Effects of Road Texture on Traffic Noise and Annoyance at Urban Driving Speeds

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Abstract

This paper describes evidence that insufficient allowance is being made for road surface effects on traffic noise in New Zealand urban areas where vehicle speeds are typically 50 km/h. Therefore low noise road surfaces could have much greater benefit in reducing community annoyance with noise in urban areas than was previously thought.

A drive-by technique, which captures both the noise level and a spectral distribution of the noise from test vehicles, and from samples of actual vehicles within vehicle streams, was used to measure the noise from a range of road surfaces. It was found that, at 40-50kmph, when compared to dense graded asphalt, the most commonly used road surfaces (the chip surfaces) may be 3 to 6dBA noisier for cars, and 0 to 2dBA noisier for trucks. These effects are much larger than is anticipated by commonly used road noise models.

Populations adjacent to roads being resurfaced were surveyed using both annoyance and behavioural scales. It was found that surface type was significant in influencing traffic noise annoyance of people living next to the roads, and that changes in behaviour could be detected for very small changes in noise, i.e. less than 2dBA

Introduction

The paper outlines the findings of a study undertaken to identify related issues concerning resealed road surfaces in urban environments. The study has two aims. First, to determine the extent that the predominantly random textured road surfaces, that are typical in New Zealand, influence the noise level at urban driving speeds (50kph). Second, to determine the extent of the effect that any noise level differences due to reseal have on the adjacent community.

The effects of road surfaces on noise at 80-100kmph are well documented internationally and have also been validated in several New Zealand studies. What is less well understood is whether similar effects occur at urban driving speeds of 40-70kmph and whether these affect community annoyance.

While the crossover from engine noise to tyre noise in the 40-70kmph zone is well identified in the international literature, the effects of the road surface were considered to be adequately represented by the equations in the Calculation of Road Traffic Noise (CRTN) model, 1988 [1] which was originally developed in the UK but is also used extensively in New Zealand. These corrections require an adjustment of −3.5 dBA for pervious surfaces at all speeds; and for impervious bituminous and concrete surfaces a correction of −1dBA for speeds below 75kmph. For speeds above 75kph a correction based on texture depth (usually 2-4dBA) is required.

A local validation [2] of the CRTN equation had proposed a modified equation, again based on texture depth. While this model predicts a noise effect at 50kmph for different textures, the effect is considered to be small. Further, the trend for heavy traffic contradicts the road surface effects embodied in the more robust Nordic model. The main pavement design guide [3] in Australia and New Zealand also advises that there is little effect by the road surface on noise at 50kmph.

The Nordic model does show some significant effects for road surfaces at urban speeds. However, the effect of chipseal appears less, and the effect of open-graded asphalt greater, than is believed to occur on New Zealand roads.

The current project was formulated as a consequence of public complaints occurring after road

surfaces were changed as part of regular street maintenance. On occasions complaints as strong as taking up petitions to the local authorities can occur after a street is resealed, and usually these complaints arise within the first month after reseal. With the previous estimations of noise these complaints are inexplicable as there should be no increase in noise to cause annoyance given the traffic speeds and surface types selected. We reasoned that if complaints were arising, they were the result of greater surface noise than is estimated by current models, or that the public is more sensitive to small changes in noise, perhaps because of tonal differences.

Figure 1: 19mm (Grade 2) Chip

Design of New Zealand Roads

Road surfaces in urban areas comprise:

Dense graded asphaltic concrete (asphalt), similar to those used in other countries.

OGPA (open graded porous asphalt) is also used but primarily for higher speed skid resistance. It has relatively low voids compared to international practise (15-20%) and is laid only in relatively thin layers (30mm thick).

Chipseal surfaces (spray seals, surface dressing) which consist of a layer of sprayed bitumen into which is embedded a layer of aggregate of specific size. The nominal aggregate sizes are: all passing:

- 19mm (Grade 2),
- 16mm (Grade 3),
- 12mm (Grade 4),
- 10mm (Grade 5) and
- 7mm (Grade 6).

