A panel study of response to road traffic noise with interventions to reduce truck noise at night

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ABSTRACT

A mangement strategy reduced truck movements at night on an urban arterial roadway. Community response to noise was measured using a panel of residents, surveyed five times over the two years of the study. Noise monitoring showed no change in L_{eq} or L_{night} levels, but the panel did report significant benefits in terms of reductions in noise annoyance and reduction in activity interferences. The conclusion was that measureable changes in the number of articulated truck movements at night lead to reduction in the number of noise events at night and to significant improvements in the community's road traffic noise response. Relatively small changes in the number of noise events in the road traffic noise stream have an effect on annoyance responses beyond their contribution to the levels of the energy-based indicators

INTRODUCTION

An eleven kilometre roadway through an urban corridor in Brisbane, Australia, links several motorways and industrial areas. The roadway carries four or six lanes of traffic in different sections, with posted speed limits of 60 to 80 km/h. It is an important regional freight route characterised by relatively high proportions of commercial vehicles, particularly articulated heavy vehicles, at night. This roadway also has fronting residential properties.

In response to community demands to provide relief from the effects of road traffic noise at night for those living adjacent to this roadway, authorities instigated measures to reduce the number of heavy vehicles using the corridor. The trial measure was a *truck diversion strategy* involving the removal of a toll for heavy vehicles on a route parallel to the study corridor to entice some heavy vehicles to reroute voluntarily. The toll removal operated only during the night hours (10.00 pm to 5.00 am). There would be no direct effect on heavy vehicle flows on the corridor during the day-time hours, or on traffic other than trucks at any time.

The community was surveyed in a longitudinal panel study over nearly two years, with repeated measurements of noise effects on each respondent. Designs such as this, that measure community response to road traffic noise longitudinally, are not common. The community study was designed specifically to test if the night-time truck diversion resulted in change in noise effects for those living in the corridor.

METHODS

The study design was based on the model for assessment of community response to a change in noise exposure proposed by Brown and van Kamp (2005). It adopted a longitudinal *panel study* of five rounds of face-to-face interviews over nearly two years, with one before, and four after repeated measures of all relevant outcomes and factors. The repeat measures of community response (CR1-5) were

accompanied by repeat measures of traffic counts (TF1-6) and noise level measurements (NL1-6).

There were 370 dwelling units along the corridor. The panel sample of adults was drawn randomly from this population of 370 units, with one per dwelling unit and with equal numbers of males and females. The target was a panel size of 100 and sampling was with replacement. The resultant panel size for the before-study was 99 respondents. The median setback of the façade of the dwellings of panel members from the centerline of the nearside carriageway was 18 m, with 80% of the dwellings located between 14 m and 32 m from the roadway.

The panel technique required reinterviewing the same individuals at each round of the survey. Over time, the panel size reduced as people interviewed in the first round moved away, declined to remain in the panel, or were otherwise unavailable for subsequent interview. Table 1 shows the panel size at each of the after-surveys CR2 through CR5.

Table 1: Number of respondents interviewed, and drop-out rate, at the before (CR1) and the four after interviews (CR2-5).

	Before-survey	**Four after-surveys (over 20 months)**			
		May	**Oct**	**Mar**	**Nov**
	CR1	CR2	CR3	CR4	CR5
Number of respondents	99	76	61	45	33
Drop-out rate	-	23%	20%	26%	26%

The survey used trained interviewers and a structured questionnaire that included :

- *Annoyance* with road traffic noise was measured according to the ISO (2003) procedure, but using a scale of 0-9. Annoyance was measured twice—the first time *without specifying any particular part of the day*, the second asking specifically about the *late night and very early morning*. *"Highly annoyed"* has been scored as any of 7, 8 or 9 on the annoyance scale.
- *Activity interference* was measured by self reports of the frequency with which traffic noise disturbed sleep, interfered with communication, or startled the respondent, on four-point scales: *never, sometimes, a lot, nearly all the time.*
- *Opinion of the neighbourhood* was rated on a four point scale: *excellent, good, poor* and *very poor.*
- Noise *sensitivity* was measured by a modified Broadbent/Gregory questionnaire (Anderson, 1971). Respondents were categorised as being of *low*, *medium* and *high sensitivity* using tertile cut-offs.

