Seminar on Measuring Social Behaviour in Road Research

SESSION III — PAPER 2

MEASURING DOSE-RESPONSE RELATIONSHIPS FOR ENVIRONMENTAL FACTORS

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ABSTRACT

Using an investigation of the dose-reponse relationship for road traffic noise as an example, this paper examines some of the methodological issues involved in studies which attempt to relate human response to some aspects of the environment. It is intended to highlight some of the difficulties involved and to provide background to policy makers and practitioners who wish to apply the results of such studies. It is suggested that studies of an environmental factor in isolation may give misleading results unless that factor is shown to be of immediate concern to the respondents. The paper examines the difficulty in defining and measuring human response and suggests that frequency of official complaints is likely to be a very poor measure of community response. It shows that psychological and physical factors, independent of the environmental factor of interest, have an influence on the response to that environmental factor; and that this influence may be greater than that of the environmental 'dose'. This means that one is not able to predict an individual's response to a given dose, and instead must rely on predicting the pooled response of groups of people. It is suggested that the range and distribution of the initial data should be examined critically before attempting to apply any results from a study of a dose-response relationship. Finally, the concepts of habituation, suppression and mobility of affected people are introduced as areas requiring further investigation.

1. INTRODUCTION

The rational control of an environmental pollutant requires recognition of its adverse effects, measurement of the amount of pollutant in terms reflecting the amount of adverse effect, and the determination of levels of the pollutant which should not be exceeded if some goal of environmental quality is to be achieved. The first two requirements - recognition of the adverse effects of the pollutant and determination of a dose-response relationship - are proper areas of scientific enquiry. The latter requirement - the setting of goals - must remain part of the social-political process, though a clear statement of the dose-response relationship can ensure that the ramifications of selecting any particular goal are known.

In general, there has been little success in determining the dose-response relationship for environmental factors relevant to roadway planning (Lassiere 1976), though in the last decade and a half there has been considerable activity in examining this relationship for road traffic noise. This activity has resulted from recognition that noise from roadways can have a major impact on the well-being of people - particularly in urban areas - and can be subject to control by roadway, housing or planning authorities.

More than a dozen field studies of the dose-response relationship for traffic noise have been completed in various countries around the world. Included among these are two in Australia. The first, a study of community response to traffic noise near the South-East Freeway in Brisbane, has been reported in Brown and Law (1976 and 1978) and Brown (in press). The second, a survey of 818 people living along 19 roadways in Brisbane, Sydney and Melbourne, has been reported initially in Brown (1978). The latter will be referred to here as the BSM study. In common with all of the overseas studies, these studies required interviews with residents to ascertain the effects of traffic noise and the measurement of the road traffic noise levels to which residents were exposed. All studies attempted to relate the effects of road traffic noise to noise exposure. For example, one such study in the UK (Griffiths and Langdon 1968) led to the adoption there of an L_{10} (18 hour)* of 68 dB(A) as the noise level above which residents affected by increased noise from road traffic would be eligible for compensation under certain circumstances (Noise Insulation Regulations 1973).

It is not the intention of this paper to present the results of these studies of the dose-response relationship for road traffic noise. This has been adequately covered elsewhere. However, it is intended to examine parts of the methodology and analysis common to most of these studies, using the BSM study as an example throughout. The purpose, apart from highlighting some of the difficulties inherent in such investigations, is two-fold. Firstly, these difficulties are likely to be common across studies of human response to other environmental factors, and while little in this paper is new, a discussion of some of the problems illuminated in the BSM study could prove useful in other areas. Secondly, presenting some of the background to studies of the dose-response relationship for road traffic noise may help the practitioner be more sympathetic (and cautious) in the application of the findings of these studies.

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* L_{10} (18 h) is the noise level exceeded for 10% of the 18 hour period from 0600 to 2400 hours.

