The noise-response relationship near a freeway

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THE NOISE-RESPONSE RELATIONSHIP NEAR A FREEWAY

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ABSTRACT

A correlation analysis is reported relating the noise annoyance of 142 respondents near the South-East Freeway in Brisbane to noise levels measured at 17 locations. No relationship was found between individuals' annoyance scores and noise levels. However, respondent opinion of the neighbourhood and noise annoyance susceptibility were together found to explain 16% of the variance in individual scores. Median annoyance scores for groups of respondents also were not significantly related to noise levels. It is suggested that these non-significant correlations have resulted from the small range and lower magnitude of noise levels relative to those pertaining in similar studies overseas. While the present data do not assist determination of maximum noise levels for use in roadway and land-use planning, one can be confident that an L_{10} *(18h) of 60 dB(A) would generally be regarded as 'acceptable'. Acceptable levels in terms of* L_{eq} *(1h) and* L_{10} *(1h) are also given. However, there is need to be cautious in applying these results to locations where noise level variability has not been similarly reduced through distance attenuation.*

INTRODUCTION

1. Brown and Law (1976 and 1978) have reported on a study of noise annoyance and other effects of traffic noise for residents adjacent to a section of the South-East Freeway in Brisbane. In addition noise levels have been measured near dwellings in the same area and the full set of noise data is available in Brown (1978*a* and *b*). This paper reports the correlation of residents' noise annoyance with measured noise levels near the freeway.

2. From the outset, it should be noted that the levels to which dwellings in the study area were exposed were lower, and covered a more restricted range, than those reported in overseas studies of the noise-response relationship for road traffic noise. These lower levels have resulted primarily from divergence over the relatively large distances between the vehicles on the freeway and the dwellings. Measured noise levels ranged from 55 dB(A) to 67 dB(A) on the L_{10} (18h) scale*, with most dwellings subject to levels in the lower portion of this range.

3. The annoyance survey was undertaken in August-September 1974 and noise level measurements in October-December 1974. At that time the total two-way flow on the freeway was approximately 44,000 veh/d with heavy vehicles estimated at less than 5% of the traffic stream. Details of freeway geometry and traffic flow on the surface streets are given in Brown and Law (1976).

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

THE SAMPLE OF RESPONDENTS

4. The study area used in the original annoyance survey is shown in Fig 1. Questionnaires had been completed by 288 respondents living adjacent to this 2 km length of the first stage of the South-East Freeway. It was not possible to measure the noise exposure of the whole sample and the correlation analysis reported here is based on a subsample of 142 respondents.

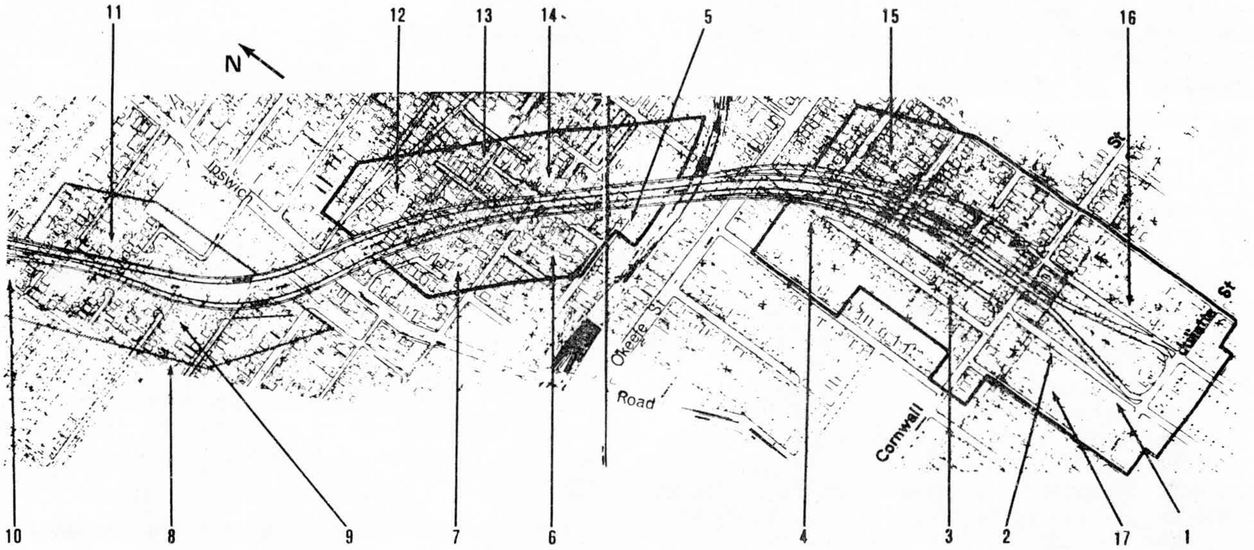

Fig 1 - Boundaries of the study area and location of the 24 hour noise measurement sites.

