reliability of complaints as an index of disturbance is further underlined by comparing the small number of complainants with the much larger number of people who had taken immediate actions to reduce intrusion from noise or who had considered moving to a quieter neighborhood.

This analysis in itself is clearly not a sufficient basis for drawing final conclusions on criteria for setting standards on road traffic noise. Nonetheless, this examination of the relations among impacts, attitudes, and actions provides important empirical findings that can serve as a partial basis for regulatory decisions.

The results of this analysis must be considered in relation to those derived from an analysis of the relations between the various impact and response measures considered here and measurements of noise level. That type of analysis is the focus of work in progress. Taken together, the results of the two analyses will significantly strengthen the existing empirical basis for decisions on standards for road traffic noise.

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Effectiveness of Shielding in Reducing Adverse Impacts of Highway Traffic Noise

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Construction of noise barriers or other forms of shielding between residential areas and noisy roadways is one of several approaches to reducing community noise levels. Some studies have suggested that the psychological effect of such shielding is greater than its acoustical effect. This suggestion was tested by using home interview data from five pairs of residential sites. The two sites that made up each pair experienced the same noise level at dwellings but had different types of shielding or barriers. It appears that there is no psychological effect for road traffic noise specifically but that there is an effect for attitudes toward overall community noise. This psychological effect appears to be negative for solid noise barriers, low for single rows of trees, and highest for a row or rows of intervening housing.

Many jurisdictions are in the process of implementing a variety of procedures for reducing the level of traffic noise that reaches residential areas. For example, in the United States, the Federal Highway Administration will provide funding for traffic management procedures to reduce noise, for the construction of noise barriers, or for the purchase of land for such construction or to serve as a buffer zone (1). In Ontario, the Ministry of Transportation and Communications has earmarked funds for construction of noise barriers along major highways through residential areas. In Britain, the government has undertaken to insulate houses for purposes of sound reduction wherever the existing sound level exceeds certain standards. Other agencies (the U.S. Environmental Protection Agency and the Canada Ministry of Transport, for example) are acting to reduce the noise produced by motor vehicles, especially trucks.

Given this variety of expensive actions to reduce noise, it seems pertinent to ask whether such actions are as effective in reducing the impact of noise on people as they are in reducing physical sound levels. All of the efforts mentioned above are predicated on the assumption that physical measures of sound are reliable indicators of the effects of noise on people. That is, these efforts assume that the kind of aggregate relations between traffic noise and response to it that many people have reported (2, 3, 4) can be applied directly to any situation in which sound levels caused by traffic are somehow reduced. This paper provides an empirical test of that assumption for one of the proposed actions—that of installing some kind of barrier or shielding between the highway and the residential area.

There are three reasons for focusing on this situation rather than on building insulation or on reduction of noise at the source:

1. It is obvious that shielding is a more comprehensive approach to noise reduction than building insulation. Insulation does not affect outdoor levels of noise at all, and the use of outdoor space in residential areas is an important part of home life in North America.
2. Transportation agencies are increasingly turning to the construction of barriers and buffers as one of the few methods under their control for reducing the effects of highway noise (5).
3. It is not obvious what the "impact effectiveness" of barriers (i.e., the effectiveness of the barrier in reducing adverse impacts) is as opposed to their acoustical effectiveness. It may well be that the two types of effectiveness are equivalent and acoustical measurement is thus a reasonable surrogate for impact measurement, as most agencies currently assume. Two other possibilities exist, however, both of which are as plausible a priori as equivalent effectiveness. On the one hand, impact effectiveness may be considerably less than acoustical effectiveness. Despite shielding, residents are still aware of the presence of a highway, and the reduced noise levels may only remind them of their proximity to the facility and lead to more annoyance, complaints, and activity interference than one would otherwise expect from the sound-level readings. On the other hand, impact effectiveness may be greater than acoustical effectiveness. Andrew and Sharratt (8), among others, suggest that a number of other highway effects, such as headlight glare, dust, or winter salt spray, are mixed in with any responses to highway noise so that eliminating these will cause adverse reaction to traffic noise to be less than one would expect from the sound levels.

