

THEORIES AND EVIDENCE ON THE EFFECT OF AMBIENT NOISE ON REACTIONS TO MAJOR NOISE SOURCES

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ABSTRACT

This paper reviews nine hypotheses and the evidence from 28 social survey findings about the relationship between residents' annoyance with a major noise source and the acoustical context in which that noise is experienced. Three bases for deriving these hypotheses are identified: acoustical, normative, and environmental. The best available evidence from these surveys of residents' reactions to aircraft and other noise under varying ambient noise conditions indicates that ambient noise in residential areas does not have an important impact on target noise annoyance. Better information about ambient noise effects will require tests of theories of ambient noise effects, stronger study designs and appropriate analysis techniques.

THÉORIES ET ÉVIDENCE SUR L'EFFET DE BRUIT ENVIRONNANTE SUR LES RÉACTIONS À PROPOS D'UNE SOURCE DE BRUIT GRAVE

Cet article évalue neuf hypothèses et l'évidence de plus que vingt études concernant la relation entre nuisance des zones d'habitations par une source de bruit grave et le contexte acoustique où on éprouve ce bruit. On a identifiés trois principes d'où on peut dériver ces hypothèses: acoustique, normatif et l'environnement. Les meilleures preuves disponibles de plus que vingt revues des réactions des habitants à propos des avions et autre bruit sous des conditions de bruit environnante différents indiquent que le bruit environnant dans des régions habitants n'a pas une influence importante dans l'objectif de bruit nuisance dans ces études.

INTRODUCTION

This paper reviews the theories and evidence about residents' reactions to a major noise source (a target noise) in the presence of a second noise source (an ambient noise). A common assumption is that residents' annoyance with a target noise will be reduced in the presence of a loud ambient noise. The assumption is obviously justified if a target noise is rendered totally inaudible by an ambient noise. The assumption is buttressed by fundamental knowledge about the perception of the loudness of tones in the presence of simultaneously presented ambient noise. When the tone and ambient noise are simultaneously presented, there is partial masking. The perceived loudness of the target sound is reduced even though it is still audible (Stevens and Guirao, 1967). Several laboratory studies have found evidence that is consistent with a similar effect for annoyance judgments of more complex target noises (e.g. aircraft) against a simultaneously presented ambient noise (Fidell, et al., 1979; Powell, 1979).

The above findings provide valuable predictions but do not provide firm evidence for determining whether annoyance with an audible target noise in a residential setting will be affected by the more general exterior ambient noise context in which it is experienced. Specifically, it is not clear whether residents' annoyance with one transportation noise source will be affected by the presence of another environmental noise source (usually another transportation noise source). If the

energy-averaging indices are correct, then even total masking of half of the target noise events would generate only a moderate 3-decibel effect on annoyance. For a continuous target noise (e.g. road traffic noise) in the presence of an intermittent ambient noise (e.g. aircraft noise) a masking of even half of the continuous noise events is unlikely. It is also not clear whether exterior environmental noises are important sources of masking noise in a home environment which contains a large amount of self-generated sound from speech, appliances and audio equipment.

This paper reviews the evidence from 28 findings about the annoyance with target noises in residential areas, identifies three theoretical bases for ambient noise effects, discusses analysis techniques which draw new information from existing community surveys and points to needed improvements in new community studies. The evidence includes 6 surveys which were published since the last IC BEN conference in 1988 and updates the evidence from previously published analyses (Fields, 1992a; Fields, 1992b; Fields, 1993).