TABLE 1

DISTRIBUTION OF ANNOYANCE SCORES IN THE ORIGINAL SAMPLE AND IN THE SUBSAMPLE WHOSE NOISE EXPOSURE WAS MEASURED

Annoyance* Score	Original† sample (n = 288)	Subsample whose noise exposure was measured (n = 142)
1	28.3%	31.7%
2	33.6%	31.7%
3	17.5%	18.3%
4	9.4%	9.2%
5	5.2%	5.6%
6	3.1%	2.1%
7	2.8%	1.4%

* Higher numbers indicate higher annoyance.

† Brown and Law (1976 and 1978).

5. It can be seen from Table 1 that the distribution of annoyance scores in the subsample was similar to that in the original sample of 288, but with a slightly lower reporting of high annoyance scores. Both distributions had high positive skewness with few respondents scoring high on the annoyance scale. Some respondents not included in the present subsample of 142 were those who lived in dwellings fronting the surface streets providing access to the freeway ramps (i.e. Cornwall and Juliette Streets in Fig 1). These respondents had reported, on average, higher annoyance scores than any other group in the freeway sample. They will be referred to again later in this paper.

NOISE MEASUREMENTS

6. The study area was acoustically complex with multiple source roadways (separately aligned freeway carriageways, ramps and surface streets) and non-parallel alignment of these roadways and dwelling facades. Noise levels were measured at 17 locations in the study area, selected so that each measurement would be representative of the levels incident on as many adjacent dwellings as possible. 'Representativeness' was determined by field inspection with the emphasis on caution in excluding dwellings with different noise level exposures. Instrumentation available at the time of the study did not enable quantification of any difference in exposure between dwellings grouped about a single measurement site. While this grouping procedure has obviously introduced some error, it is believed that it has provided the best available measure of respondent exposure (short of one noise level measurement at one or more facades of each dwelling) given the complex acoustic terrain. The number of respondents' dwellings grouped about a measurement site ranged from 4 to 17.

7. Noise levels were measured at each of the 17 sites for one 24 hour period of a weekday. Measurements were not located at dwelling facades (because of their non-parallel alignment with the source roadways) but

instead were located inside the grounds of residential properties but as far from building surfaces as possible. Variable reflection conditions would have existed at sites but small effects on the measurements so introduced have not been quantified.

8. All measurements referred to in this paper are 'in the absence of a facade'. Approximately 2.5 dB(A) must be added to them to equate them to measurements made where a facade is present. Design levels for highway noise in the U.S.A. are given as levels measured in the absence of a facade but the present U.K. criterion for compensation is based on facade measurements.

9. The distribution of the 17 sites across the range of noise levels measured and the proportion of the sample of 142 respondents represented at each site are shown in Fig 2.

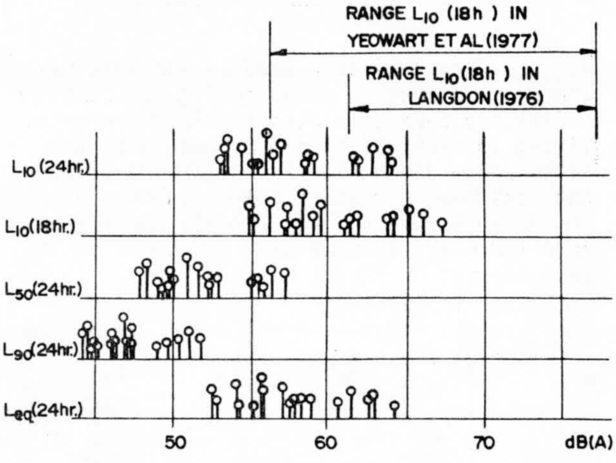

Fig 2 - Range of noise scales at the 17 Freeway sites. The height of each stem indicates the proportion of the 142 respondents grouped at each site. To facilitate comparison the ranges used in the Langdon (1976) and Yeowart et al (1977) studies have been corrected to measurements taken in the absence of a facade.

NOISE-RESPONSE MODEL AND SCALE OF ANNOYANCE

10. A conceptual model of the noise-response relationship for people in their homes is shown in Fig 3. The model has three parts: noise, intervening variables and effects of noise. The freeway study collected data on all variables shown in the figure and each was included at some stage of the correlation analysis. However, only the more important results are reported below. The techniques used to measure each variable have been fully discussed in Brown and Law (1976 and 1978).