It seems clear that the cost-effectiveness of shielding for noise along highways must ultimately be expressed in terms of what it does for people rather than simply what it does for sound levels. Consequently, it is important to know whether acoustical effectiveness and impact effectiveness are identical or whether perhaps greater or lesser sound level reductions are required for a certain target level of reduction in impacts. This paper investigates responses to road traffic noise in a number of residential areas that have some form of shielding between them and the highway. The impact effectiveness of the shielding is analyzed by comparing responses at each site with the responses to traffic noise at a second site that experiences the same sound levels at dwellings but is either unshielded from the road or is shielded by different material.

SUGGESTIONS FROM PREVIOUS STUDIES

Several earlier studies have suggested that the impact effectiveness of shielding is greater than the acoustical effectiveness. As early as 1972, one study in Toronto noted that, though a particular experimental barrier had not significantly reduced sound levels (yielding reductions of only 1 or 2 dB(A) in L_{10} and L_{50} at residences), "people living behind the barriers considered them beneficial" (9, p. 13). Reasons for this reaction were not investigated, but the authors suggested that the effects of shielding in relation to dirt, debris, and the sight of traffic might be important.

A more recent study in Toronto focused on changes in these latter highway effects, in addition to noise, after the construction of a privacy fence (8). The fence, a solid steel wall, accomplished a reduction in sound levels of from 5 to 7 dB(A) and led to some reduction in annoyance from traffic noise 6 months after construction. However, 12 months after construction, annoyance had risen again (although not to prefence levels). Furthermore, in the second row of housing away from the highway, some residents reported greater annoyance than before the fence was constructed, commenting that the sound "bounced over" the fence whereas previously they had felt that it was "absorbed by the first row of houses" (8, p. 33). That study also reported but was unable to explain satisfactorily that the reduction in annoyance was least at those houses in the first row where the reduction in sound level was greatest whereas other houses in the first row experienced less reduction in noise levels. It appears from that study that the impact of shielding is not obvious and that more needs to be known about it.

Other studies have been more definite in their conclusion that impact effectiveness is greater than the acoustical effectiveness of barriers (7, p. 16) and explain it by the conjunction of the visual screening with the noise reduction. Other studies have also noted the possible beneficial effects of visual screening (10). Because visual screening is important, the appearance of the barrier itself also becomes important (7). (The rather stark appearance of the Toronto barrier studied by Andrew and Sharratt may be part of the reason for the decrease in its impact effectiveness between the 6- and 12-month data collections.)

The appearance of the barrier is also emphasized in a study of the subjective and physical effects of noise barriers at Heston, England, by Scholes and others (11). Measurements were taken with a board fence, with no barrier, and with an experimental barrier. The barrier was found to reduce noise levels by 3 to 9 dB(A) (based on an L_{10} measurement) below the noise level experienced when there was no fence and to improve the reduction beyond that caused by the fence by approximately 4 dB(A). The population interviewed recognized that the noise in the neighborhood had decreased, but a considerable number disapproved of the barrier because of its unsightly appearance.

There is, however, another study that raises questions about this visual effect that have not been considered in these previous studies. Aylor and Marks (12) report that visual shielding is not tied so simply to the impact effectiveness of a barrier. Partial visual shielding results in a reduction in the perceived loudness of noise; full visual shielding does not (12, p. 400). The psychological effect can be the equivalent of as much as 7 dB(A) in sound pressure level. This may help to explain some of the anomalies of previous studies, such as that reported by Andrew and Sharratt in which some people in the second row of housing reported increased annoyance after the fence was constructed (8). Aylor and Marks express caution in applying these findings, however, especially with respect to the stability over time of the psychological effect, which could not be covered in their necessarily artificial experimental study design.

DATA FOR ANALYSIS

As part of the study design for data collection conducted during the summer of 1976, we deliberately selected a number of sites that had different types of shielding between the houses and the roadway so as to examine in a real-world setting the effects on response to noise suggested by these earlier studies. Each site consisted of a single row of housing parallel to the roadway in question and containing 40 or more units. No other major sources of noise affected any site; that is, they were not near industrial areas, rail lines, or airports.