EVIDENCE FROM COMMUNITY STUDIES

Methodology An examination of over 670 publications from 328 social surveys of noise annoyance has identified the 28 study findings listed in Table 1 which test the assumption that residents' reactions to one noise (a "target" noise) are affected to an "important" extent by ambient noise exposure. The residents' reactions are measured with answers to social survey questions about the extent of annoyance or disturbance from the specified target noise. Five alternative criteria have been used in Table 1 to measure whether there are "important" observed differences between reactions in high and low ambient noise environments. In order of precedence these criteria are: (1) a difference in annoyance which is as large as that associated with a 3-decibel difference in target noise exposure [3dB], (2) a 5% difference in the percentage annoyed [$\Delta 5\%$], (3) an accounting for 1% of the variance in annoyance [$.01r^2$], (4) a $p < .05$ statistically significant difference [$p < .05$], or (5) an unqualified *verbal* statement supporting an effect [Vb]. A detailed description of the methodology has been published (Fields, 1992a).

Results The pie charts in Figure 1 divide the study findings between those supporting an "important" tendency for higher ambient noise to decrease annoyance, those supporting an "important" tendency for ambient noise to increase annoyance and those finding no important effect. The divisions of the charts are based on either the numbers of studies (first column) or the numbers of responses in each study (second column). The numbers of findings and responses appear beside each pie slice. For the first four pairs of charts, the total numbers of studies and respondents below each pie [in square brackets] are smaller than the sums of the slices (in parentheses) because respondents in five of the 23 studies independently evaluated two target noises (e.g. both aircraft and road traffic).

The first pair of charts ("All findings") summarizes the total evidence from 23 studies in which 29,308 respondents made 34,456 evaluations of 28 different target noises. About 23 to 25% of the evidence finds support for the conventional ambient noise assumption (higher ambient noise decreases target noise annoyance); 64-71% finds that ambient noise has no "important" effect and 5-11% finds ambient noise increases annoyance.

The remaining charts in Figure 1 assess the possibility that an ambient noise effect could have been obscured by some types of methodological weaknesses or by the type of noise source. Each of these charts excludes some of the findings which appeared in the "All findings" charts (Row A). Findings for only aircraft noise annoyance are presented in rows E, F and G. Row H presents findings from studies which did not measure ambient noise levels but instead utilized surrogate indicators by contrasting reactions in urban and rural areas or in predominantly industrial and

residential areas.

Three progressively more exclusive definitions of the quality of the findings are presented in Figure 1. The "Standard" findings (Rows B to G) must control for both target and ambient noise level in the analysis and measure the effect size using a 3dB, $\Delta 5\%$, or $.01r^2$ criterion. The rationale for this definition has been presented previously (Fields, 1993). In addition to meeting the "Standard" requirement, the "Standard + better quality noise" findings (Rows C, D, F, G) must either be based on direct noise measurements or on moderately sophisticated noise estimation methods (aircraft noise must be adjusted for variations in operating conditions while road traffic noise must be adjusted for at least the number of vehicles at a site and the distance of dwellings from roads). "Standard + 20 dB range" findings (Rows D and G) meet the previous criteria and also include a 20 dB range in ambient noise exposure.

The data in Figure 1 show that the majority of the evidence from all analyses supports the conclusion that ambient noise does not have an important effect on annoyance in these studies.

EXAMINING THEORETICAL BASES FOR EXPECTING AN IMPACT

Most previous social survey publications have hypothesized that ambient noise would decrease annoyance with aircraft or other "target" noises, but have not been explicit about the theoretical bases for the hypothesis. Several discussions have advanced theories. Powell (1979) has applied a theory of inhibition of annoyance to analyze results from a laboratory study of the annoyance with a total noise environment consisting of multiple sources. Miedema (1984) has provided a review of the literature which highlights both masking and annoyance sensitivity theories of ambient noise effects. The remainder of this section considers three theoretical frameworks to derive nine explicit ambient noise impact hypotheses. Six of the hypotheses predict that higher ambient noise decreases target noise annoyance. Two hypotheses, the sensitizing and synergistic nuisance hypotheses, predict that higher ambient noise increases target noise annoyance. One hypothesis, the independent judgment hypothesis, predicts that ambient noise does not affect target noise annoyance.