2. TAKING THE ENVIRONMENTAL FACTOR OUT OF CONTEXT

There is always a danger in attempting to isolate one particular environmental factor in a social survey, in that, taken out of its context, it may assume disproportionate importance during the course of an interview. Its complex interactions with other factors will often not be understood, probably not even recorded. As an example of these complex interactions, Troy (1972) found that only 8% of the variance of residents' opinion of their neighbourhood could be explained by their assessment of the physical environment, and only 4% of the variance of this latter assessment by their attitude to noise.

To some extent, the context of the environmental factor of interest can be examined by masking the purpose of the questionnaire, at least in the initial stages. As an example, Fig 1 presents the results from an early unprompted question in the BSM questionnaire, where the purpose of the survey was still masked. This provided reasonable evidence of the ranking of different environmental factors and of the legitimacy of a specific investigation of the effects of noise from road traffic on the sample of people in the survey. The survey was initially presented to respondents as an attempt to ascertain what people thought of the area in which they lived. By contrast, if the questionnaire survey along the roadways in the BSM study had been concerned with air pollution, it is unlikely that an unmasked survey would have produced results with a similar degree of legitimacy.

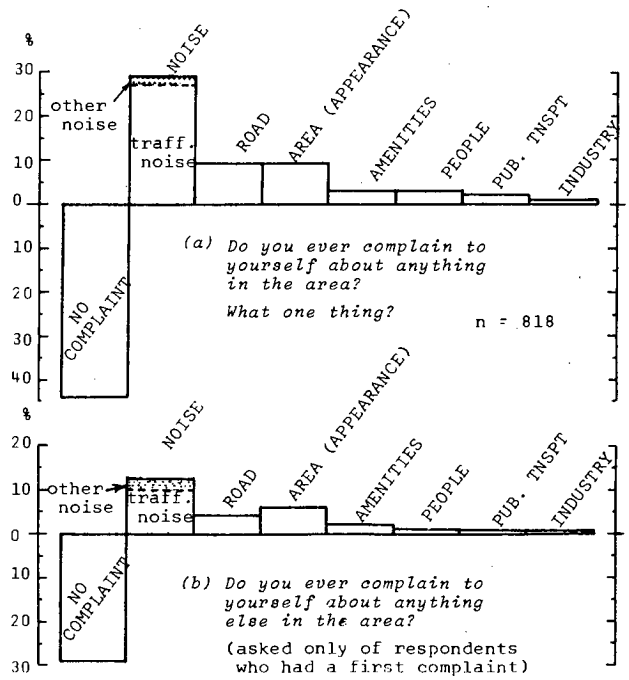


Fig 1 - Proportion of the BSM sample 'complaining' about aspects of their neighbourhood.

3. MEASURING RESPONSE

Are the responses to an environmental factor simple or complex?

The primary instrument used for measuring the effects of noise in the BSM study was a seven-point semantically labelled annoyance scale for the question: 'How much does traffic noise in the area annoy you?' However, traffic noise has other effects besides annoyance : communication interference, sleep interference, the shutting of windows, to name a few. In fact the BSM questionnaire yielded measures on fourteen variables concerning the effects of noise, each representing respondents' opinions about traffic noise and its effects, reported interference with activities, or respondents' actions regarding the noise. Even this list was not necessarily exhaustive.

What were the relationships between these noise-effect variables? Could 'noise-effects' be regarded as a single concept, or did these variables measure various aspects of noise interference? In particular, did a simple self-reported annoyance scale parsimoniously measure all the effects of noise? To examine these questions, noise-effect variables were subject to a principal component analysis, analysing across individuals. The plot of percentage of total variance accounted for by successive factors extracted is shown in Fig 2. This figure indicates the existence of only a single, general factor. While the first factor accounted for only 39% of total variance in the variables, no single additional factor accounted for a high proportion of the remaining variance. Further, factors after the first appeared to have no reasonable interpretation. Each of the variables loaded highly on the first factor, and the concept of 'noise-effects' as a single dimension can be accepted. In addition, the variable loading highest on the first factor was the self-rated annoyance scale. This result is in accord with McKennel (1970) who, in discussing the measurement of the effects of aircraft noise, commented that annoyance-scale responses have been shown to constitute a very robust general factor. Thus a simple self-rating by informants (i.e. How much are you annoyed?) provided a measure of noise-effects that was almost as reliable and valid as one obtained from a scale carefully constructed from answers to a series of questions. It should be noted that this fortunate result is quite unlikely to apply in other areas of attitude measurement, e.g. attitudes to severance caused by road construction. The relationship between annoyance and other effects of noise is further demonstrated in Fig 3.