At each site, 25 to 30 households were interviewed by using an extensive questionnaire that was slightly modified from one used in a similar collection of data in 1975. The questionnaire was introduced as a general neighborhood attitude survey; then the focus on noise was explicitly stated to facilitate collecting detailed information on attitudes to noise, activities interfered with by noise, perceived effects of noise on health, and actions taken because of noise—all with reference to the specific sources of noise mentioned by the respondent. The standard personal data were also collected.

After completion of all interviews at each site, a 24-h record of noise levels was taken. Three different kinds of equipment were used for this purpose: (a) a timer-activated Uher 4200 Report Stereo tape recorder that sampled at the rate of 55 s every 12.5 min, (b) a DA603A digital monitoring device that sampled once per second, and (c) a BBN model 614 noise monitor system that sampled every half second. All field devices were calibrated at the start and end of each monitoring session by using a GR1567 sound-level calibrator. The Uher recordings were subsequently analyzed by using a B&K microphone amplifier (to obtain the A-weighting), a level recorder, and a statistical distribution analyzer with 5-dB(A) intervals. The other two devices provide A-weighted readings directly. In keeping with the practice of one of the project sponsors, the Ontario Ministry of the Environment, sound levels have been separately analyzed for three time periods: daytime (7:00 a.m. to 7:00 p.m.), evening (7:00 to 11:00 p.m.), and night (11:00 p.m. to 7:00 a.m.). For each period, L_{99}, L_{90}, L_{50}, L_{10}, L_1, and L_{eq} have been calculated. These time periods do not allow exact calculation of the day-night equivalent sound level L_{dn}, so we have calculated a day-evening-night equivalent level L_{den} by applying a 5-dB(A) penalty to the evening L_{eq} and a 10-dB(A) penalty to the nighttime L_{eq}. This provides a single number for direct comparison of noise levels at different sites.

On the basis of this information, all sites in both the 1975 (13) and 1976 (14) data-collection efforts were considered to find pairs of sites with sound-level readings at residences that were as similar as possible and with different kinds or degrees of shielding between the housing and the road. Five pairs of sites were identified (Table 1). The acoustical effectiveness of the barrier or shield was not investigated.

The sound levels at the housing units are the same in each pair, but the noise generated by the road is not. For example, the first pair compares the responses of people in the second row of housing along the Queen Elizabeth Way, which has a traffic volume of almost 90 000 vehicles/d, with the responses of people who live adjacent to Dixie Road, which carries fewer than 30 000 vehicles/d. Clearly, the noise at the road edge is much higher in the first instance than in the second. The point is that the sound levels at the residences are the same for each pair of sites, as shown by the monitor readings given in Table 1. Although the L_{den} was used as the principal identifier of similar sites, L_{eq}, L_{10}, and L_{50} for each of the three periods are also reported to allow more detailed comparison.

For each pair of sites, a large number of variables from the household interviews were investigated to see if there were any significant differences between the two sites in the responses. Two variables deal with the overall attitude of people toward the noise in their neighborhood: (a) whether or not the respondents volunteered that noise was something they disliked about their neighborhood and (b) their rating, on a nine-point bipolar scale (from extremely agreeable to extremely disturbing), of the overall noise. The remaining variables deal with responses to specific noise sources, which in this analysis have been limited to the main road in general and trucks in particular. For each of these sources, there are sets of variables that deal with attitudes, activity interruption, actions taken, and perceived effects on health.

Attitudes were measured three ways: (a) by whether or not the person volunteered that the specific source was a noise he or she noticed, (b) by a rating on an ordinal nine-point bipolar scale for each person who mentioned the noise source, and (c) by a rating on an

Table 1. Descriptions of site pairs for analysis.