Acoustical phenomena A *masking hypothesis* assumes that ambient noise levels mask some target noise events and thus effectively reduce exposure and the resulting annoyance. An *alerting hypothesis* assumes that as the target noise events intrude higher and higher above the ambient noise the target noise involuntarily and annoyingly demands residents' attention. An *anchoring hypothesis* assumes that the ambient noise provides an acoustical calibration point against which target noise is compared. A *sensitizing hypothesis* assumes that higher ambient noise exposure creates increased sensitivity with noise generally.

Personal values Both of these hypotheses assume that quiet neighborhoods either attract or produce residents who are either more sensitive to noise or who place a greater value on quiet environments. A *quietness norm hypothesis* assumes that low ambient noise neighborhoods tend to include residents who highly value quietness. An *escape norm hypothesis* assumes that low ambient noise neighborhoods tend to include residents who place a high value on their residence as a location for escaping from crowded, technologically complex, and, incidentally, noisy urban environments.

Nuisance definition A *baseline nuisance hypothesis* assumes that ambient noise implicitly creates a local definition of an unavoidable noise nuisance against which all other noise nuisances are judged. A *synergistic nuisance hypothesis* assumes that the combined effect of ambient noise and target noise nuisances is to broaden the definition of noise nuisances generally.

Comments While each hypothesis is reasonable, a more careful examination suggests reasons why, as the evidence in Figure 1 suggests, each of the theories might be rejected. For example, the *anchoring* and *sensitizing hypotheses* are weakened by that fact that residential environments include other, more pervasive sounds (voices and household appliances) for calibration points. The *personal value* hypotheses must consider the fact that most previous surveys have not found a relationship between general noise sensitivity and environmental noise levels (Fields, 1992a:25).

Alternative approaches The simple alternative to the previous eight hypotheses is an *independent judgment hypothesis* that assumes that residents judge each environmental noise source independently. The hypothesis assumes, for example, that residents draw on deep-seated values to evaluate the importance of quiet, and use broad-based political/environmental standards to define nuisances.

Another alternative is to recast the ambient noise issue in more complex terms. This perspective suggests that we should not simply be asking "Does ambient noise affect target noise annoyance?" Instead, we should be asking "Are there specific types of situations in which ambient noise affects annoyance and other situations in which ambient noise does not affect annoyance?"

This perspective leads to a restatement of some of the previous nine hypotheses into such speculative, more complex hypotheses as the following: the *alerting hypothesis* is restricted to new residents who have not yet learned to expect intrusive sounds; the *masking hypothesis* is restricted to relatively low-level intermittent target noises (measurable effects are only expected for surveys if inaudible noise events have been included in the calculated noise exposures); the *anchoring hypothesis* is restricted to individuals with very quiet total personal noise exposures; the *baseline nuisance hypothesis* is restricted to clearly preventable target noises in areas that do not contain important non-noise problems; the *escape norm hypothesis* is restricted to rare, truly remote areas where individuals are removed from contact with the manifestations of a technological society (e.g. shopping centers) which are found in suburban and most rural areas.

Inadequate bases Any of the above hypotheses could provide a logical framework for developing a theory of ambient noise effects. However, two fundamental confusions have provided inadequate, less logical support for conventional ambient noise theories.

First, the concept of the comparative ranking of two noises is sometimes confused with the direct rating of the level of annoyance with a single target noise. Which of two noise sources will be comparatively ranked as being relatively annoying will vary with the relative noise levels of the two sources. However, the level of annoyance with each of the individual sources may be completely unaffected by the presence of the second source. Just because one noise source is the "lesser of two evils" may not make that noise source any more acceptable than it would be in the absence of ambient noise.

Second, the concepts of private annoyance feelings and public complaint actions are often confused. Acousticians' and administrators' experiences come primarily from public complaints which, unlike private annoyance, may well be associated with ambient noise. Such an association would be expected if protest organizations direct their limited resources at only one problem at a time, the worst of the worst problems, despite the fact that the importance of other problems is undiminished.