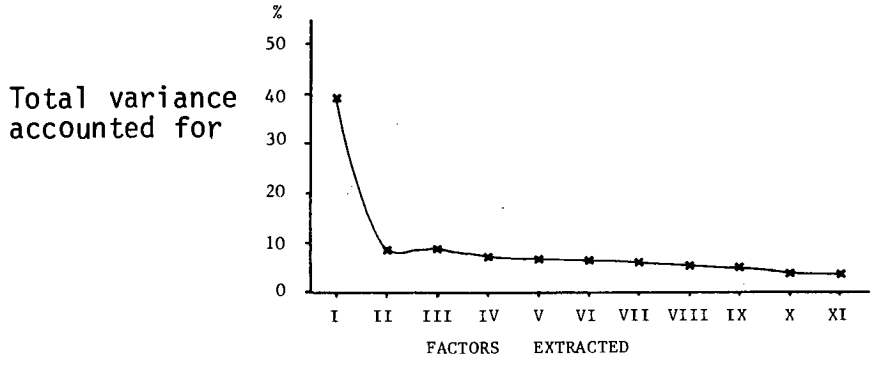
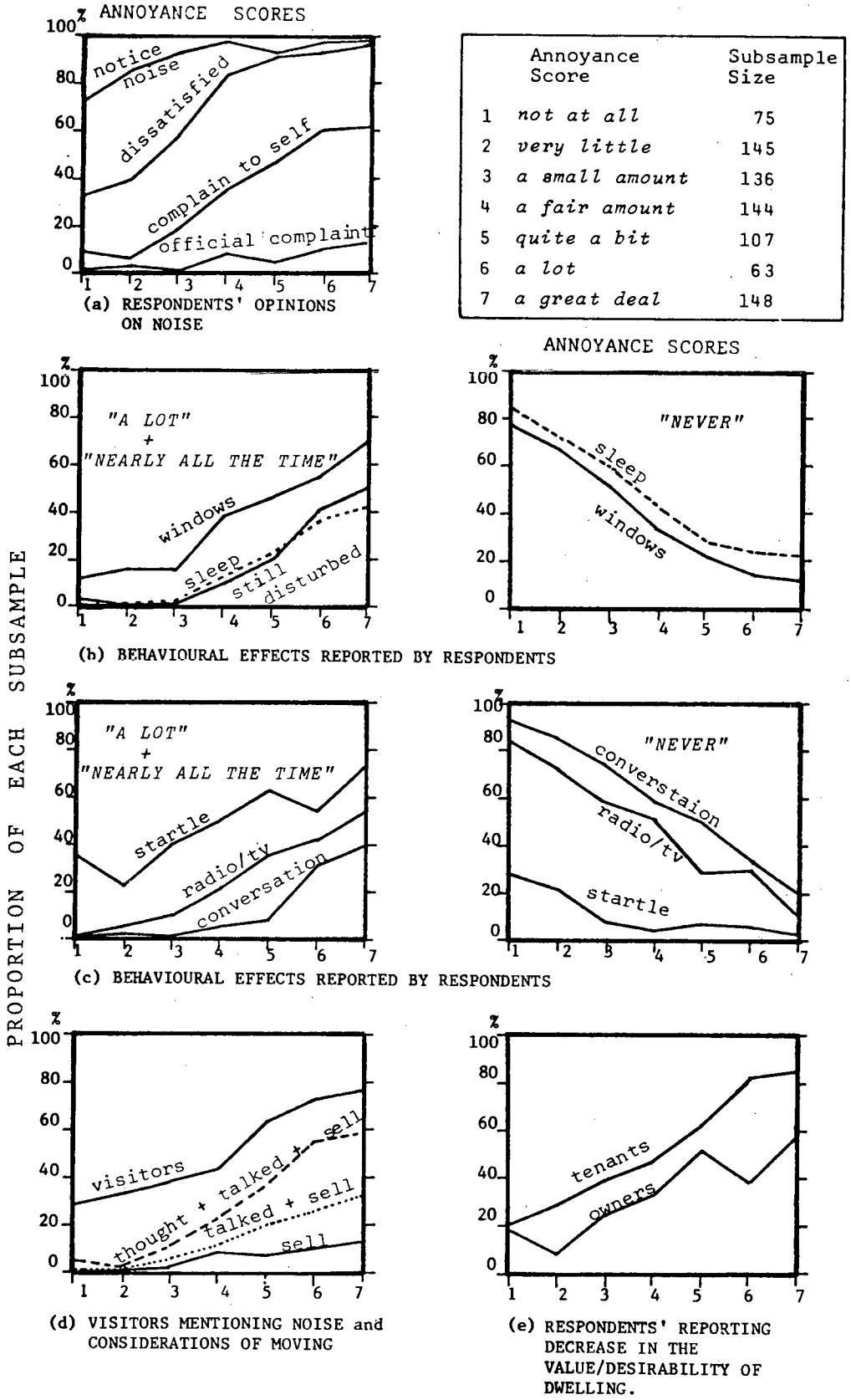


