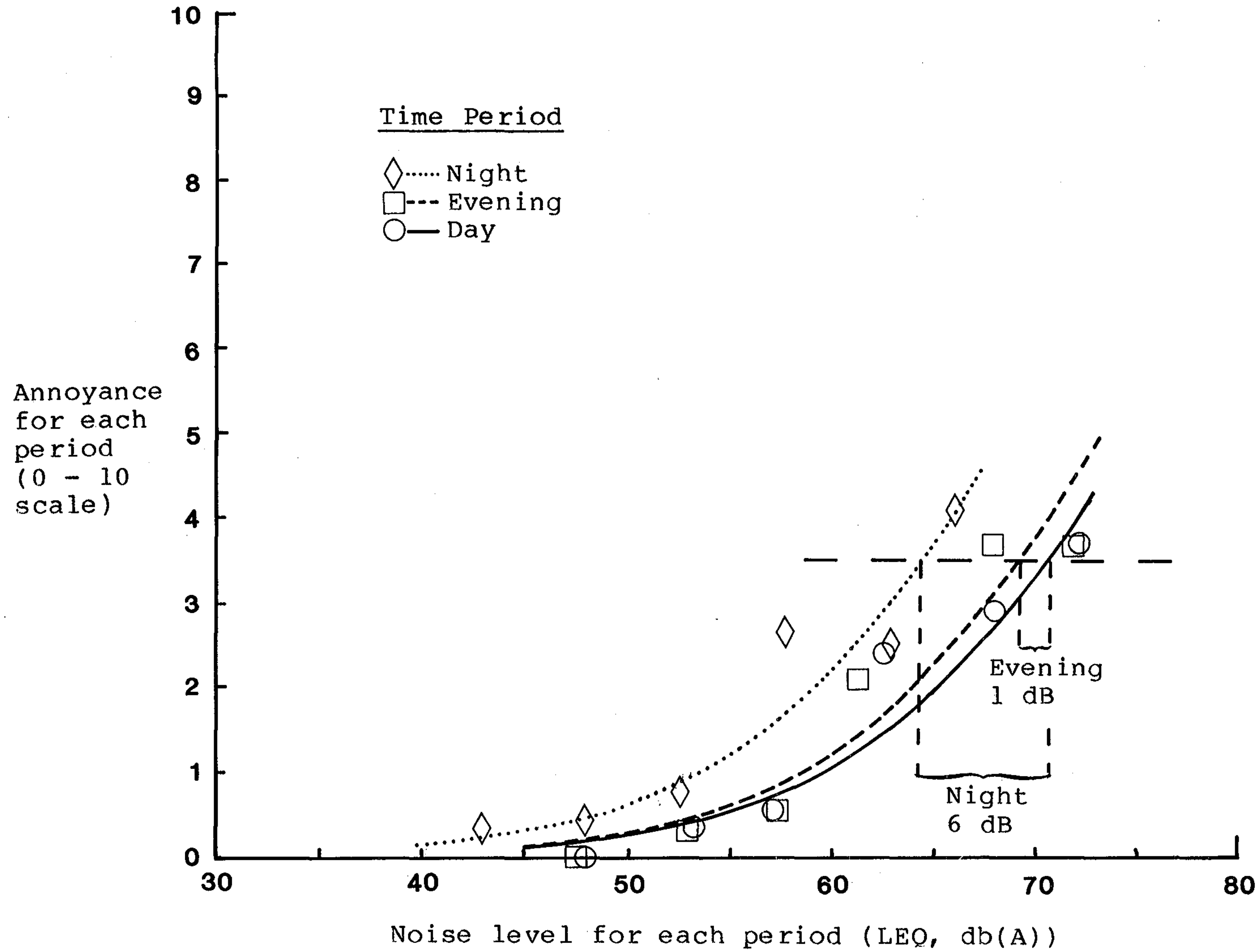


Figure 8. - Relationship between annoyance and noise level in three time periods (1978 Ontario Road)

(Source: Analyses at NASA performed on the original data set obtained from the ESRC data archive)