11. With regard to the effects of noise it is sufficient here to note that a simple self-rated scale of annoyance succinctly measured all the effects reported by a respondent. This simple annoyance measure was obtained by asking during the household interview 'Looking at this card, to what extent does traffic noise in your area annoy you?', with an accompanying show-card labelled :

not at all
very little
a small amount
a fair amount
quite a bit
a lot
a great deal

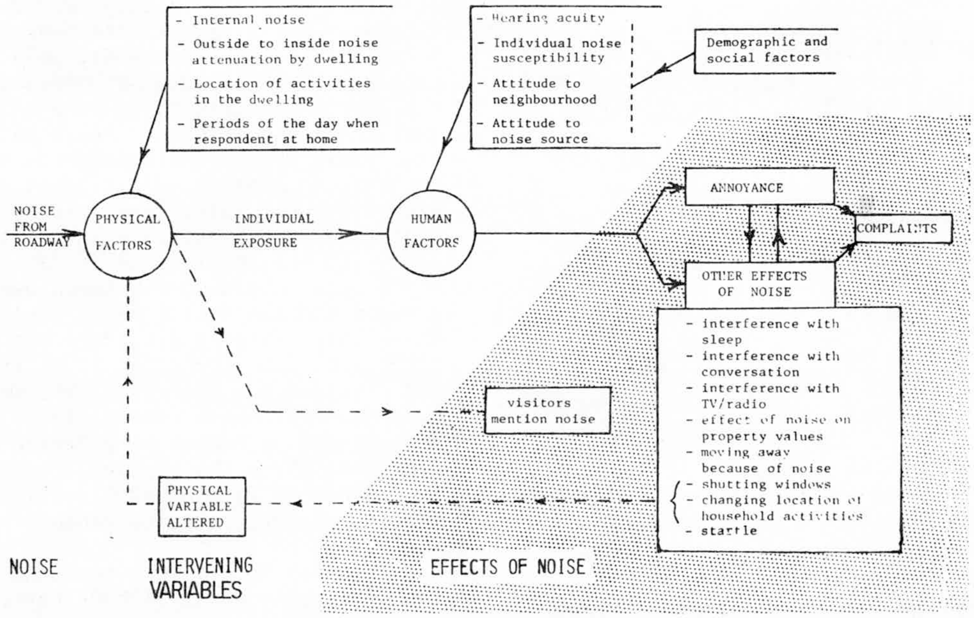

Fig 3 - A conceptual model of the relationship between road traffic noise and its effects on people in their homes (after Brown and Law 1976).

For convenience in this paper the numerals 1 to 7 will be used as surrogates for the semantic labels of the scale*, the higher numbers indicating higher annoyance.

CORRELATION OF NOISE LEVELS WITH ANNOYANCE

12. Two approaches can be adopted when attempting to correlate annoyance scores with noise levels. Individual respondents' annoyance scores can be related to noise levels, or individuals who are subject to the same noise exposure can have their annoyance scores pooled and this group annoyance score can be related to the noise levels. Both approaches are adopted here. Schultz (1972) has argued that practical noise control measures have to be based on group response. However, others (e.g. Bryan and Tempest 1972) point out that the consequence of using group response is harmful in that susceptible sections of the population are not accounted for.

INDIVIDUAL RESPONSES

Bivariate Correlations

13. Pearson product-moment correlation coefficients† were computed between individual respondents' annoyance scores and a variety of measures of the noise levels to which each respondent was exposed. Noise measures consisting of different noise scales and different periods of aggregation were used (all measures have been fully defined in Brown (1978*a*)). The results are shown in Table II. Only one of the coefficients was significant at the 0.05 level. It is quite clear that with this one exception there was no relationship between traffic noise annoyance and any of the physical measures of noise level. Individual annoyance scores have been plotted against one of the noise scales L_{10} (18h) in Fig 4 though from the lack of any significant relationships in Table II and the known high intercorrelations between most of the noise level measures (Brown 1978*a*) different scales would have produced similar plots.

TABLE II

PEARSON PRODUCT-MOMENT CORRELATION COEFFICIENTS (r) BETWEEN INDIVIDUAL RESPONDENTS' ANNOYANCE SCORES AND NOISE SCALES

NOISE SCALE	24h	18h 0600-2400	12h 0600-1800	12h 1800-0600	6h 1500-2100
L_{01}	0.08	0.08	0.09	0.06	0.10
L_{05}	0.04	0.05	0.04	0.05	0.06
L_{10}	0.05	0.05	0.04	0.05	0.06
L_{50}	0.04	0.05	0.04	0.03	0.06
L_{90}	0.02	0.03	0.01	0.03	0.04
L_{99}	-0.02	-0.02	-0.06	0.03	0.01
L_{eq}	0.05	0.05	0.05	0.05	0.05
L_{np}	0.06	0.07	0.07	0.06	0.07
σ	0.09	0.11	0.14*	0.05	0.06
TNI	0.06				
L_{dn}	0.04				
L_{10}(1h:max)	0.04				
L_{eq}(1h:max)	0.04				

n = 142   *$p < 0.05$

Noise scales have been defined in Brown (1978*a*).