Fig 2 - Percentage of the total variance explained by successive factors in the principal component analysis of noise-effects.



	Annoyance Score	Subsample Size
1	*not at all*	75
2	*very little*	145
3	*a small amount*	136
4	*a fair amount*	144
5	*quite a bit*	107
6	*a lot*	63
7	*a great deal*	148

Fig 3 - Opinions and effects reported by BSM respondents grouped into subsamples of the same annoyance score. The noise annoyance scale and subsample sizes are shown in the top box.

In summary, individuals' self-rating of their annoyance could be regarded as a suitable and comprehensive measure of 'response' in investigating the dose-response relationship for the noise from road traffic.

3.1 OFFICIAL COMPLAINTS AS A MEASURE OF RESPONSE

Is the frequency of complaints to authorities such as local governments, police, etc. a good alternative measure of the response of the community to an environmental factor? It is highly likely, in the absence of specific surveys, that complaints might be the only measure of community response practitioners have available.

Results of the BSM study indicate that complaints are likely to be a very poor measure of response, at least for the response to road traffic noise. For each of the 19 BSM sites, the percentage of respondents at each site who reported having made an official complaint is shown in Fig 4 (5% is approximately 2 respondents). Frequency of complaints bore no relationship to the noise levels along the roadways (within each city, higher site numbers indicate higher noise levels). However, frequency of complaints was much higher along roadways where some form of community action had taken place with respect to the roadway, e.g. petitions, local meetings, etc. This suggests that complaint data is likely to be more a function of level of organisation in the community rather than of the noise 'dose'.

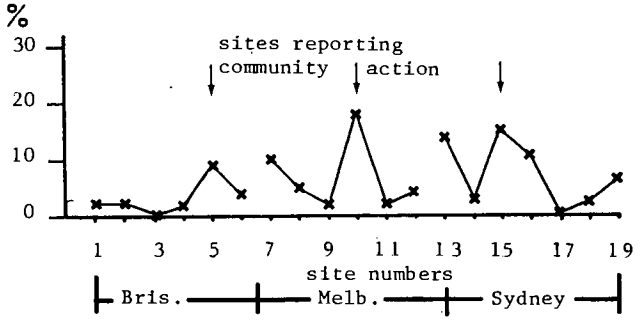


Fig 4 - Percentage of respondents at BSM sites who reported making an 'official' complaint about traffic noise.