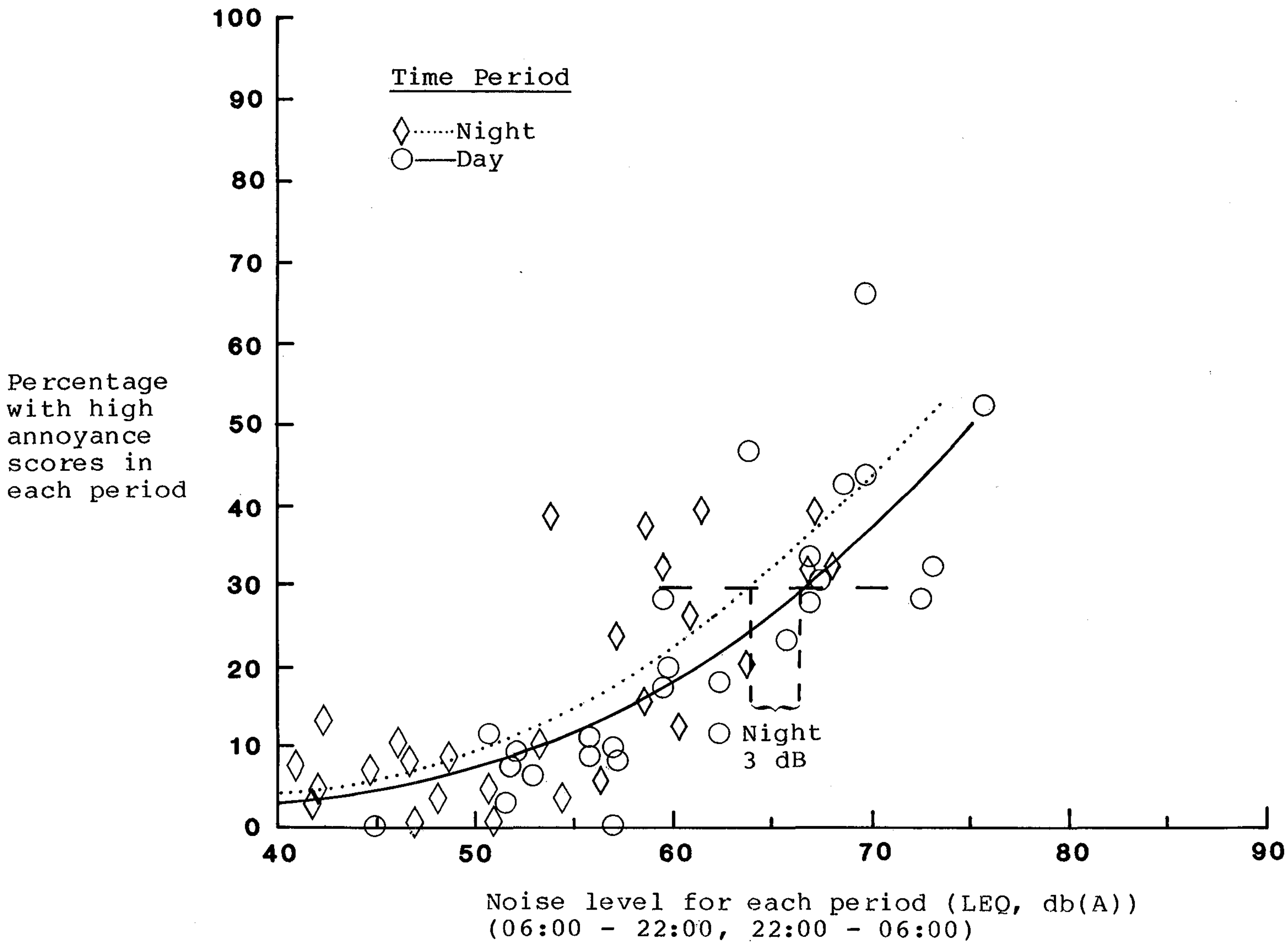


Figure 9. - Relationship between annoyance and noise level in two time periods (1978 Zurich Road)

(Source: Nemecek, et. al., 1981: fig. 3)