ANALYSIS

Across survey rounds CR1-CR5, there were 314 separate measurements of each of the annoyance and activity interference responses (99 in the before survey CR1; 76 in CR2; 61 in CR3, 45 in CR4 and 33 in CR5).

To test for change in noise outcomes as a result of the truck diversion trial, it is necessary to take into account that repeat scores of any one individual are not independent across successive surveys, and also that the panel size decreased across CR1-CR5. The MIXED Procedure in SPSS (Linear Mixed-Effects Modelling: IBM SPSS Statistics, Version 21) was utilized as its assumptions allow both correlation between repeat measures on the same individual, and an unbalanced

design resulting from the reducing panel size. The MIXED Procedure provides tests, over the duration of the truck diversion trial, for change in the mean value of noise response variables predicted in the fitted model.

RESULTS

The interrelationships between the two available annoyance scores (annoyance when no specific period of the day had been specified, and annoyance during the late night and very early morning) and the frequency of the reports of traffic noise interference with activities are reported below based on all 314 of the outcome measurements available.

Of the two annoyance scores, the first is the measure of annoyance according to ISO (2003) which seeks a general reaction to the noise source in the respondent's home. That reaction is presumed to be global - integrated over a considerable, but non-specified, period, but generally assumed to be annoyance over a "whole day". The second is annoyance specific to the late night and very early morning hours alone – it being appropriate to have respondents additionally focus on these night hours in this study because the truck diversion could affect noise only at night. The correlation between the two annoyance scores is 0.64.

Table 2: Spearman rank order correlations between annoyance scores and activity interferences caused by noise. All correlations are significant at 0.01 level (n = 314).

		No period specified			Late night & early morning			
		Annoyance	Shut windows	Hearing	Annoyance	Shut windows	Sleep	Startled
No period specified	Annoyance	1.0	.36	.53	.64	.39	.47	.51
	Shut windows		1.0	.38	.32	.74	.33	.35
	Hearing			1.0	.42	.33	.39	.40
Late night & early morning	Annoyance				1.0	.41	.64	.56
	Shut windows					1.0	.42	.38
	Sleep						1.0	.61

There is reasonable consistency between each of the annoyance scores and the range of activity interferences, with correlation coefficients ranging from .32 to .64. Higher annoyance scores are associated with a greater incidence of interference with activities. Annoyance at night has its highest correlation (.64) with sleep interference, and is also highly related to being startled at night (.61).

Noise exposures and levels of annoyance

Road traffic noise exposures of the dwellings of the panel were high. Mean L_{den} ($L_{10,18h}$) road traffic noise levels at the facade of the 99 dwellings was 70 (72) dB(A), with no façade reflection included. Variation in the setbacks of dwelling in the panel from the roadway resulted in some variation of façade exposures, but 90% of all dwellings in the panel were exposed to levels within -5 to +2.5 dB of this mean.

Given such high levels of exposure, the annoyance scores reported by the panel were also high. For example, at CR1, prior to the commencement of the truck diversion, the percentage of the panel who reported they were *highly annoyed* was

70%. This is a much greater proportion than would be predicted from the synthesis of road traffic noise exposure-response relationships by Miedema and Oudshoorn (2001). At equivalent exposures to those in the present study (for example, at L_{den} levels of 65, 67.5, 70 and 72.5 dB) Miedema and Oudshoorn (2001) estimated that the proportion of any exposed population *highly annoyed* would be 16%, 20%, 25% and 30% respectively.