4. INDIVIDUAL OR GROUP RESPONSE

While a dose-response relationship may exist for each individual, the relationship appears to be different across individuals, with different responses being recorded for the same noise exposure. This variation has been attributed to factors which intervene in the dose-response relationship; including both psychological factors pertaining to the individual and physical factors pertaining to the immediate environment. In any event, such variation has resulted in very low correlations being reported between the dose of road traffic noise and individual responses in all studies to date, including those reported by the author. This means that one is not able to predict an individual's response to a given noise exposure.

The predictable reaction on the part of researchers is to pool the responses of individuals exposed to the same noise dose. The dose-response relationship can then be examined using this group data. In this manner, most studies have been able to report relationships which would allow 'useful' prediction of group response to a given noise level. Schultz (1972) has categorically supported this pooling by his comment that in setting out to select a suitable rating scale for assessing community noise, for whatever application, no attempt should be made to predict individual response. Instead, one should be concerned with expressing, in physical terms, the magnitude of noise exposure affecting whole neighbourhoods. However, others have argued that the use of group response 'distorts reality' and that the consequences of this are harmful in that the susceptible sections of the population are not accounted for.

It seems inevitable that practitioners must resort to a noise-response relationship based on group data in any planning application. However, any such application must be tempered with the knowledge that the criterion level adopted indicates only the central tendency of human response and is certainly not the level below which no adverse human response will occur. For example, the UK criterion for compensation for noise (68 dB(A)) was based on median response for groups and is set such that one is reasonably confident (1 in 40 chance of being wrong) that half of the people exposed to that noise level will be less than moderately annoyed. The other half, of course, will be more than moderately annoyed. 'Moderate' has been determined arbitrarily by the researchers.

In addition to the likely problem of a criterion level set for *group response* being interpreted in practice as though it were set for *individual response*, it is not out of place here to comment that as soon as any such level is adopted there is a prevalent misconception that it can be used for design purposes as an *environmental standard*. For example, it is clear from the above that the adoption of the UK level of 68 dB(A) as a design goal for new urban areas is unlikely to result in a *desirable* acoustic environment.

Group response can be reported in different ways. The use of the median response for each group introduces no statistical difficulties into the analysis. However, the interpretation of a dose-response relationship based on medians is somewhat clumsy. Alternatively, group response can be expressed as the proportion of people in the group exceeding certain levels of annoyance, e.g. per cent highly annoyed. While these results can be interpreted more easily, there are problems in arbitrarily determining the breakpoints in the scale used to measure response. For example, Fig 5 shows the results of the BSM study in terms of median response, percent 'highly' annoyed, and percent 'moderately' or 'highly' annoyed - the latter two being based on arbitrary breakpoints of 5.5 and 3.5 on the 7 point annoyance scale. The use of terms such as 'moderately' and 'highly' is quite subjective, but can be given some credence if an attempt has been made to calibrate the simple scale of annoyance in terms of other, more tangible, effects of noise, e.g. window shutting, sleep or communication interference.

5. FACTORS INTERVENING IN THE DOSE-RESPONSE RELATIONSHIP

There are difficulties in defining a dose-response relationship where factors unrelated to the stimulus play a significant role in determining an individual's response. Such intervening factors contribute to the low correlations between dose and individual response.