L_x(1h:max) = maximum L_x(1h) recorded in 24 hour period.

* Brown and Law (1976) reported annoyance scores which were an average of scores on two scales applied during the household interviews: Scale A, a seven-point semantic differential scale of dissatisfaction and Scale B, the seven-point semantically labelled annoyance scale given above. They found that Scale B performed as well as the averaged scale and better than Scale A when correlated with the other effects of noise. Scale B is used here exclusively though correlations using either Scale A or the averaged scale were found to be little different.

† The square of the Pearson product-moment correlation coefficient indicates the proportion of the variance of two variables which is common, e.g. if r = 0.8, 64% of variance is shared, if r = 0.2, only 4% of the variance is shared.

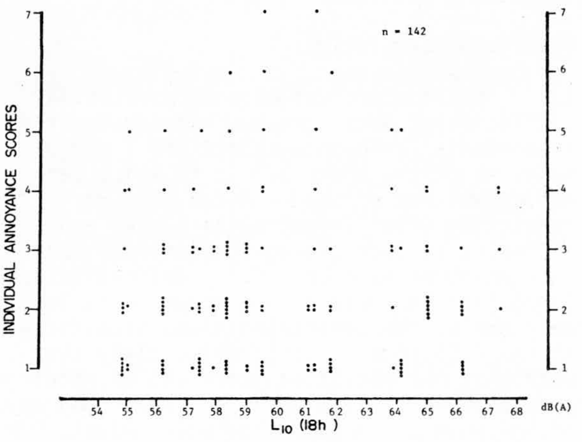

Fig 4 - Individual annoyance scores plotted against L_{10} (18h).

Noise Pollution Level (L_{np})

14. The only noise measure correlating significantly with annoyance was the standard deviation (σ) of the noise levels measured over the daytime period 0600 to 1800 hours, with the trend being increasing annoyance with increasing variability in the noise. However, while significant, the relationship was hardly substantial with only 2% of the variance in annoyance being explained. To examine if the variability of the noise combined with its level might be a better predictor of annoyance,a multiple regression analysis was used with annoyance as criterion and σ and the Equivalent Continuous Sound Level (L_{eq}) as predictors (i.e. the Noise Pollution Level Concept,$L_{eq} + k\sigma$,but allowing the regression procedure to determine the optimum value of the coefficient k). Three periods of the day were used - 24 hours, 0600 to 2400 hours and 0600 to 1800 hours - but none of the correlations were significant on the 0.05 level.

Intervening Variables

15. The effect of the intervening variable on annoyance scores was examined by a stepwise (forward) regression procedure with the simple annoyance scale as criterion and each of the intervening physical, psychological and social variables as predictors. One of the noise scales,L_{10} (18h),was also included as a predictor. The analysis was stopped when a variable failed to contribute significantly to the explained variance in annoyance ($p < 0.05$). Only two variables contributed significantly: opinion of the neighbourhood and susceptibility to noise annoyance.* Between them they explained 16% of the variance in annoyance scores. Respondents with a poor opinion of their neighbourhood reported higher annoyance scores than those with a good opinion of their neighbourhood and respondents with higher noise annoyance susceptibility scores reported higher annoyance. As to be expected from the low bivariate correlation,the noise scale,L_{10} (18h),still did not contribute significantly to explained annoyance nor did any of the demographic or housing variables. The results of the analysis are shown in Table III.

TABLE III

MULTIPLE REGRESSION ANALYSIS PREDICTING INDIVIDUAL'S NOISE ANNOYANCE FROM INTERVENING VARIABLES

	R	R^2	R^2 change(%)	$F_{1,139}$
Opinion of neighbourhood	0.326	0.106	10.6%	14.2
Noise susceptibility	0.402	0.162	+5.6%	8.5

The Coefficient of Determination R^2 can be interpreted in a similar way to the square of the Pearson product-moment correlation coefficient, i.e. proportion of variance explained.