The New Zealand classification is shown in parenthesis. The aggregates are of a roughly uniform size, within about 65-100% of the maximum size for the grade, and shaped so that the longest dimension is about 100% greater than the smallest dimension. As in other countries, two coat seals, where a smaller chip is fitted into the matrix of a larger chip, are used to increase mechanical properties, stabilise developing failure or increase skid resistance. They are also used in the belief that two coat seals are quieter. Common combinations are 19/12mm, 16/10mm, 16/7mm and 12/7mm.

Every 8 to 15 years short streets, or portions of longer streets, are resealed, usually with a change in seal type.

Procedure

The experimental method needed to determine both the physical effect and the subjective response of residents to the changed noise resulting from the placement of a new seal. Noise measurements were made in conjunction with the resealing maintenance programmes. This enabled noise levels of surfaces near end of life and in new condition to be obtained. Adjacent residents (about 10-20) at each site were surveyed for their response to the traffic noise levels, both before and after the reseal programme.

Figure 2: 10mm (Grade 5) Chip

Noise Measurements

The noise measurement was a version of the drive-by at constant speed technique. Test vehicles - a car, an ATV and 4 x 6 tractor unit of a truck, were driven by at a 5 metre distance from a microphone linked to a high-speed A-D card, and a 1 second sample of noise was analysed both for 1/3- octave band spectra and total noise level. Generally, 5 passes were taken for each vehicle and for each site an average spectrum and noise level were determined.

To relate the test vehicles to the typical fleet in that area, measurements of about 20 passing cars and 10 trucks were taken at 40% of the sites. For each vehicle type, an average spectrum and noise level were produced. At these sites, the differences of fleet vehicles to test vehicles were used to modify the measurements made at the remaining sites.

Texture measurements were made with a non-contact laser profilometer. The mean profile depth (MPD) was calculated according to ISO 13473-1 (1997). For smooth surfaces MPD was about 0.3 – 0.6mm, for two coat seals 1 – 1.5mm and new large seals 3.0 – 4.5mm.

Annoyance Survey

Participants

138 participants from 12 locations (streets) are presented within these analyses. There were 62 males and 74 females (with 2 missing) ranging in age from '16 to 25' to '86 or more'. Of this sample approximately 82% were unaware that their street was scheduled for reseal at the first interview but 99% were aware that the road had been resealed at the second interview. A letter outlining the interviewer's intention to call to discuss road surface noise was read by 82% of the sample.

Materials

Noise annoyance is measured in three scales presented within a 44-item survey. The first measure is a 10-point semantic differential scale, anchored with 'Not at all annoying' and 'extremely annoying'. The item is introduced following the standards recommended by Fields et al (1998) [4] and asks participants to record how much the road noise annoys, bothers or disturbs. This scale is corroborated with a Likert scale introduced towards the end of the survey that ranges, "Not at all, a little, moderately, very and extremely'.

Two objects are considered: the first being traffic on the road, the second being the noise generated by trucks.

The third measure of annoyance is a 13-item behavioural disturbance index that follows from the research of Job et al., (2001) [5]. Job et al. found that scales measuring a reaction to noise are more reliable than scales of annoyance. Job identifies that 'annoyance' consists of psychological/attitudinal components as well as sensitivity to noise.

As a consequence the survey presented 20 items concerning attitudes towards noise and two items concerning noise sensitivity. The remaining items concerned requests for demographic details.

Survey Method

All those who lived adjacent to the reseal area were potential participants. All houses were sent

Location	Surface Treatment Before	Surface Treatment After	Noise Level Change (dBA)
1. Esplanade	Grade 3/5	AC	-7.0
2. Marine Parade	Grade 5	AC	-2.2
3. Cuba St	Grade 3/6 VF	Grade 3/6	-0.9
4. Moxham Ave	Grade 3	Slurry	-4.2
5. Epuni St	Grade 4/6	Grade 3/5	+1.7
6. Muritai Rd	Grade 3/6	Grade 6	-3.3
7. Naenae Rd	Grade 4/6	Grade 3/5	+0.7
8. Ruahine St	Grade 3	OGPA	-6.0
9. Abilene Cres	Slurry	Grade 4/6	+6.0
10. Stokes Valley Rd	Grade 6	Grade 3	+1.0
11. Brees St	Grade 4/5	Grade 4	+1.4
12. Scapa Tce.	Grade 6	AC	-3.9