There is no direct evidence in the present study to explain why the panel reported such high levels of annoyance with before conditions, but feasible explanations may include the attitudinal factors that are known to affect annoyance scores. For example, the panel had a high degree of awareness that: the truck diversion trial was planned and about to be implemented; there were ongoing community consultations between the responsible road authority and the community regarding issues concerning the study roadway; and respondents had been informed by the original letter to the community that the present survey, while conducted by a university research team, was funded by the road authority.

In any case, the important question is not the absolute level of annoyance in the community, but whether this level changed over the duration of the study in response to the truck diversion strategy.

Change in annoyance scores of the panel during truck diversion strategy

Over the twenty-two months of the truck diversion trial, the community surveys provided five repeat measures of annoyance with late night and very early morning traffic noise. Individual night-time annoyance scores were modelled, across the survey rounds, as the dependent variable using the SPSS MIXED Procedure, with noise sensitivity, opinion of the neighbourhood, and other respondent attributes, all entered in the model.

Table 3: Output from the initial mode. Annoyance Scores in *late night and very early morning* as the dependent variable, with survey round and other fixed factors (as measured in before study) as listed.

	Type III Tests of Fixed Effects			
	df		**F**	**Sig.**
Source	**num.**	**denom.**		
Survey round	4	188.402	9.221	< .001
Noise sensitivity	2	86.919	2.145	.123
Overall neighbourhood opinion	3	84.466	2.037	.115
Associated with trucking industry	1	77.740	11.353	< .001
Awareness of consultations	1	71.813	2.993	.088
Knew of truck strategy trial	1	78.664	1.822	.181
Expectation of improvement	2	77.260	.326	.723
Survey * Noise sensitivity	8	189.854	1.811	.077
Survey * Neighbourhood opinion	12	188.472	1.542	.112

The initial model was run using the measures of respondent's attitudes and attributes obtained in the before study CR1 (implicitly assuming these would be unvarying characteristics of the individual). Results from the initial model are shown in Table 3. Only two of the factors were significant in the model. Based on Type III tests, the effect of survey round was highly significant ($p < .001$), as was household association with the trucking industry—respondents associated with trucking had lower annoyance scores than those who were not.

Estimated marginal means (EMM) of annoyance in the *late night and very early morning* at each round of survey during the truck diversion trial are shown in Figure 1. The EMM of annoyance dropped sharply after the beginning of the trial, staying low out to some 12 months (> CR3) after the trial began, then with some recovery in annoyance scores towards the end of the trial. Using the Bonferroni adjustment for multiple comparisons, post-hoc comparisons of the EMM shows a reduction from CRI to CR2 of 1.1 points on the 10-point annoyance scale. The reduction in annoyance from CR1 to CR2-CR4 were all highly significant ($p < .001$) with the difference from CR1 being 1.1, 2.2, and 1.0 points (of the 10 point annoyance scale). By the final survey round (CR5) the EMM of night-time annoyance score was still 0.4 points lower than at the before survey, though this difference was not significant. In summary it can be concluded that the annoyance of the panel in the *late night and very early morning* did change significantly during the truck diversion trial period ($F_{4,170.4} = 12.18$, $p < .001$).