Coding of opinion of neighbourhood was :
excellent = 1 good = 2
poor = 3 very good = 4

GROUP ANALYSIS

Bivariate Correlations

16. Median annoyance scores were computed for each group of respondents at a measurement site and Pearson product-moment correlation coefficients calculated between these group scores and noise levels. The coefficients are shown in Table IV. Most of the correlation coefficients did not reach significance at the 0.05 level; the exceptions being the L_{01} (6h) and the standard deviations of the noise levels. However when group annoyance was plotted against a selection of the noise scales (Fig 5), it can be seen that whereas on most of the scales sites were uniformly distributed across the range, on the L_{01} (6h) and standard deviation scales one site has unduly influenced the product-moment coefficient. This site (Site 1 in Fig 1) was close to the freeway on-ramp and had the highest levels recorded at any of the 17 sites. The analysis was repeated with this site excluded - with the result that there were no significant correlations between group annoyance and any of the noise scales. The noise scales shown in Fig 5 were chosen to illustrate the lack of a linear relationship between group annoyance and any of the peak, median, background or variability measures of the noise distributions.

* The measurement of these variables is discussed in detail in Brown and Law (1978).

TABLE IV

PEARSON PRODUCT-MOMENT CORRELATION COEFFICIENTS (r)
BETWEEN GROUP ANNOYANCE SCORES AND NOISE SCALES

	24h	18h 0600-2400	12h 0600-1800	12h 1800-0600	6h 1500-2100
L_{01}	0.31	0.33	0.33	0.28	0.45*
L_{05}	0.25	0.27	0.24	0.27	0.33
L_{10}	0.25	0.26	0.24	0.26	0.32
L_{50}	0.15	0.22	0.21	0.06	0.24
L_{90}	0.04	0.12	0.13	-0.06	0.17
L_{99}	-0.10	-0.02	-0.07	-0.12	0.14
L_{eq}	0.28	0.28	0.26	0.32	0.33
L_{np}	0.34	0.36	0.33	0.37	0.40
σ	0.45*	0.47*	0.49*	0.39	0.38
TNI	0.38				
L_{dn}	0.22				
L_{10}(1h:max)	0.27				
L_{eq}(1h:max)	0.27				

$n = 17$ $\quad$ $*p < 0.05$

Noise Pollution Level

17. As was done for individual annoyance a Noise Pollution Level function ($L_{eq} + k\sigma$), was regressed against group annoyance. Again the correlation was not significant at the 0.05 level for any period of aggregation.

Intervening Variables

18. Mean values were calculated for each site on most of the intervening variables shown in Fig 3 and these means were used in a multiple regression analysis to predict group annoyance scores. None of the mean values of the intervening variables contributed significantly to the explanation of group annoyance scores at the 0.05 level.

DISCUSSION

19. The present data do not support the proposition that traffic noise annoyance is significantly related to measured traffic noise levels. The question must be asked: why are the results of this study so different from those of other investigations of the noise-response relationship? For example, Langdon (1976) reported Pearson product-moment correlations of individual annoyance with noise scales of the order of 0.2 and of group annoyance with noise scales of the order of 0.8. In particular for freeway -type roadways, Yeowart, Wilcox and Rossall (1977) reported group correlations of 0.8 near motorways in Manchester in the U.K. and Jenkins and Pahl (1975) reported correlations for individuals of 0.2 to 0.3 near freeways in Los Angeles in the U.S.A.

20. It would appear reasonable to attribute the lack of any correlation in this study to the lower range of noise level exposure experienced by respondents near the freeway. For example, the ranges used by Langdon (1976) and Yeowart et al (1977) in their studies of the noise-response relationship - corrected to noise levels measured in the absence of a facade - are compared to the freeway data in Fig 2. The differences in ranges are, of course, a function of factors such as shielding and distance from the source and not necessarily indicative of different noise emission levels from the roadways in the various studies.

21. The different results can be reconciled by postulating a form of the noise-response relationship illustrated in Fig 6. This