Table 1: Overall Noise Level Changes at Surveyed Sites Only for Light Vehicles at 50 km/h

Key to Tables 1—3

AC:	asphaltic concrete
Slurry:	slurry seal (or micro surfacing)
OGPA:	open graded porous asphalt
Cape Seal:	slurry seal over a chip seal
7mm:	nominal chip sizes, single coat
12/7mm:	nominal chip sizes; two coat seal

Vehicle	Bituminous Mixes				Chip Seal Over Bitumen Layer								
	AC (dBA)	Slurry (dBA)	OGPA (dBA)	Cape Seal	7mm (dBA)	10mm (dBA)	12/7mm (dBA)	12mm (dBA)	16/7mm (dBA)	16/10mm (dBA)	19/12mm (dBA)	16mm (dBA)	19mm (dBA)
Test light vehicle	68	69	69	68	71	71	74	72	75	74	74	73	75
Typical fleet (light	69	70	69	68	72	72	74	72	75	74	73	73	75
Difference relative to AC light	N/A	+1	0	-1	+3	+3	+5	+3	+6	+5	+4	+4	+6
Test truck	79	76	77	76	77	79	79	77	80	80	–	80	–
Difference relative to	N/A	-3	-2	-3	-2	0	0	-2	+1	+1	–	+1	–

Table 2: Effects of Different Surfaces at 50 km/h for Car and Truck (Tractor Unit)

a letter inviting the occupants to participate in the study and provided details of a scheduled date for interviewing involving a questionnaire. Participants were sent the letter to orient themselves to the road noise. The design of the research is a "within –subjects" or "repeated measures" experiment. Thus, participants were surveyed before and after reseal to determine the influence of nay change on their measurable levels on annoyance and behavioural disturbance. The independent variable is the manipulation of the road surface or the change in conditions between the first and second interviews. The data presented are analysed using repeated measures *t*-

Car							Truck				
Speed	AC	OGPA	16/10mm	16mm	19/12mm	19mm	OGPA	16/10mm	16mm	19/12mm	19mm
50	68	69	74	73	74	75	77	80	80	–	–
70	72	73	78	77	79	81	80	82	82	81	83
90	–	–	–	–	–	–	82	85	84	84	85
100	–	77	83	82	85	84	–	–	–	–	–

Table 3: Effects of Surfaces on Drive-by Noise Levels at Three Different Speeds

tests.

Results and Discussion

Road Surface Effects on Noise

The results of the effects of the road surface are shown in Tables 1 to 3.

Tables 2 and 3 show that there is a significant road surface effect for cars at 50kmph. Relative to asphalt, a difference of +3 to +6 dBA for chipseals is common. The effect for trucks is much less, at 0 to +2 dBA relative to asphaltic concrete. It appears that some bituminous surfaces may be quieter for trucks when compared to asphalt but there is uncertainty as the numbers of these sites is small.

For cars, there is no significant difference between dense asphalt and open graded porous asphalt at 50kmph. This was expected as in New Zealand OGPA is typically used in depths of 30mm, and the percentage voids is usually less than 20%. In addition most of the asphalt is based on 10mm chip while the OGPA is mainly 14mm chip.

A plot of texture depth versus noise is shown in Figure 3. From this it can be seen that a texture depth/ noise relationship is not strong. However, it was noted that many of the two coat seals give a much higher noise than expected for their mean profile depth. Their noise effect is very similar to the single coat chip. It is possible that variability of chip and road sealing procedures does not provide the intended texture and that more detailed procedures for roading contractors are needed.

Annoyance Survey

Three main dependent measures are: perceived annoyance for traffic; annoyance specifically for trucks; and a behavioural disturbance index developed from Job (2001). The means for "before resealing" and "after resealing" are recorded in Table 4.