PROPOSED APPROACH TO FUTURE ANALYSES

The balance of the evidence in Figure 1 indicates that ambient noise did not have an "important" impact in most of these studies. However, the published analyses which generated these findings could conceal an impact which has important policy implications. An impact which

appeared to be relatively unimportant in some studies, because only a narrow range of ambient differences was considered, might be important for a policy which considers a very wide range of ambient noise exposures. An impact might also have been concealed if a more complex ambient impact model is appropriate. Two analytical approaches help to address these possibilities.

Equivalent impact ratio In this paper the term "equivalent impact ratio" (R) refers to a measure of ambient noise impact which is unaffected by the range of ambient noise which happens to be included in a study. If annoyance is regressed on noise level, the equivalent impact ratio is found by dividing the unstandardized regression coefficient for ambient noise by the coefficient for target noise. The ratio can be estimated from either linear or non-linear regression analysis. A value of $R=0.2$ indicates that a one-decibel change in ambient noise displaces a dose/response by only 2/10 of the distance which is caused by a one-decibel change in target noise. The standard error of the equivalent impact ratio provides a direct test of the statistical significance of the ambient noise effect and could be used to differentially weight estimates from several studies (on the basis of their precision) to form a pooled, best estimate of the ambient noise effect.

Examining more complex models The more complex, alternative hypotheses which are suggested above imply that analyses must be more complex. Some hypotheses imply that a more complex noise metric than L_{Aeq} or DNL is needed to characterize the noise exposure (for example, a spectra-dependent measure of detectability). While such frequency-spectra data are not available from existing surveys, routinely gathered noise data can be used for other analyses. All hypotheses imply that there are interactions between the ambient noise level and either the target noise level or other variables. Visual displays of target noise dose/response relationships in different ambient noise groups are a simple but effective means of beginning any such exploration. More complex analyses need to be based on models which include interaction effects which can be tested for statistical significance.

LESSONS FROM PREVIOUS STUDIES TO APPLY TO FUTURE RESEARCH

The amount of information that we can extract from previous studies is substantially limited by two aspects of the community survey publications. Firstly, these publications have not discussed in detail the mechanisms which are inherent in the nine ambient noise hypotheses which were outlined above. Secondly, the surveys do not provide detailed information about the environments. The surveys have not, for example, indicated whether any of the target noise was ever inaudible at outdoor locations. Some surveys may have based aircraft noise estimates on annual flight traffic data without determining whether all types of flights in the flight traffic are audible. Other surveys may have based noise estimates on observed noise events and automatically excluded inaudible events.

The review of these studies and of noise studies generally suggests that there is no guarantee that additional, similar ambient noise studies will generate useful new information. Community research will only be valuable if future studies include the following practices: (1) carefully consider both complex and simple theories of ambient noise effects, (2) design studies and measurements to test the theories supporting ambient noise hypotheses, (3) estimate target noise levels which are uncontaminated by noise from other sources, (4) obtain reliable estimates of the target noise levels, (5) report absolute levels of annoyance rather than relative levels of annoyance with each noise source, (6) gather information on the audibility of target noise, (7) report information about the intrusiveness of the target noise, (8) include a sufficient number of study areas, and (9) explicitly control for the effects of confounding area characteristics.

CONCLUSION

The best available social survey evidence (reviewed in Figure 1) does not support an ambient noise effect. Better tests of ambient noise hypotheses require that equivalent impact ratios and their standard errors be compared across studies and that the possibility of interaction effects and non-linear relationships be systematically explored. New studies will only be valuable if they direct their attention at specific, complex ambient noise hypotheses, design samples to test the hypotheses, collect and report relevant acoustical data, and select appropriate analysis techniques.