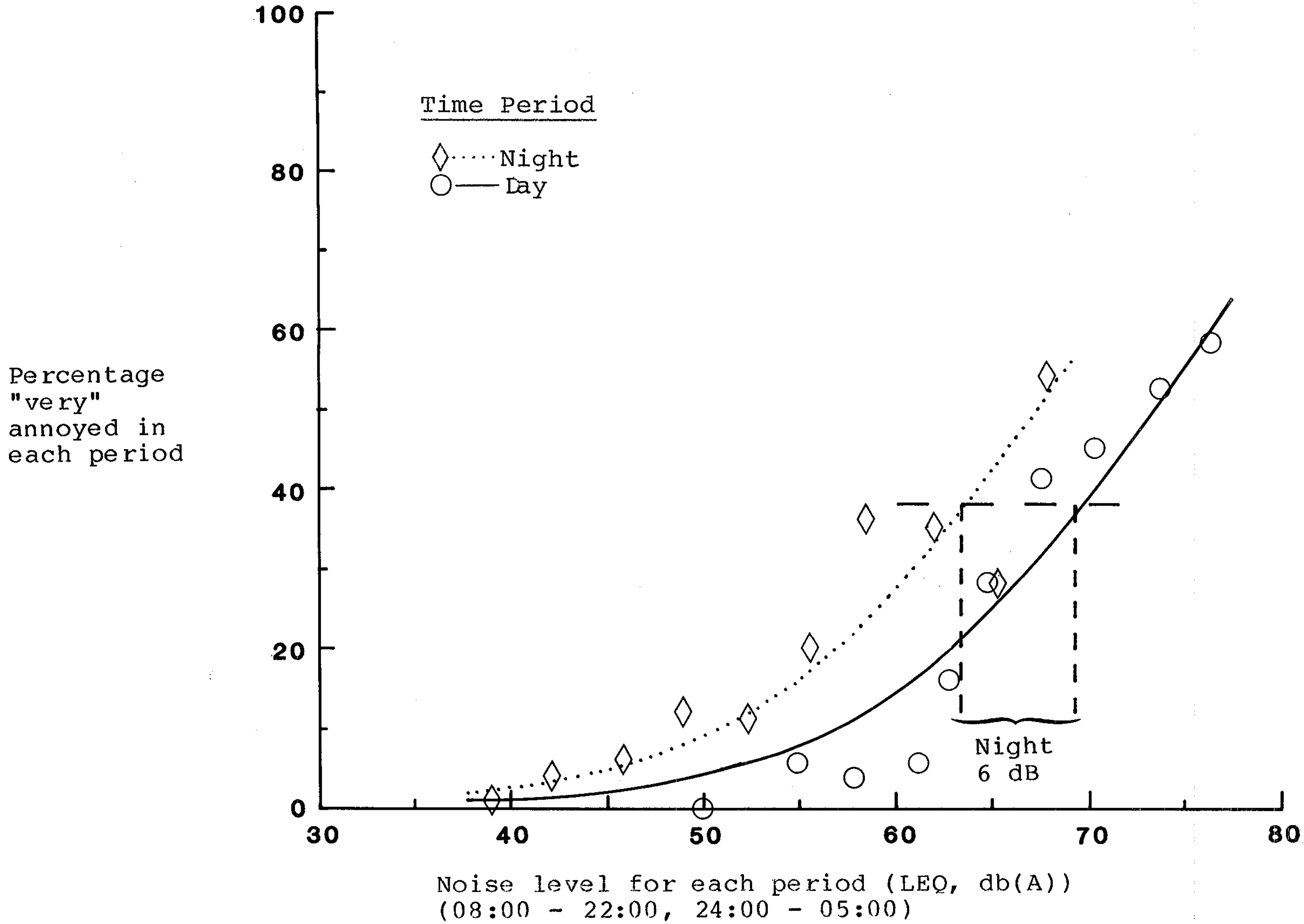


Figure 10. - Relationship between annoyance and noise level in two time periods (1979 French Road)

(Source: Lambert et. al., 1984: fig. 3 and 4)