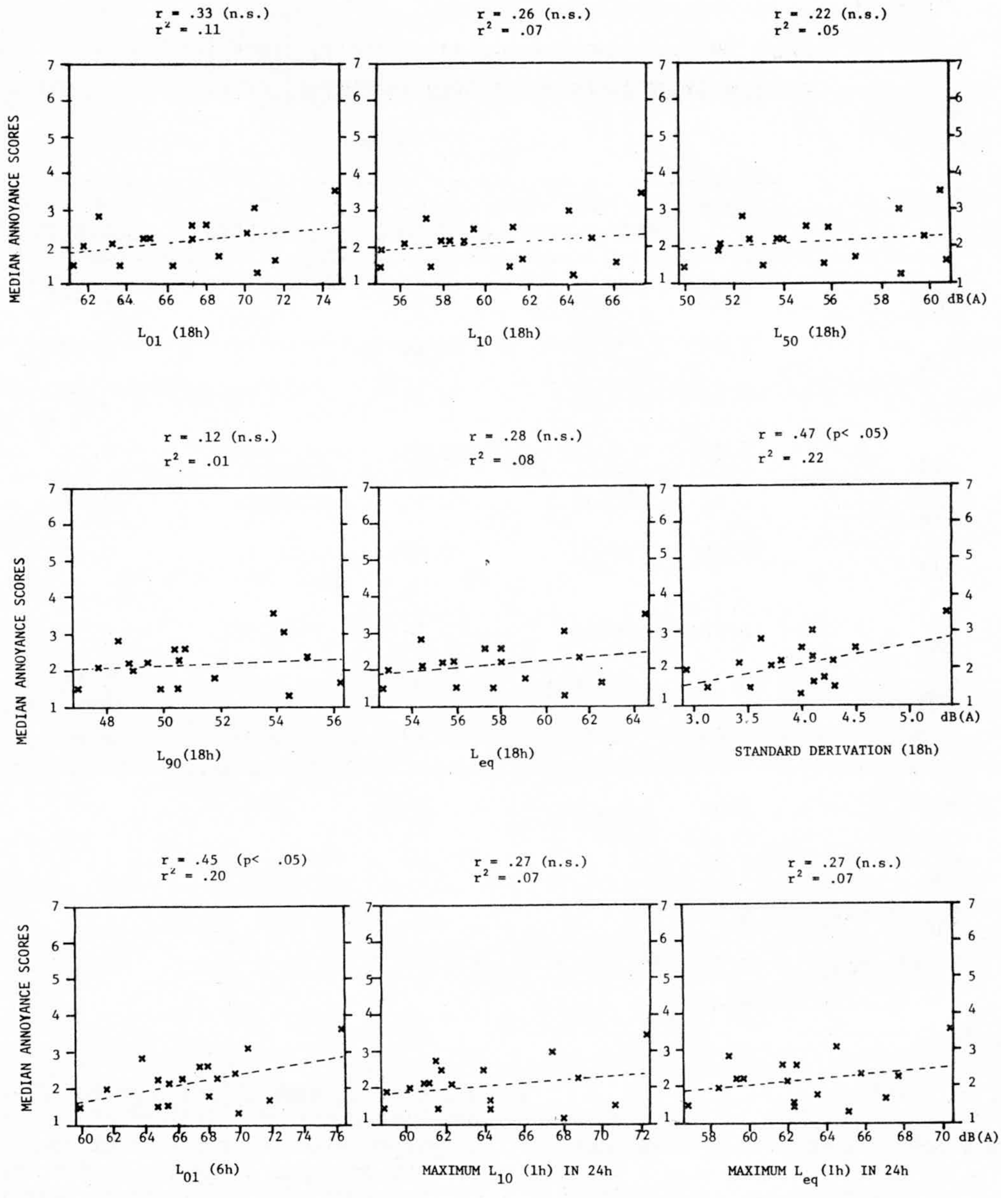

Fig 5 - Group annoyance scores plotted against various noise scales. The regression lines are shown broken.

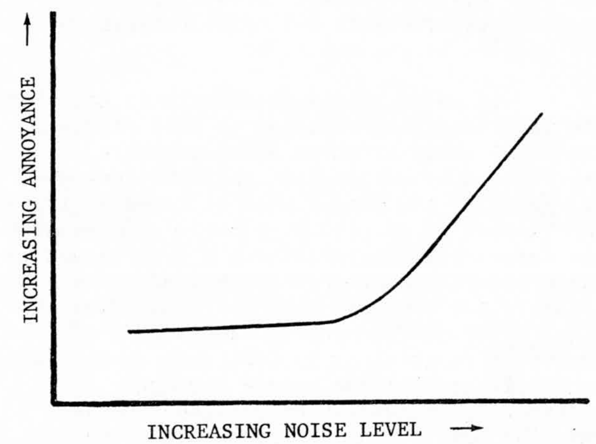

Fig 6 - Postulated noise-response relationship.

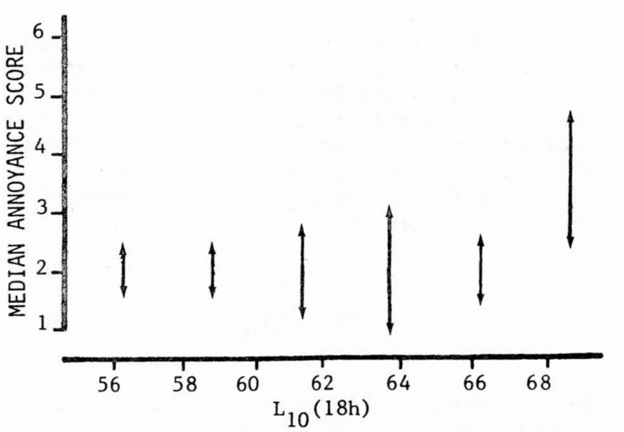

Fig 7 - 95% confidence intervals for median annoyance score of subsamples of respondents when grouped into 2.5 dB(A) wide exposure cells. Varying intervals are mainly a function of different subsample sizes.

suggests that at lower noise levels median annoyance scores are relatively low but, above some 'threshold', median annoyance increases steeply. It is suggested that noise levels in the present study fell mainly along the low gradient leg of the curve in Fig 6. Non-linear noise-response relationships have also been suggested by other authors (e.g. Stevens, Rosenblith and Bolt 1955; Langdon in Alexander et al 1975) though most have suggested a sigmoidal relationship with no-one annoyed at lowest noise levels and everyone annoyed at highest noise levels.