		Sound Level (dBA)									
			Daytime			Evening			Nighttime		
Site Pair	Type of Shielding	L_{den}	L_{eq}	L_{10}	L_{50}	L_{eq}	L_{10}	L_{50}	L_{eq}	L_{10}	L_{50}
1											
Queen Elizabeth Way, row 2	One row of housing	65	62	60	55	60	61	56	57	58	54
Dixie Road	Single row of trees	64	61	63	58	60	61	57	55	58	53
2											
Stevenharris	Several rows of housing	68	67	66	63	63	63	61	60	61	57
Sterling Street	None	68	68	70	58	65	68	55	60	61	53
3											
Horizon Village	Concrete wall (3.7 m high)	70	69	64	61	63	64	59	62	63	60
Garth Street	None	69	67	70	59	65	69	59	61	62	50
4											
Islington North	Single row of trees	76	74	77	72	72	76	70	67	72	64
Islington South	None	76	74	77	72	72	76	69	67	72	57
5											
Islington North	Single row of trees	76	74	77	72	72	76	70	67	72	64
Upper James	None	77	73	76	69	71	74	66	70	72	58

Note: 1 m = 3.3 ft.

interval-level disturbance scale for each person disturbed by the noise source. Activity interruption is based on whether or not the respondent volunteered the information that any of the following activities were interrupted by noise from each source:

1. Sleeping,
2. Relaxing indoors or outdoors,
3. Conversing indoors or outdoors,
4. Working indoors or outdoors,
5. Watching television,
6. Conversing on the telephone, and
7. Eating.

Information on actions taken derives from the following list that was read to the respondent:

1. Close windows;
2. Use air conditioning;
3. Stay indoors;
4. Turn television, radio, or records on or up;
5. Wear earplugs;
6. Wait for noise to stop;
7. Take individual complaint action; and
8. Take organized complaint action.

Respondents were also asked if the specific noise source had any effect on their family's health; the following items were specifically mentioned:

1. Nervousness,
2. Hearing loss,
3. Irritability,
4. Headaches,
5. Sleep interrupted, and
6. Kept awake.

Thus, in addition to the two variables on overall attitudes to noise, there are a total of 27 source-specific responses available for analysis.

RESULTS OF THE ANALYSIS

Despite the large number of variables available for analysis for each of the five pairs of sites, the method of analysis is quite straightforward. All we are examining is whether the response to the same noise level is different when different types of shielding or barriers are present. Given the nature of most of the variables (i.e., nominal or ordinal, with one exception), this comparison can be accomplished by means of several simple statistical tests: a chi-square test for the nominal variables; the Mann-Whitney U-test for the ordinal variables; and a t-test for the interval rating scale. For this particular problem, the results of such tests will be informative no matter what the outcome. If there is no significant difference between responses at the two sites in each pair, it suggests that the present working assumption—that acoustical measurements are good surrogates for noise impacts—is correct. On the other hand, if there is a significant difference in responses at the two sites, it would strengthen support for the suggestion that shielding has some kind of psychological effect over and above its acoustical properties (or it could suggest a negative psychological effect, depending on the direction of the relation). It may well be the case that such a psychological effect exists for some impacts and not for others. For this reason, the results are discussed by the main categories of variables listed in the previous section.

In all five pairs of sites, there is a significant difference in attitude toward overall community noise (Table 2). In two of the five pairs, the difference is in the number who volunteer noise as a problem; in the other three pairs, the difference occurs on the rating scale. Pair 1 indicates that a single row of housing is more effective in improving such attitudes than a single row of trees that grow close together and provide a visual screen. Pair 2 indicates that several rows of housing are more effective than no shielding at all, and pair 3 suggests that no shielding at all is more effective than a solid concrete wall. The remaining two pairs suggest that a screen of trees is more effective than no shielding at all (but note that the same shielded site is used for both comparisons). Consequently, if one is willing to postulate transitivity for such comparisons of effectiveness, the apparent effectiveness of these several types of shielding in improving attitudes toward overall noise in a neighborhood is as shown in Figure 1.

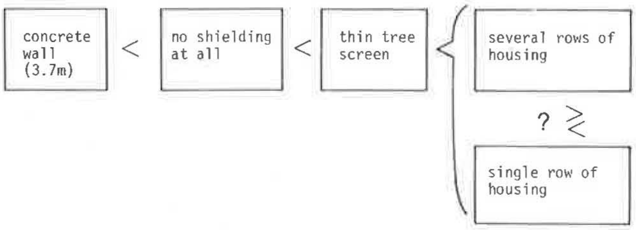
There is considerably less effect when one looks at variables that refer directly to main-road traffic noise. There is no significant difference in attitudes toward traffic noise in four of the five pairs for any of the three variables analyzed. It is important to note, therefore,

Table 2. Significant levels of variables for tests of association.