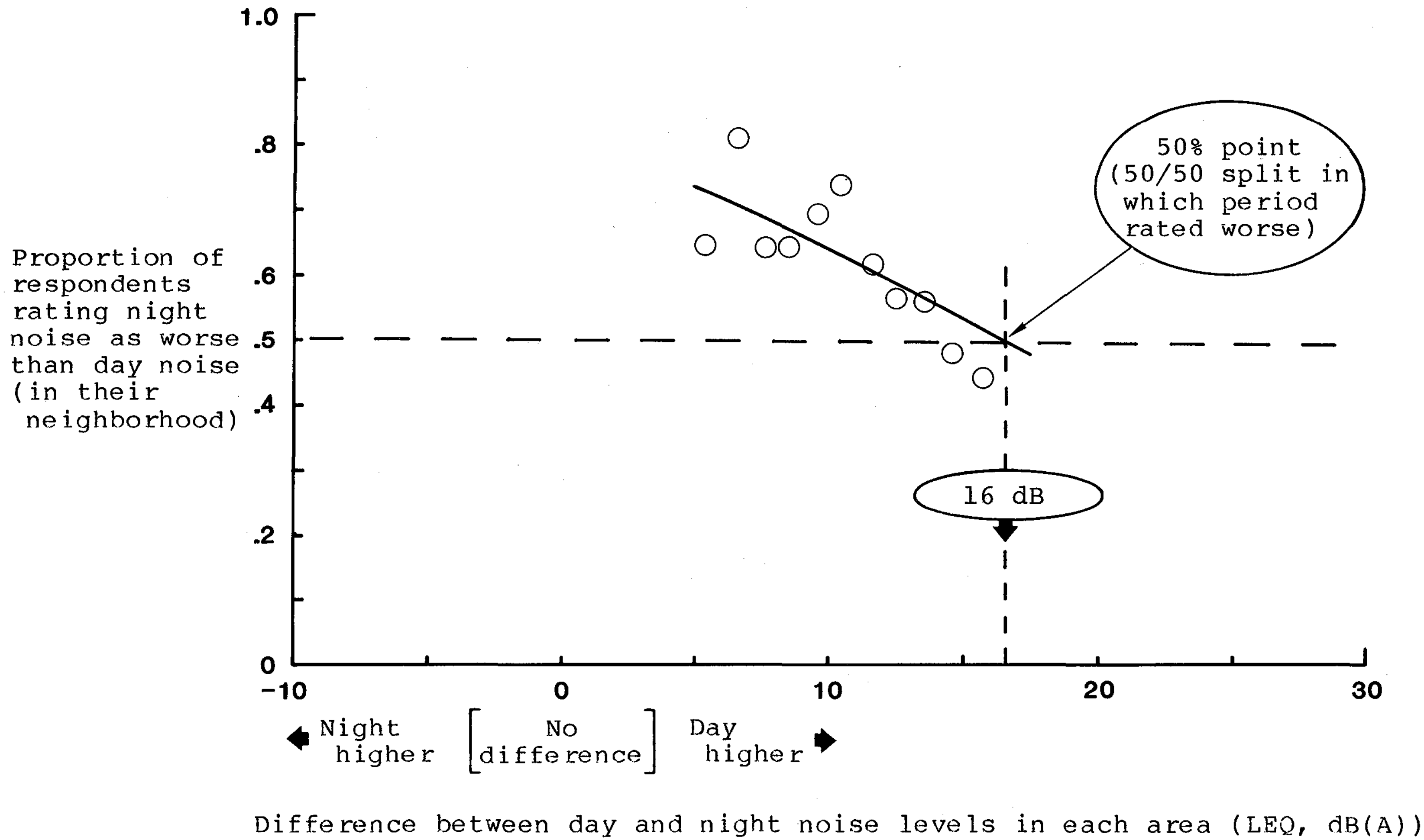


Figure 11. - First method for identifying the difference in noise levels at which day and night noise are equally annoying (1967 Heathrow)

(Source: Analyses at NASA performed on the original data set obtained from ESRC data archive)