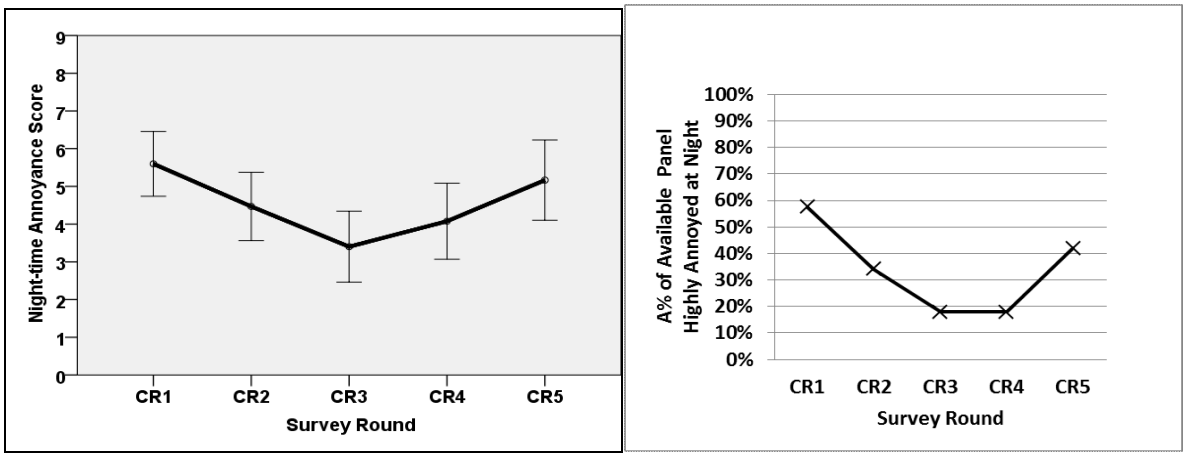

Figure 1. Change in the estimated marginal means of annoyance scores, and the percentage of the panel Highly Annoyed, across the five rounds of survey (95% confidence intervals shown).

The changes in outcomes over time can also be examined in the percentage of the panel who were highly annoyed at each survey round. Figure 1 shows that, starting from a base of 58% of the panel highly annoyed with road traffic noise in the *late night and very early morning* in the before study, the percentage dropped to 18% at CR3 and CR4, then increased to 42% by the end of the trial period. This pattern of change follows that of the EMMs. These analyses of annoyance over the five rounds of the survey (activity interference responses followed a similar pattern) provide convincing evidence that the community living adjacent to the study roadway responded positively to the truck diversion strategy. The reductions in response were consistent out to 12 months after the truck diversion strategy commenced, but then trended upwards towards the end of the 22 month period of the trial.

DISCUSSION

The observed changes in community responses to road traffic noise over the period of the truck diversion trial was not caused by change in the exposure of the community to road traffic noise, even when traffic noise levels were measured as $L_{Aeq\ (7hour)}$ over the 10:00 pm to 5:00 am period of the truck diversion. Within usual measurement limits, there was effectively no change in noise exposure, at four sites, across the six monitoring rounds which spanned the same period as did the community response measurements (CR1-5).

Could the observed changes in community response be a result of using a panel design, with repeat interviews of the same respondents leading to *demand-response bias* or *response set*? Job (1988) had suggested that demand-response bias could be a problem where a panel is interviewed before and after a change, with respondents likely to perceive that that the interviewer is expecting (demanding) a changed reaction. There is no recent work that deals with this issue, but Brown and van Kamp (2009) concluded, from a review of past noise survey evidence, that demand-response bias generated by repeated questioning in noise annoyance surveys is unlikely. The limited evidence included work by: Fields *et al.* (2000) who analyzed a range of panel studies, concluding they do not appear to introduce survey-resurvey bias in noise response, particularly if repeat surveys are at least one month apart; Jonsson and Sörensen (1973); and Fidell *et al*. (1985) who reported that after-change annoyance responses (for short-term annoyance) were similar over three repeat rounds of interviews (in what they regarded as being tantamount to a panel study) conducted over three months.

Measurement were also conducted on the traffic volume and composition on the corridor. As the truck diversion strategy was directed at articulated vehicles, examination of the traffic counts was directed at change in the numbers of articulated vehicles on the corridor at night throughout the period of the trial. There is high day to day variability in heavy vehicle flows on this corridor depending on factors related to seasonal flow of commodities, shipping deliveries, etc. and, further, regional traffic flows were continuing to grow at an annual rate of some 3.5%.