22. However, because of limitations in the present data it would be a gross misinterpretation to infer that the 'threshold' or turning point in the curve necessarily occurs at a noise level higher than those measured in the present study. As was illustrated in Fig 2, the sample of respondents was predominantly concentrated at lower noise levels (half of the respondents were subject to L_{10} (18h) of less than 60 dB(A)) and the number of respondents grouped at any measurement site was small.

23. The effect of this is best illustrated in Fig 7 where 95% confidence intervals* for the median annoyance scores of respondents grouped into 2.5 dB(A) bands of noise exposure have been shown. The narrow confidence limits at the lower levels (resulting from most respondents being exposed to low levels) can be contrasted to the generally wider limits at higher noise levels. Fig 7 shows basically the same data as the L_{10} (18h) plot of Fig 5. The data in Fig 5 give little suggestion of a curvilinear relationship but in Fig 7 various relationships are possible ranging from a linear one to one including that postulated in Fig 7. In the extreme a 'threshold' could occur as low as 60 to 62 dB(A).

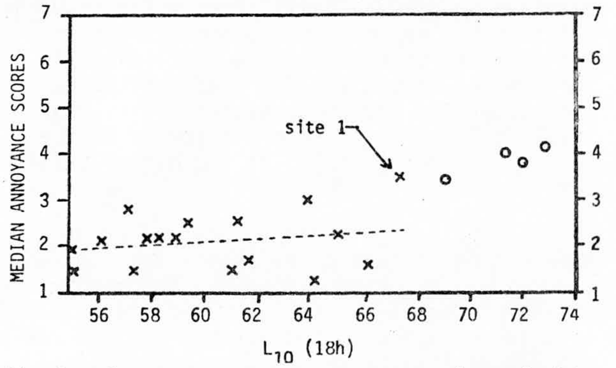

Fig 8 - Group annoyance scores supplemented by data (o) from the surface roadways which provided access to the freeway ramps.

24. In summary the present data are inadequate for determining the form of the noise-response relationship and provide little assistance in determining maximum noise levels for use as acoustic criterion in land use and roadway planning. However, they do allow specification of levels which are known to be 'acceptable' (i.e. most people exposed to such levels would report low annoyance). Because of the large number of respondents at lower noise levels one can be confident that median annoyance scores are likely to be low if L_{10} (18h) levels are less than 60 dB(A). These limits are, of course, particular to the present data and a larger sample of respondents at levels higher than 60 dB(A) may indicate that some higher level was also acceptable.

25. Similar statements of acceptability can be made using scales simpler than the L_{10} (18h). For example, one can be confident that maximum L_{10} (1h) of 65 dB(A) or maximum L_{eq} (1h) of 63 dB(A) would generally be regarded as acceptable. In this study, maximum one-hour levels always occurred during the morning or evening peak hours.

26. It is fruitful to compare the results to criteria in use elsewhere. The Federal Highway Administration in the U.S. has set design noise levels (L_{10} (1h)) as follows :

60 dB(A) - Tracts of land in which serenity and quiet are of extraordinary significance.

70 dB(A) - Residences, hotels, schools, etc.

These levels are to be used in planning new highways and are presumably intended to produce an 'acceptable' acoustic environment (U.S. Dept. of Transportation 1973). In the U.K. The Noise Insulation Regulations (1975) have adopted an L_{10} (18h) facade level of 68 dB(A) (65.5 dB(A) in the absence of a facade) as that above which certain dwellings are eligible for acoustic treatment. This criterion is for compensation purposes and is not intended as a design level for planning an 'acceptable' acoustic environment. The finding in the present study that an L_{10} (18h) of 60 dB(A) or an L_{10} (1h) of 65 dB(A) were regarded as 'acceptable' is clearly not in conflict with these overseas criteria.

SUPPLEMENTARY DATA

27. In para 5 mention was made of respondents in dwellings fronting the surface streets which provided access to the freeway ramps. Noise level measurements were not available for these respondents and they were not included in the subsample of 142 used in the previous analyses. However, it is a simple matter to estimate the noise levels

* The standard error of estimate for the median of a sample, size n, with standard deviation s, is given by 1.25 s/$\sqrt{n}$. 95% confidence limits for the median annoyance score at a site ranged from $\pm$ 0.5 to $\pm$ 1.8 units on the simple annoyance scale.