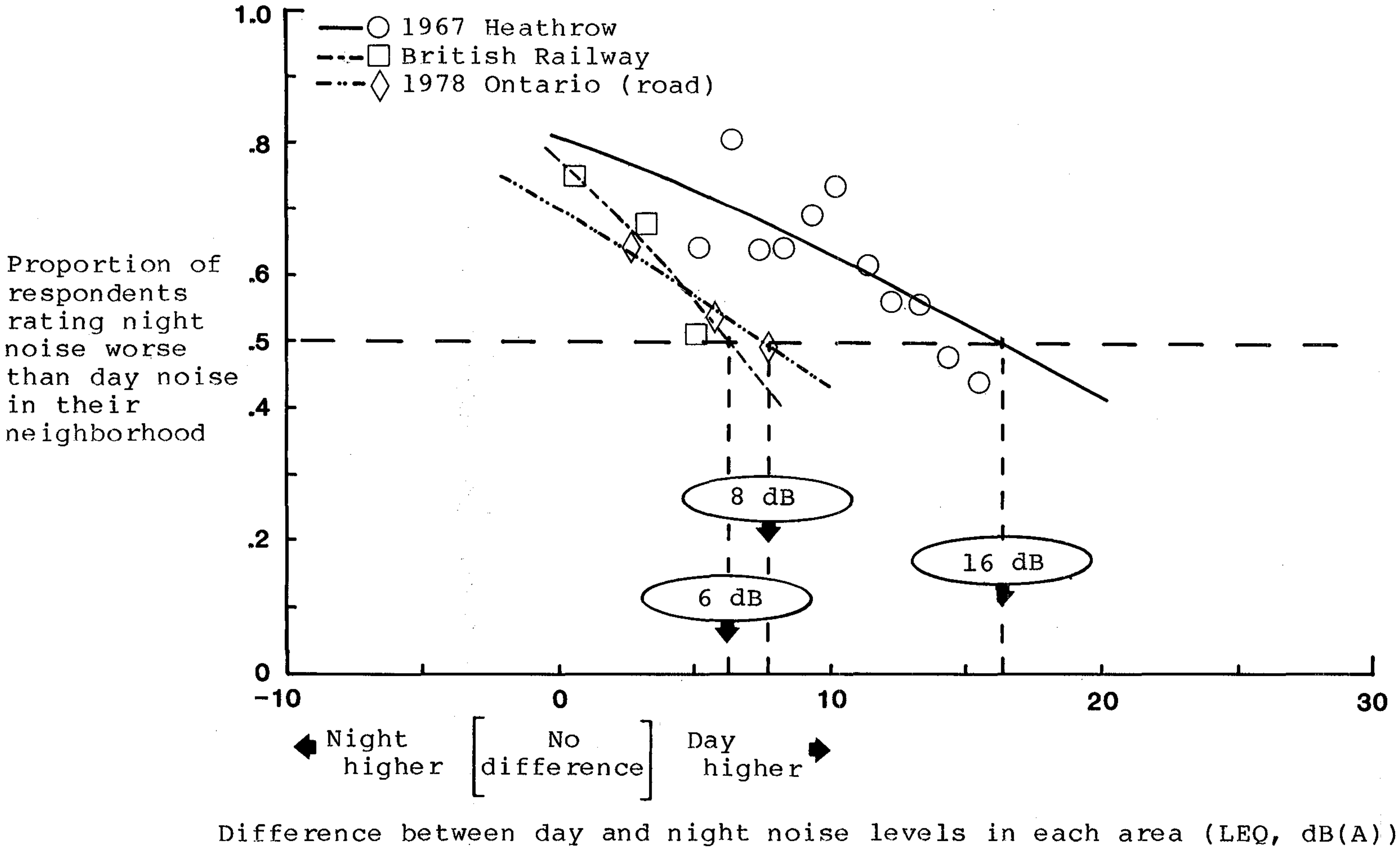


Figure 12. - Three estimates of the difference in noise levels at which day and night noise are equally annoying (first method)

(Source: Analyses at NASA performed on the original data set obtained from ESRC data archive)