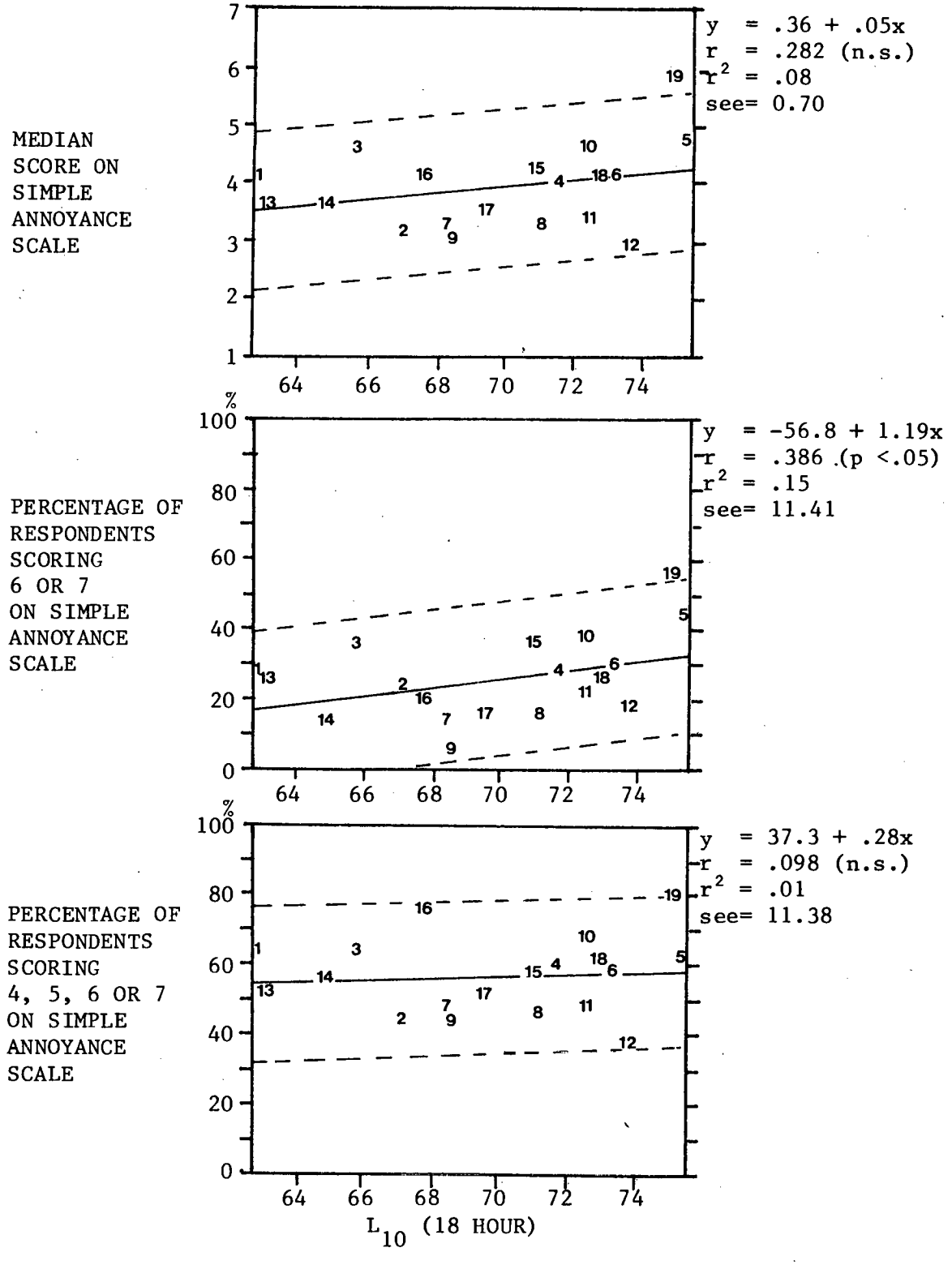


Fig 5 - The relationship of L_{10} (18 h) noise levels to different measures of group response for the 19 sites used in the BSM study.

For the dose-response relationship for road traffic noise, two factors have consistently been reported as significant predictors of individual response : viz, a person's susceptibility to noise annoyance and a person's opinion of the neighbourhood as a place to live. Noise annoyance increases with increasing susceptibility (a psychological attribute invariant with noise exposure) and with decreasing opinion of the neighbourhood. In the BSM study, the importance of these factors was confirmed, and two additional factors - location of activities within the dwelling (i.e. in rooms near the roadway or in rooms away from the roadway) and housing type (high-set house, low-set house or terrace/unit) were also significant predictors. While bearing in mind the instability of regression weights, the following give some idea of the relative influence of these intervening factors on individual response to noise. For a given noise exposure, individuals with low and high susceptibility scores differed by roughly 2.5 points on the 7 point annoyance scale; with poor and high opinion of the neighbourhood, by roughly 1.5 points; with different activity locations by roughly 1 point; and with different housing type, by roughly 0.5 points.