This table shows the means (SD in brackets) of the three scales measuring traffic noise annoyance, before and after road surface re-sealing. The extent of annoyance is in relation to the scale ranging from 0 ("not at all annoying") to 10 ("extremely annoying").

"Behavioural Disturbances" are reported as the item score for the 13 items with a larger scores indicating greater behavioural disturbance. The behavioural disturbance index makes no adjustment for incomplete forms and records only the total reported behavioural disturbances.

Figure 4 shows the change in annoyance with resealing, while Figure 5 illustrates the change in behavioural disturbance with resealing.

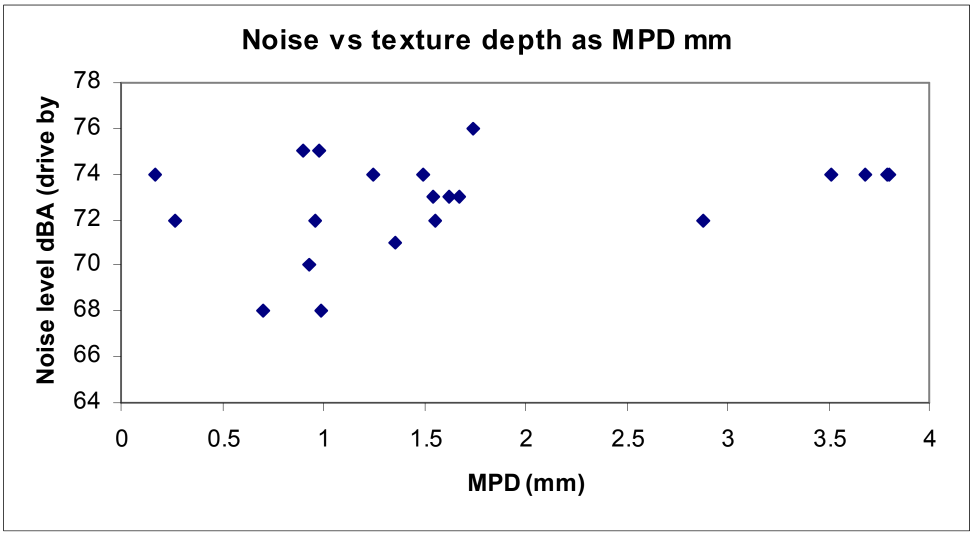

Figure 3. Relationship of Road Surface Texture (Mean Profile Depth) at Trial Sites and Sound Level Generated (dBA).

Location	Level Change (dBA)	Traffic Noise		Truck Noise		Behavioural	
		Before	After	Before	After	Before	After
1. Esplanade (n = 14)	-7.0	6.43 (2.8)	4.24 (2.5)*	7.64 (2.6)	5.96 (2.6)*	5.64 (3.2)	3.79 (3.5)*
2. Marine Parade (n = 12)	-2.4	1.83 (1.8)	1.17 (1.1)	1.00 (0.8)	0.86 (0.7)	0.67 (1.2)	0.08 (0.3)
3. Cuba St (n = 4)	-0.9	5.75 (1.7)	5.00 (3.9)	7.25 (1.0)	6.00 (4.5)	4.25 (3.4)	4.75 (4.6)
4. Moxham Ave (n = 13)	-4.2	5.12 (2.7)	4.92 (2.4)	4.50 (2.9)	4.78 (2.3)	4.31 (4.0)	3.77 (4.2)
5. Epuni St (n = 15)	+1.7	3.87 (2.5)	5.13 (2.9)	5.33 (3.5)	5.77 (3.3)	1.87 (2.5)	2.20 (2.8)
6. Muritai Rd (n = 16)	-3.3	5.04 (3.2)	5.52 (2.6)	6.13 (3.5)	6.73 (2.4)	3.56 (3.5)	3.44 (2.9)
7. Naenae Rd (n = 3)	+0.7	5.83 (1.4)	7.00 (1.7)*	6.87 (2.6)	7.00 (3.6)	5.67 (1.5)	6.00 (4.0)
8. Ruahine St (n = 11)	-6.0	6.96 (1.7)	6.45 (1.8)	7.06 (1.6)	7.09 (2.3)	6.00 (1.9)	3.36 (2.3)**
9. Abilene Cres (n = 13)	+6.0	1.92 (1.9)	3.62 (2.9)*	3.50 (2.6)	4.38 (3.2)	0.08 (0.3)	0.92 (1.7)
10. Stokes Valley Rd (n = 18)	+1.0	4.50 (2.8)	5.67 (3.1)*	4.73 (3.2)	5.67 (2.8)	2.72 (3.1)	4.22 (2.9)*
11. Brees St (n = 7)	+1.4	3.91 (3.3)	3.44 (2.8)	2.42 (3.2)	2.34 (3.6)	2.43 (3.0)	0.86 (2.3)
12. Scapa Terrace (n = 12)	-3.9	3.00 (2.7)	2.17 (1.2)	4.85 (3.3)	3.30 (2.5)	0.67 (1.1)	0.33 (1.2)