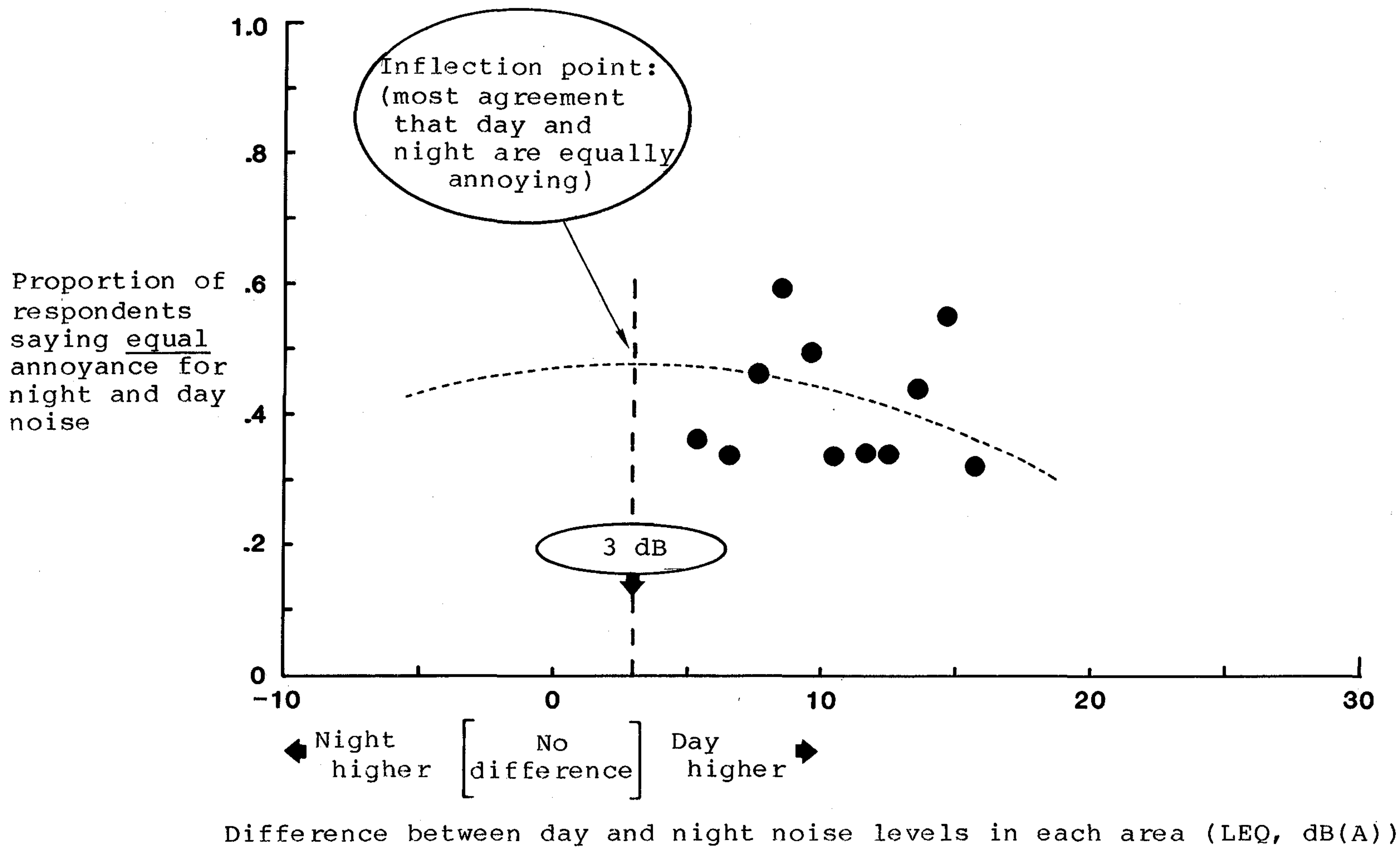


Figure 13. - Second method for identifying the difference in noise levels at which day and night noise are equally annoying (1967 Heathrow)

(Source: Analyses at NASA performed on the original data set obtained from ESRC data archive)