(L_{10}) at these dwellings using the DoE procedure (U.K. Dept. of the Environment 1975). This allows the original data set to be extended by inclusion of an additional four groups of respondents (group sizes of 5, 9, 9 and 10).

28. The supplemented data set is shown in Fig 8. Noise levels at dwellings along the surface roadways were higher than at dwellings adjacent to the freeway (as a direct result of their proximity to the noise source) and group annoyance scores were also higher. Subject to the subsequent discussion on noise level variability,it can be seen that the supplementary points tend to support the suggested relationship of Fig 6.

CHARACTERISTICS OF FREEWAY NOISE

29. In the reconciliation of the results of this study with previous studies the assumption has been made that a scale such as L_{10} (or for that matter L_{eq}) is an adequate and sole determinant of annoyance whether the noise is measured at some distance from the traffic source (as for dwellings near the South-East Freeway) or at closer distances (as for dwellings along surface roadways).

30. One of the effects of distance on noise levels is to reduce their variability. Excluding site 1 which was located near the freeway on-ramp,the standard deviation of the noise levels at freeway sites (σ(18h)) ranged from 2.9 to 4.5 dB(A). By contrast σ(18h) was 5.4 dB(A) at site 1 and would have been roughly 6.0 to 7.0 dB(A) at the supplementary sites along the surface roadways. (Estimated by analogy with measurements made by the author in a separate study along 19 surface roadways where L_{10} (18h) ranged from 60 to 74 dB(A) and σ(18h) ranged from 5.1 to 8.8 dB(A).) Traffic noise at dwellings located close to the traffic is characterised by high variability but at the greater distances which applied in this study,is characterised by low variability.

31. The ramifications of this are not initially obvious because in the present study sites of high and low noise level variability were also differentiated as sites of high and low noise level (L_{10}). This is not necessarily so. For example, on roadways carrying lower volumes of traffic L_{10} and variability are negatively correlated, i.e. it is possible to have a low L_{10} and high variability.

32. Because most of the respondents in the present study were subject to moderate L_{10} and low noise level variability - but it is also possible for people living along surface roadways to be subject to similar L_{10}, but high noise level variability - it is necessary to be cautious in applying the results of the present study to surface roadways which have traffic noise characteristics different to those that apply near a freeway.

CONCLUSIONS

33. For a sample of residents living near the South-East Freeway in Brisbane no relationship was found between physical measures of noise level and individuals' self-reported noise annoyance. This was so no matter which noise scale was used to describe the noise level distribution nor over which period of the day noise levels were aggregated. Two psychological attributes,viz respondents' opinion of the neighbourhood and noise annoyance susceptibility,were together found to explain 16% of the variance in individuals' annoyance scores. Respondents with poor opinions of the neighbourhood reported higher annoyance scores as did respondents with high noise annoyance susceptibilities. Demographic variables and housing characteristics did not contribute significantly to the explanation of individual annoyance.

34. Median annoyance scores were calculated for respondents grouped around each noise measurement site. No relationship was found between these group annoyance scores and any of the noise scales. Further, none of the physical, psychological or demographic intervening variables were useful in explaining group annoyance scores.

35. It is suggested that the absence of any noise-response correlation in this study around the South-East Freeway has resulted from the small range and lower magnitude of measured noise levels relative to those pertaining in similar studies. L_{10} (18h) levels at the freeway measurement sites ranged from 54 dB(A) to 68 dB(A) but more than half of the respondents in the sample were exposed to levels of less than 60 dB(A). To reconcile the results of this study with those of previous studies, a curvilinear noise-response relationship has been postulated. However, the scarcity of higher noise level sites in the present sample and the wide confidence limits for the median annoyance scores have resulted in no satisfactory evidence of the form of the relationship at the higher noise levels.

36. The present data do not assist in determining maximum noise levels for land use and roadway planning. However, one can be confident that L_{10} (18h) levels of less than 60 dB(A) measured in the absence of a facade would generally be regarded as acceptable (i.e. low median annoyance scores). Maximum L_{10} (1h) and L_{eq} (1h) levels which would similarly be regarded as acceptable are 65 dB(A) and 63 dB (A) respectively. These levels are not incompatible with those adopted overseas.

37. The low variability of noise levels measured at sites near the freeway when compared to the variability measured at dwellings along the surface roadways has been noted. It is believed that this is sufficient reason to be cautious in applying the present results to those situations where the traffic noise has not been similarly attenuated by distance or where the characteristics of the traffic stream are different to those of the South-East Freeway.

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