	Site Pair				
Variable	1	2	3	4	5
Comparison of shielding					
a	One row of housing	Several rows of housing	3.7-m concrete wall	Trees	Trees
b	Screen of trees	Nothing	Nothing	Nothing	Nothing
Attitudes toward overall community noise					
Dislike noise (volunteered)	ND	ND	ND	0.05 (a > b)	0.01 (a > b)
Overall noise rating	0.05 (a > b)	0.01 (a > b)	0.001 (a > b)	ND	ND
Responses to noise from main road					
Attitudes	ND	Mention of road, 0.01 (a > b)	ND	ND	ND
Activity interference	ND	ND	ND	Relaxing outdoors, 0.05 (b > a)	Relaxing indoors, 0.05 (a > b) Working indoors, 0.05 (a > b)
Actions taken	Close window, 0.05 (a > b)	ND	ND	ND	ND
Effects on health	Sleep interrupted, 0.05 (a > b)	ND	ND	ND	ND

Notes: 1 m = 3.3 ft.
ND = no difference.
a > b or b < a means that type of shielding a is more effective than type b or vice versa for the particular impact. All variables not reported in the table showed no significant differences between sites.

Figure 1. Comparative effectiveness of types of shielding for improving attitudes toward overall community noise.



that Figure 1 applies only to attitudes toward overall community noise and not to attitudes toward noise specifically from road traffic. Similar findings resulted from the examination of variables that refer to truck noise. No significant difference in attitudes toward truck noise was found in any of the five pairs.

For activities interfered with by main-road traffic noise, there are significant differences at only two of the five pairs of sites. These relate to relaxing (outdoors at pair 4 and indoors at pair 5) and working while indoors (pair 5). The remaining seven activities covered in the questionnaire show no significant differences in the amount of interference by traffic noise at any of the five pairs. In other analyses of the full data set, including that of Taylor, Hall, and Gertler in another paper in this Record, relaxing and working have not shown up as particularly important activities. This, together with the fact that each of these specific activity interferences is statistically significant at only one of the five pairs of sites, leads us to discount the substantive significance of these particular results. In essence, we would argue that a result that appears at only one of the five pairs needs a much tighter confidence limit. If a result has a probability of 0.05 of occurring by chance in the data for a site, it follows that in investigating results for five sites there is a probability of almost 0.23 of seeing such a result at at least one site. Consequently, we would conclude that, for activity interference variables as well as attitude variables, there are no meaningful differences between types of shielding when people are talking specifically about road traffic noise.

Similar reasoning applies to the results for both actions taken and health effects. In each case, only a single variable of the eight action or six health variables shows up as significant and these only at a single site. It is possible, as it was for activity interference, that it is only this particular comparison of types of shielding that has an effect. In that case, one must conclude that a single row of housing is more effective than a screen of trees in reducing the extent to which people must close their windows to reduce noise or the extent to which sleep is interrupted. But we are influenced more by the general tendency of all of the variables at all of the sites, and we would conclude that there is probably no meaningful difference in types of shielding with respect to actions taken or to the perceived effects of road traffic noise on health. There are no significant differences for any of the above variables in response to truck noise.

CONCLUSIONS AND IMPLICATIONS

The results of this analysis are both reassuring and cautionary. They support a number of previous findings but also go beyond them.

The reassuring part of the results is that all forms of shielding investigated appear to be equally effective with respect to a large range of responses to road traffic noise. Given that the sound level at the dwelling is the same, attitudes, activity interference, actions taken, and perceived effects on health are not significantly different at two locations with different kinds of shielding. The working assumption that the measurement of sound level is a reasonable surrogate for the measurement of the impacts of road traffic noise is supported. It follows that any barrier that reduces sound levels will also reduce impacts equally.