* p. < .05 ** p. < .01

Table 4: Means and Standard Deviations of Three Dependent Measures: Traffic Noise Annoyance, Truck Noise Annoyance and Behavioural Disturbance Due to Traffic Noise

Traffic noise annoyance shows a significant increase at site 7 (Stokes Valley Road), when measured on the scale recommended by Fields et al. The same site shows an increase in behavioural disturbance, as measured by the scale following Job et al (2001). Similarly, site one showed a significant decrease in annoyance and significant decrease in behavioural disturbance. Thus both the measures of Fields et al and Job et al identified differences in behaviour or annoyance corresponding to both increased and decreased actual physical noise. However, site 8 shows a significant decrease in behavioural disturbance not matched by a detected difference in annoyance.

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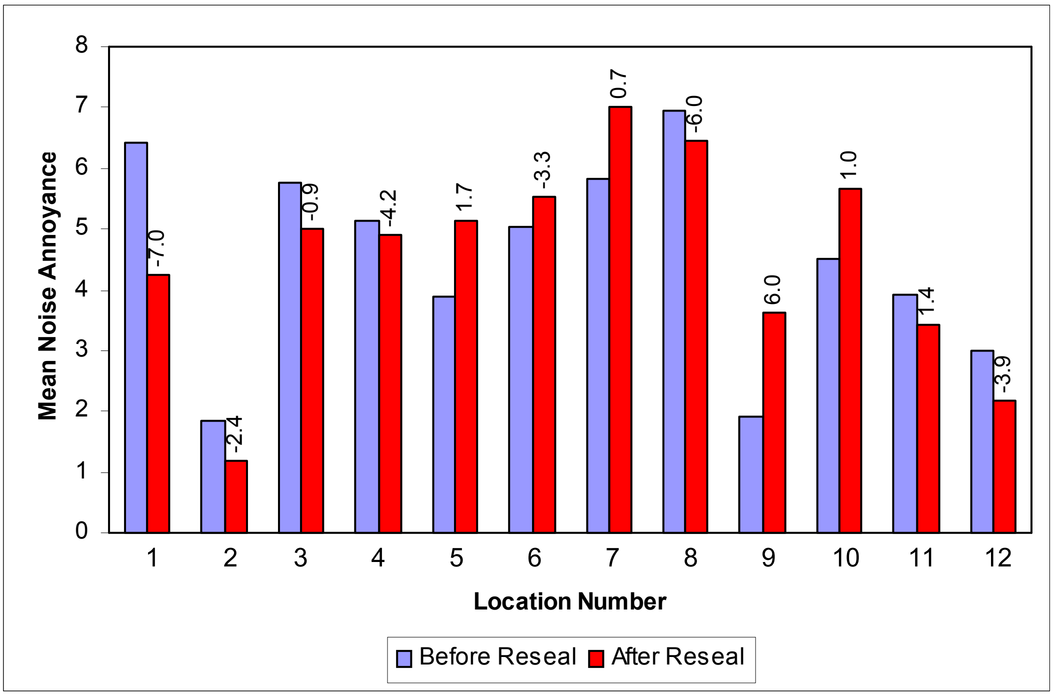

Figure 4. Means for the Annoyance Scale (N=138) for 12 Reseal Locations

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Further, site 9 shows differences in annoyance not matched by behavioural disturbance. The likely influence explaining these data is traffic volume. A large difference in physical noise in a quiet area may yield a change in annoyance but not develop any behavioural change because the events that were annoying were too infrequent to cause significant behavioural alteration initially.