Figure 2 shows manual two-way counts of articulated vehicles at two sites on the corridor throughout the trial. The large variability in the mean from day to day is shown by the error bars (+/- 1 sd) about the plotted mean number of articulated vehicles. The numbers of articulated vehicles on the roadway in 24 hours, and between 10.00 pm and 5.00 am, are shown separately. While the variability is high, at both sites there is a discernible drop in the number of articulated vehicles on the roadway, during the late night and early morning and over twenty-four hours, when the truck diversion began after TF1. After the initial reduction in articulated trucks in the first year or so of the truck diversion, this becomes increasingly buried in the overall annual growth in traffic. By the end of the trial, the numbers of articulated trucks on the study roadway have increased to the extent they approach the numbers present before the truck diversion trial began.

The trends in the number of articulated vehicles using the study roadway from 10.00 pm to 5.00 am over the period of the truck diversion is remarkably simlar to the trends in annoyance with traffic noise in the late night and very early morning reported by the panel. This is strongly suggestive of a causal link between the number of articulated vehicles on the study roadway in the late night and very early morning and community response to noise in this same period.

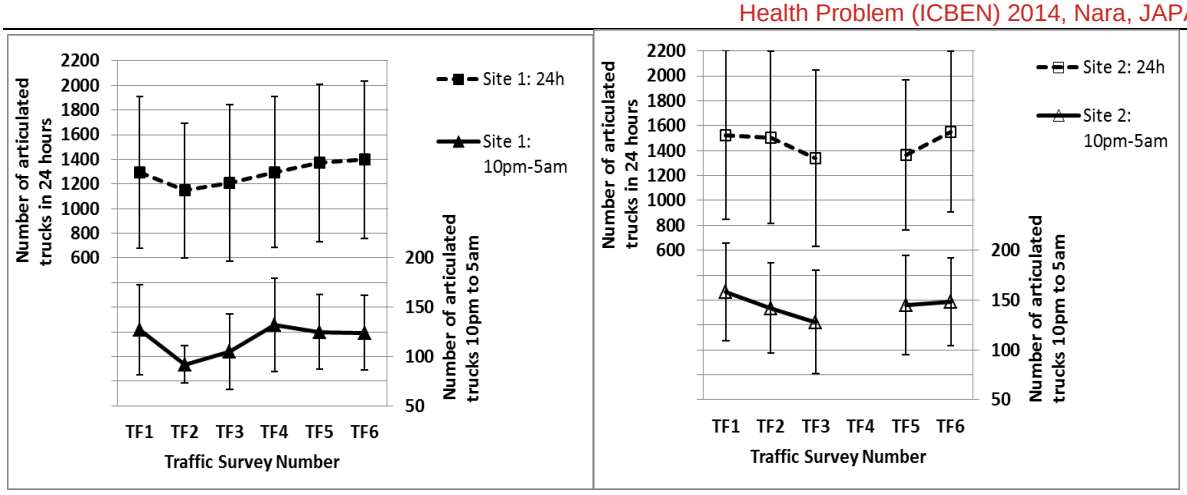

Figure 2. Number of articulated trucks over the 22 months of the truck diversion study (mean of repeat counts over several days at each site +/- 1 s.d. bars.

CONCLUSIONS

The notion that the number and level of noise events in a road traffic noise stream may drive human responses to traffic noise is not new. There have been persistent assertions that the presence of heavy vehicles may separately contribute to annoyance (Langdon, 1976 a, b; Björkman, 1991), and either number, or proportion, of heavy vehicles in the road traffic stream has been identified as determinants of annoyance responses over and above their contribution to equivalent sound levels (Lercher and Kofler, 1996; Öhrstrom, 2004; Bannerjee at al., 2009; Dratva et al., 2010).

The current study provides evidence that, while reduction of the number of heavy vehicles in the traffic stream did not result in change in the noise exposure of the study panel (L_{night}), the panel did respond to a decrease in the number of noise events in the night-time traffic stream by persistent and significant reductions in both their annoyance scores and their reports of noise inteference effects. The consequence is that the number and level of noise events needs to be considered as a noise indicator in the face of non-responsiveness of conventional measures of road traffic noise to interventions such as truck restriction strategies.