The cautionary part of these findings is that they apply only to source-specific reactions. There does appear to be a significant difference in the effectiveness of different kinds of shielding with respect to the attitudes of people toward overall noise in their neighborhoods. As a result, it would appear that one could prove or disprove the psychological effectiveness of a particular barrier depending on what one asks. If questions are addressed specifically to traffic noise, the barrier will be shown to be effective. If questions relate to general or overall noise levels, the barrier may not prove effective.

For overall neighborhood noise, the findings support and extend the experimental results of Aylor and Marks (12) as well as the findings of previous barrier studies. Aylor and Marks noted a beneficial psychological effect of partial visual screening compared with full screening but were cautious about the temporal stability of this effect. Our results support the notion of such an effect and also imply that it is relatively stable over time since the data are derived from persons who live at each site rather than being exposed only briefly to each source as in the experiment of Aylor and Marks. The effect of visual screening appears to be more complicated than in their results however. In Figure 1, situations that imply full visual screening appear at both ends of the range of effectiveness—a concrete wall at the low end and several rows of housing at the high end (again, assuming that the relations identified in Table 2 are transitive).

Unfortunately, we are forced to resort to conjecture to explain this somewhat unexpected result. It is generally accepted that noise causes adverse attitudinal reactions not simply as a result of its level but also because of meanings associated with it. For example, a rushing stream may generate as much sound as a roadway but hardly ever leads to as much annoyance. A concrete wall removes the sight of a road, but not all the characteristics associated with the traffic. People who live in such a situation are constantly reminded by the noise that they live next to a busy highway. Several rows of housing constitute an effective visual screen, but they also serve to put distance and other people between a resident and the highway. Consequently, the negative associations of the noise are more remote and not necessarily a part of the neighborhood in question. It is important to note, of course, that two such sites were not directly compared in this analysis (clearly, the noise is much less at the latter type of site). Rather, each was compared with a site that had similar noise levels.

The question that remains unanswered by this analysis and that seemed intuitively obvious before the study by Aylor and Marks (12) is whether adding trees or other landscaping to an effective sound barrier improves attitudes in any way. Our results indicate that a screen of trees has more impact effectiveness than a concrete wall. This would seem to be a simple matter of aesthetics: The former is more pleasant to look at than the latter. The suggestion of Aylor and Marks–that the difference might be attributable instead to being able to see the source—needs further investigation. Certainly, in their experiment the more aesthetic barrier was a cedar hedge that completely hid the source rather than a snow fence. A study of the effect of the appearance of barriers on attitudes would seem useful given the amount of money that has been and will be spent on improving such appearances (7).

The important conclusion of this analysis depends on whether one construes the problem of traffic noise narrowly or broadly. If one sees the problem narrowly, then this study suggests that the adverse effects specifically attributed to road traffic noise are equally affected no matter what shielding is used. If one sees the problem as one related more generally to the quality of life in urban areas, the type of shielding used does appear to have some effect. This in turn argues for the importance of an explicit study of the effect of the visual appearance of barriers. An acoustically effective barrier will clearly reduce the adverse effects of traffic noise. Will an aesthetically pleasing barrier improve general attitudes even more?

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Effects of Highway Noise on Residential Property Values

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Previous studies of highway noise have shown an effect on the price of housing that seems to vary considerably with location. In this analysis, six sites that consist of similar housing in parallel rows adjacent to major roads were identified, and data on real estate transactions and noise levels were collected. Analysis of variance indicated that there were significant differences in price between rows of houses only at the two noisiest sites. Consequently, multiple regression analysis was performed for two subsets of the sites based on noise level. The results show that at very noisy locations [daytime L_{eq} of 73 dB(A) or higher] noise is strongly related to differences in housing prices and is valued at approximately $650/dB. At less noisy sites [daytime L_{eq} less than 70 dB(A)], noise is not significantly related to differences in housing prices. These results suggest that some noise impacts are not a linear function of sound level and that noise reduction at very noisy locations is more important than at less noisy ones.

Noise from road traffic has been recognized as an environmental problem in many countries, and many studies have documented the relation between traffic noise and annoyance (1, 2, 3). As these countries have begun efforts to reduce traffic noise, or at least its adverse effects, it has become obvious that this reduc-