The reverse is true. These data show evidence for behavioural adaptation that occurs in the absence of significant alteration in levels of annoyance. Put another way, people alter their behaviour to accommodate to changes in noise levels at levels below those that would be detected using noise annoyance scales.

Other Post-Reseal Observations

Participants of the study completed a 20-item questionnaire concerning potential sources of noise and their responses to it. These questions helped to interpret the findings of the annoyance and disturbance scales. "Before" and "after" comparisons are analysed with repeated measures t-tests. These comparisons reveal the ability of people to detect the source of change in their noise environment. The results suggest people are deliberate in their consideration of the role the road surface has in the change to the noise environment.

Residents at site 1 (The Esplanade), which reduced its average noise by 7.0 dBA, increased their agreement that they "don't mind the traffic noise on their street" t (12) = 2.309 p. < .05 and were less likely to describe their street as 'noisy' (t (13)=3.229 p. < .01). Site 12 (Scapa terrace) also reduced in noise and here residents correctly disagreed that the "noise outside had become worse" t(12) =2.887 p.< .05. Residents of site 5 (Epuni St) were more likely to agree that the "noise outside their house had become 'worse' recently" (t (11) = 2.70 p. <. 05), therefore recognising an increase in noise of 1.7 dBA. At site 8 (Ruahine St) residents gained a large improvement, with the traffic noise being reduced by 6dBA following the reseal. This is recognised in the post reseal disagreement with the statement that the "traffic noise has gotten worse recently" (t (11) = 3.63 p. < .05).

Residents at site 4 (Moxham Ave) benefited from a 4.2dBA reduction in traffic noise, but became more inclined to disagree with the statement that "a better road surface would result in less noise" (t (12)= 2.80 p. <. 05). Following the resurfacing these people were more likely to disagree that the "traffic noise was 'bad' when they first moved in", (t(12) = 2.30 p. <.04). Post reseal, these residents tended to agree more strongly that they "enjoyed peace and quiet" (t (12)= 2.92 p. <. 05). Traffic noise at Site 6 (Muritai Rd) reduced by 3.3 dBA but residents became more inclined to disagree that "they would eventually adjust to an increase in traffic noise" (t