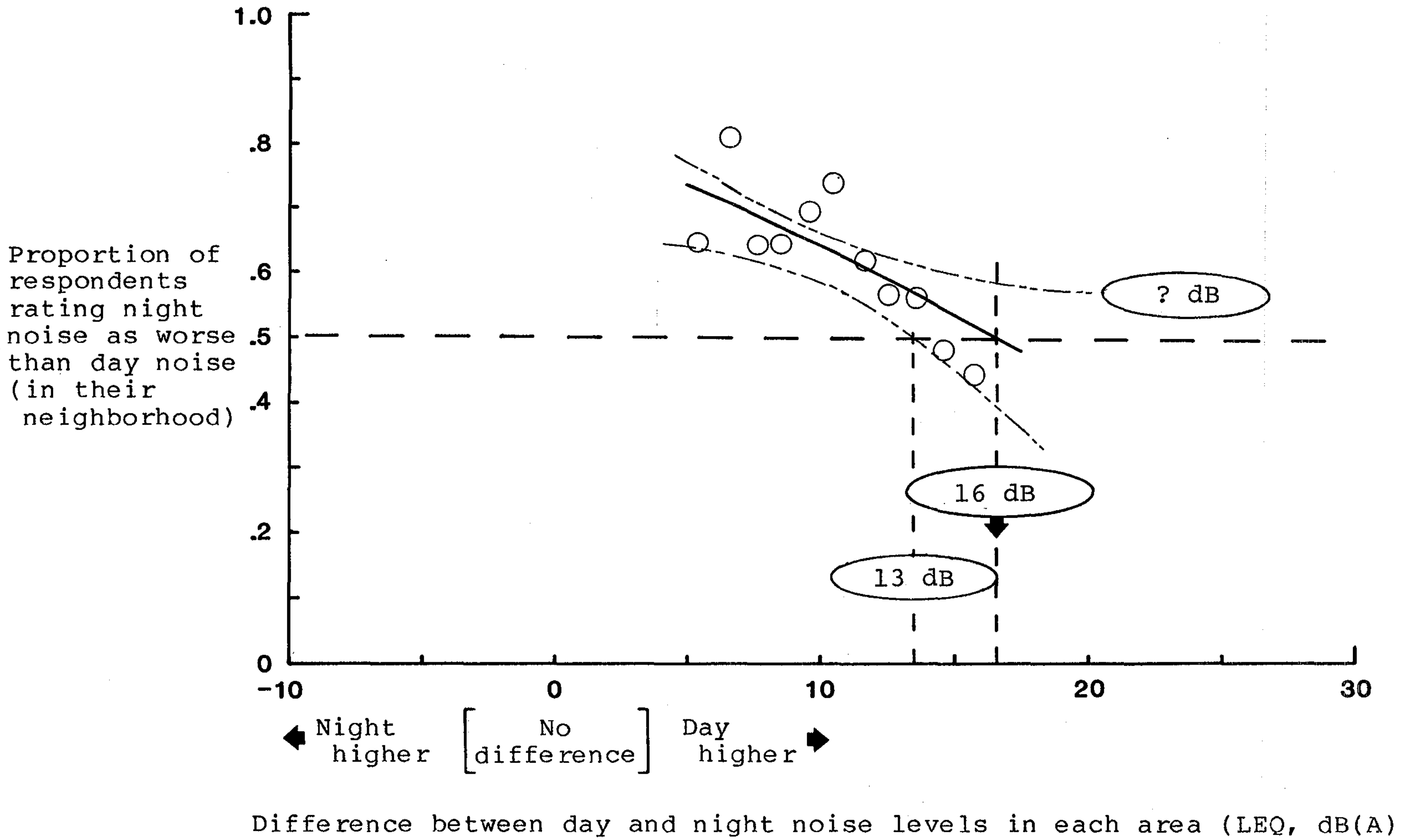


Figure 14. - Confidence interval (95%) for the difference in noise levels at which day and night noise are equally annoying (1967 Heathrow)

(Source: Analyses at NASA performed on the original data set obtained from ESRC data archive)

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15. Supplementary Notes

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16. Abstract

This report examines survey evidence on the relative impact of noise at different times of day and assesses the survey methodology which produces that evidence. Analyses of the regression of overall (24-hour) annoyance on noise levels in different time periods can provide direct estimates of the value of the parameters in human reaction models which are used in environmental noise indices such as LDN and CNEL. In this report these analyses are based on the original computer tapes containing the responses of 22,000 respondents from ten studies of response to noise in residential areas. The estimates derived from these analyses are found to be so inaccurate that they do not provide useful information for policy or scientific purposes. The possibility that the type of questionnaire item could be biasing the estimates of the time-of-day weightings is considered but not supported by the data. Two alternatives to the conventional noise reaction model (adjusted energy model) are considered but not supported by the data.

The importance of noise at different times of day is also analyzed with survey questionnaire items about the amount of annoyance felt at different times of day. The answers to these questions generally indicate that annoyance is greater in the evening or nighttime than during the day. Severe problems in interpreting answers to these questions mean that analyses of the questions can not provide valid estimates of the time-of-day weightings.

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