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Table 1: Findings grouped by direction of ambient noise effect

Title ^a (Catalog ID from Fields (1991))	Crite- rion	Noise ^b		Ambient noise		Number of interviews
		Control (✓)	Qual- ity	Type ^e	Range	
7 findings that ambient noise decreases annoyance						
1984 CEC Aircraft/Road (CEC-3 ^c)	3dB	✓	+	Air	24 L _{Aeq}	1,739
1989 Muroran Road/Rail (JPN-319 ^h)	3dB	✓	+	Rail	19 L _{Aeq}	204
1980 Salt Lake Rating [AIR] (USA-219)	3dB	✓		Comu	30 L _{Aeq} ^f	100
1969 Mixed Road/Aircraft (UKD-033)	3dB	✓		Road	10 L10	315
1990 Toronto Air conditioner (CAN-322 ^h)	3dB	✓		Comu	16 L _{Aeq} ^g	550
1967 Heathrow Aircraft (UKD-024)	.01r ²	No		Road	22 PNDB	4,690
1986 Sydney Aircraft/Road (AUL-307)	Vb	No		Road	30 L _{Aeq}	420
18 findings that ambient noise has no important effect						
1984 CEC Aircraft/Road (CEC-3 ^c)	3dB	✓	+	Road	24 L _{Aeq}	1,739
1982 Heathrow Air/Road (UKD-241)	3dB	✓	+	Road	20 L _{Aeq}	417
1980's Brussels Airport (BEL-288)	3dB	✓	+	Comu	12 L _{Aeq}	677
1972 London Construction Site (UKD-074)	3dB	✓	+	Air Road	0 NNI 17 L _{Aeq}	535
1972 London Construction Site [AIR] (UKD-074)	.01r ²	✓	+	Road Const	17 L _{Aeq} 40 L _{Aeq}	535
1971 3-City Swiss [AIR] (SWI-053)	.01r ²	✓	+	Comu	28 L50	3,930
1971 3-City Swiss [ROAD] (SWI-053)	.01r ²	✓	+	Air	32 NNI	949
1978 Canada 4-Airport (CAN-168)	.01r ²	✓	+	Road	23 L _{Aeq}	670
1969 Mixed Road/Aircraft (UKD-033)	3dB	✓		Air	40 NNI	315
1989 Oslo Airport (NOR-311)	3dB	✓		Road	10 Ldn	3,337
1979 Swiss Gen'l Aviation (SWI-180)	Δ5%	✓		Comu	6 dB ^l	1,010
1972 Paris-Area Railway (FRA-063)	p<.05	✓		Comu	20 L _{Aeq}	350
CEC Impulse [ROAD] (CEC-4 ^d)	Vb	✓		Impulse	45 L _{Aeq}	1,610
1977 Dutch Railway (NET-153)	Vb	✓		Comu	7 L95	670
CEC Impulse Noise (CEC-4 ^d)	Vb	✓		Road	30 L _{Aeq}	1,610
1964 Oklahoma Sonic Boom (USA-012)	Δ5%	No		Area	NA	3,000
1977 Hampshire [ROAD] (UKD-160)	Δ5%	No		Area	NA	1,595
1978 Zurich Night [ROAD] (SWI-173)	Vb	No		Comu	NA	1,600
3 findings that ambient noise increases annoyance						
1975 British Railway (UKD-116)	3dB	✓		Comu	20 L _{Aeq}	1,453
1987 Seoul Traffic (KOR-295)	3dB	No		Area	NA	351
1968 Coventry Railway (UKD-029)	Vb	No		Nbr's	NA	85

Notes: ^aThe target noise appears in bold print. ^b+="better quality noise" as explained in text. ✓=target noise controlled for in the analysis. ^cCEC-3= 3 surveys: FRA-239, UKD-238, and NET-240. ^dCEC-4= 4 surveys FRA-GER-253 IRE-254 NET-255. ^e"Comu" = Community noise, "Nbr's" = neighbors' noise. ^fDescribed only as "dB(A) a study publication. ^g 24-hour L_{Aeq}. ^h Consult the references for these two surveys which were published after catalog (Bradley, 1993; Izumi and Yano, 1990).

Figure 1: Effect of ambient noise on target noise annoyance -- division of evidence