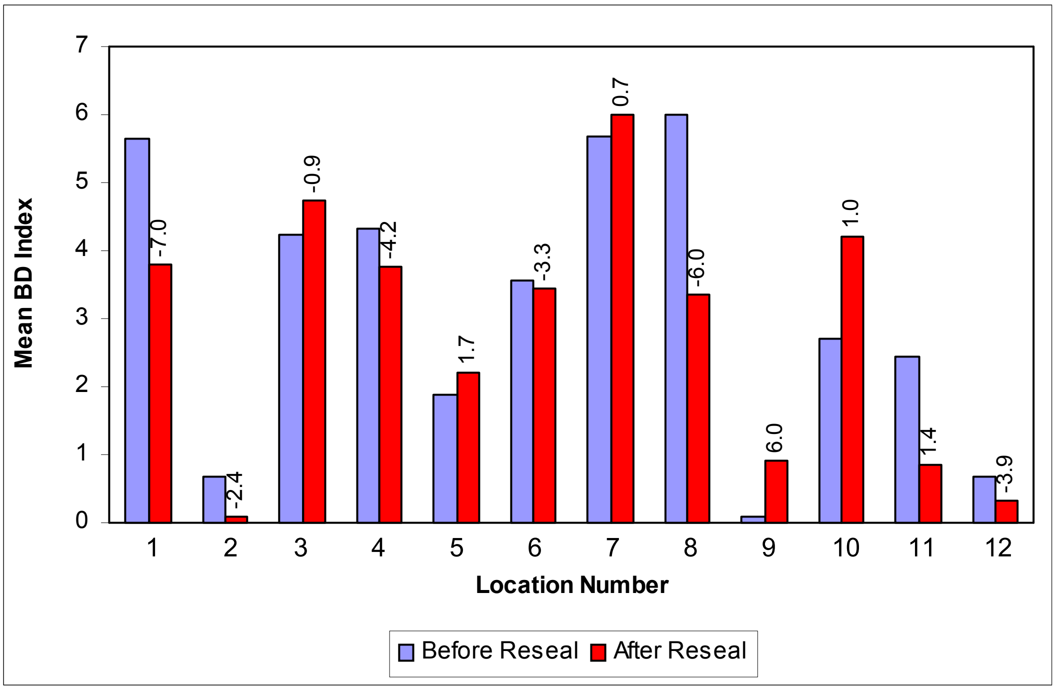

Figure 5. Means for the Behavioural Disturbance Index (N=138) for 12 Reseal Locations

(15) = 2.16 p.<.05.

Site 9 (Abilene Crescent), with the greatest increase in traffic noise, was also a site with low traffic volumes. The 6dBA increase was not reflected in a significant change in either indicators of annoyance or in behavioural disturbance. Residents were more inclined to disagree that "they don't mind the noise of traffic on their street" (t (11) =3.71 p. <. 05) and recognised that the noise on the street "had gotten worse recently" (t (11) = 1.94 p. <. 05). More important, the residents were more likely to agree that "a better road surface would result in less noise" (t (11) = 2.64 p. <. 05).

In contrast, a small increase in overall noise on Stokes Valley Road (site 10), a high traffic volume road, led to significant differences in indicators of annoyance, behavioural disturbance, and attitudes towards the traffic noise. Residents became more likely to: disagree that "they don't mind the traffic noise" (t (17) = 2.4 p. <. 05); recognise that "the noise had gotten worse recently" (t (18) = 2.15 p. <. 05); and claim, "a better road surface would reduce the traffic noise" (t (18) =2.65 p. <. 05). These people were also more likely to disagree that they thought the noise was "bad" when they first moved in (t (18)= 2.15 p. <. 05) and disagree that "if traffic speed were reduced it would reduce the noise to an acceptable level" (t (18) = 2.40 p. <. 05).

Sites 3, 7 and 11, and (Cuba St, Naenae Rd and Brees St) showed no differences in any of the twenty items. Residents at site 2 (Marine Parade) reduced their concern that "younger people in cars are responsible for the noise" (t (11) = 2.63 p. < .05), and became more likely to disagree that "other people put up with roads that are much more noisy" t (11) = 2.61 p. < .05).

Conclusions

There are significant road surface effects regarding traffic noise at speeds of 40-50kph. Relative to asphaltic concrete, for light vehicles these are +3 to +6dBA, and for heavy vehicles 0 to +2 dBA. The road surface effect is substantially the same at 40-50 kph as it is at 80-100kph. Two - coat seals (as made in New Zealand) are no less noisy than single coat seals.

The behavioural disturbances index, following Job (2001), is a more sensitive measure of noise annoyance than those recommended by Field et al (1998). Whereas a decrease in noise did not correspond with a reduced level of annoyance using the Fields et al recommend scale, the behavioural disturbance index detected significant improvements for those affected.

"…There are significant road surface effects regarding traffic noise at speeds of 40-50kph. The road surface effect is substantially the same at 40-50 kph as it is at 80-100kph…

Very small increases in noise level are matched with changes in behavioural disturbance… even if the change is less than +3dBA "

The participants correctly identified the source of noise annoyance as being the road surface, and not cars, truck or other characteristics, such as service covers.

Very small increases in noise level are matched with changes in behavioural disturbance. This is true even if the change is less than +3dBA (c.f. Raw & Griffiths 1988) [6]. The reverse is true also: behavioural disturbance reduction can be anticipated even when the reduction in noise is very small.

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