The effect of the truck diversion strategy of reducing the affected community's high adverse response to noise was persistent after the original reduction in night-time articulated vehicles. However, the annual growth rate of traffic on the study roadway was also persistent. Over the near two years of the study, the number of articulated trucks at night climbed back near to the numbers before the intervention, with the truck reduction achieved by the diversion subsumed in the annual traffic flow increases.

The importance of longitudinal studies of outcomes to assess the effect of noise management interventions has been demonstrated. Measures of outcomes are required, not just before and after the intervention, but as a time series of repeat measures extending after any intervention. The model proposed by Brown and van Kamp (2005) is an appropriate starting point for the design of such longitudinal studies.

REFERENCES

Anderson, C.M.B. (1971) The measurement of attitude to noise and noises. National Physical Laboratory Acoustics Report, ac 52.

Bannerjee, D., Chakraborty, S.K., Bhattacharyya, S., and Gangopadhyay, A. (2009) "Attitudinal response towards road traffic noise in the industrial town of Asansol, India," Environ Monit Assess, 151, 37-44

Björkman, M. (1991) "Community noise annoyance: importance of noise levels and the number of noise events," J.SoundVib., 151, 497-503.

Brown, A.L. and van Kamp, I. (2005) "Towards a design for studies of response to a change in noise." *Proceedings of InterNoise 05*, Rio de Janeiro, Brazil. pp 2958-2967. Institute of Noise Control Engineering.

Brown, A.L. and van Kamp, I. (2009) "Response to a change in transport noise exposure: competing explanations of change effects," J.Acous.Soc.Am., 125 905-914.

Dratva, J., Zemp, E., Dietrich, D.F., Bridevaux, P.-O., Rochat, T., Schindler, C. and Gerbase, M.W. (2010) "Impact of road traffic noise annoyance on health-related quality of life: results from a population-based study." Qual.LifeRes., 19, 37-46.

Fidell, S., Horonjeff, R., Mills, J., Baldwin, E., Teffeteller, S., and Pearsons, K. (1985). "Aircraft annoyance at three joint air carrier and general aviation airports," J.Acous.Soc.Am., 77 (3) 1054-68.

Fields, J.M., Ehrlich G.E., and Zador, P. (2000). Theory and Design Tools for Studies of reactions to abrupt changes in noise exposure. NASA-CR-2000-210280. Hampton, VA: NASA Langley Research Center.

ISO (2003) ISO/TS 15666:2003 Acoustics -- Assessment of noise annoyance by means of social and socio-acoustic surveys.

Job, R.F.S. (1988). "Over-reaction to changes in noise exposure: The possible effect of attitude," J.SoundVib., 126 (3) S. 550-552.

Jonsson, E., and Sörensen, S. (1973). "Adaptation to community noise - a case study," J.SoundVib., 26 (4) 571-75, L.

Langdon, J. (1976a) "Noise nuisance caused by road traffic in residential areas: Part I." J.SoundVib., 47, 243-263.

Langdon, J. (1976b) "Noise nuisance caused by road traffic in residential areas: Part II." J.SoundVib., 47, 265-282.

Lercher, P. and Kofler, W.W. (1996) "Behavioral and health responses associated with road traffic noise exposure along alpine through-traffic routes." Sci. Total Environ., 189/190, 85-89.

Miedema, H.M.E. and Oudshoorn, C.G. (2001). "Annoyance from transportation noise: relationships with exposure metrics DNL and DENL and their confidence intervals." Environ Health Persp. 109: 409-416.

Öhrström, E. (2004). "Longitudinal surveys on effects of changes in road traffic noise - annoyance, activity disturbances, and psycho-social well-being," J.Acous.Soc.Am.115 (2) 719-29.