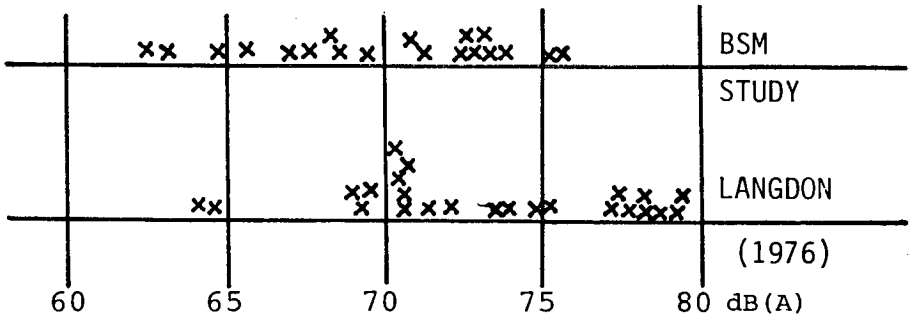
The difficulty for the practitioner is how, if at all, to take account of these intervening variables. It could be argued that their incorporation into planning is necessary if the goal of such planning is to set maximum limits to the response (annoyance) rather than to the dose (noise). However, this author believes that environmental criteria should be applied to the location, rather than to people at that location for the simple reason that, even in the short term, the turnover of dwelling occupants is quite high. Thus intervening factors which are person-specific, susceptibility and opinion of the neighbourhood, are not constant at a location, and even if they could be obtained by survey, have little validity for long term planning. Other intervening factors related to the dwelling structure are more tractable, but as the reliability of these in predicting annoyance is yet to be tested, these too should be ignored for planning purposes. It is suggested that while intervening factors are of little use in planning, practitioners should be sensitive to the effects that they may have on individual response.

6. RANGE AND DISTRIBUTION OF THE DOSE

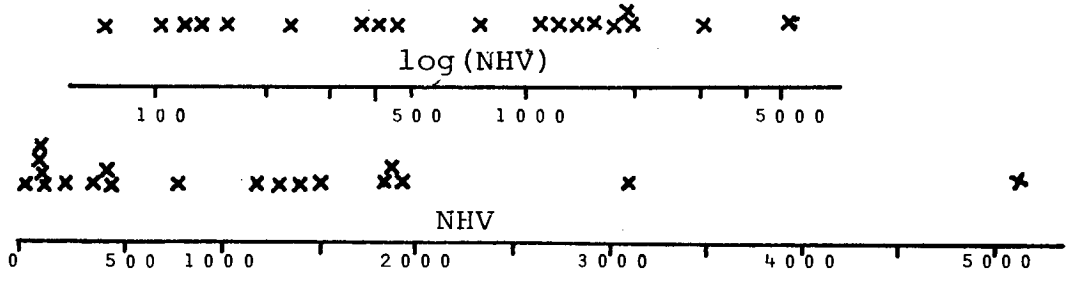
Very few surveys are unrestricted in terms of resources, and in a study of response to an environmental factor this usually means a restriction in the number of sample sites, with two resultant undesirable effects. Firstly, the range of the dose may be restricted. Secondly, the distribution of sample sites across the range of the dose may be unsuitable for correlation analysis. In field studies of environmental factors this problem is often compounded in that the magnitude of the dose at sites selected for the study can only, at best, be estimated during the design of the experiment, and the final range and distribution is often largely fortuitous.

Fig 6(a) demonstrates different ranges and distribution of noise levels used in two studies of the dose response relationship for road traffic noise. The BSM study included no sites with noise levels higher than 75 dB(A) (no noisier roadways fronting residential properties could be located in Brisbane, Sydney or Melbourne) and the Langdon study had few sites below 70 dB(A). Other studies could also be indicated with quite different ranges and distributions. These differences have had little attention in the literature. Most studies rely on finding the best linear relationship between dose and response and report the correlation coefficient from this linear analysis. What happens, in effect, is that each study defines its own noise-

response relationship as the best fitting linear relationship across the (usually limited) range of noise levels encountered in the study. If the dose-response relationship for road traffic noise is, in fact, linear across the complete range of levels of interest, this presents no difficulty. However, if the relationship is curvilinear, then the restriction of range in each study becomes significant, with the linear relationship reported from each study merely indicating a chord of the curvilinear relationship over the restricted range. While the curvilinear relationship in this case is conjectural, the important point is that one should examine the range of the noise-levels reported in such studies, and not rely merely on the reported correlation coefficients.



(a) L_{10} (18hour)



(b) Number of heavy vehicles, BSM Study.

Fig 6 - Range and distribution of some 'dose' variables.

An allied problem is the extrapolation of the observed linear relationship beyond the range of the data. It is interesting to note, in this context, that Langdon's data was used to confirm the suitability of the 68 dB(A) L_{10} (18 h) criterion level in the UK. While 68 dB(A) does not lie outside the range of his data, the paucity of sites with levels less than 70 dB(A) gives some cause for concern.

Not only the range, but also the distribution of the noise levels should be examined. There are pressures on a researcher to report the maximum correlation coefficient that can be extracted from the data, but an example of how the distribution of the dose can influence the magnitude of the correlation coefficient is shown in Fig 6(b). In the BSM study, the highest correlation coefficient reported was that between the number of heavy vehicles using the roadway (NHV)* and annoyance scores ($r = 0.72$). However,

* NHV can be regarded as a proxy acoustic dose by considering it as an indicator of number of 'noisy' events.

the high positive skewness of this variable has noticeably inflated the correlation coefficient, i.e. the two high values of NHV have had undue influence. However, the log transform of the dose (log(NHV)) had a near uniform distribution and its correlation with annoyance can be accepted at face value ($r = 0.52$). Blind acceptance of a researcher's reported correlation coefficient, without examination of the distribution of the variables, is to be discouraged.

7. HABITUATION, SUPPRESSION AND MOBILITY

Finally, there are several other questions which should be raised in any study of a dose-response relationship - though as yet they have had little quantitative investigation, or even recognition. They include habituation, suppression, and the mobility of susceptible fractions of the exposed population. Using noise from traffic as an example, *habituation* is the phenomenon which imputes that response to a given noise exposure decreases over time. It is evidenced by statements such as 'but you get used to it', although two minor studies have failed to measure any such phenomenon. *Suppression* is another mechanism which may affect the dose-response relationship. It is suggested that people may be affected to a greater extent than indicated by their self-reported annoyance. Given that many respondents in the BSM study commented on the inevitability of the continuation of high traffic noise levels at their dwelling, it is not unreasonable to speculate that they may invoke some defence mechanism which lowers their expectations of their acoustic environment. It is suggested that these respondents may be surprised at how much the noise had affected them if for some reason the noise was eliminated.

Finally, in areas exposed to higher noise levels it is possible that the annoyance-susceptible fraction of the population may be more *mobile* than other fractions. Over time, this results in lower levels of community annoyance. The BSM study clearly indicated the mechanism by which noise-susceptible residents could be removed from areas of high noise level, though this cannot be verified without time-series data.

It is suggested that these speculative phenomena should be kept in mind when examining or planning any study of a dose-response relationship, especially if some change in the dose has occurred, e.g. the opening of a new roadway.

8. CONCLUSION

Field studies of dose-response relationships for environmental factors are likely to be time consuming and relatively expensive because gathering data on human response is generally labour-intensive. For this reason a certain amount of reliance will have to be placed on studies from overseas countries in the formulation of a criterion level for adoption in Australia. Hopefully, this paper may encourage critical examination of the data used in such studies so that debate about which criterion level to adopt will be based on an understanding of what that level means in terms of human response; rather than on some vague notion that an environmental factor becomes 'unacceptable' at some specified level.

In addition this paper has highlighted some of the methodological issues which should be confronted in future studies.

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