Improved effectiveness and innovation for audio tactile profiled roadmarkings

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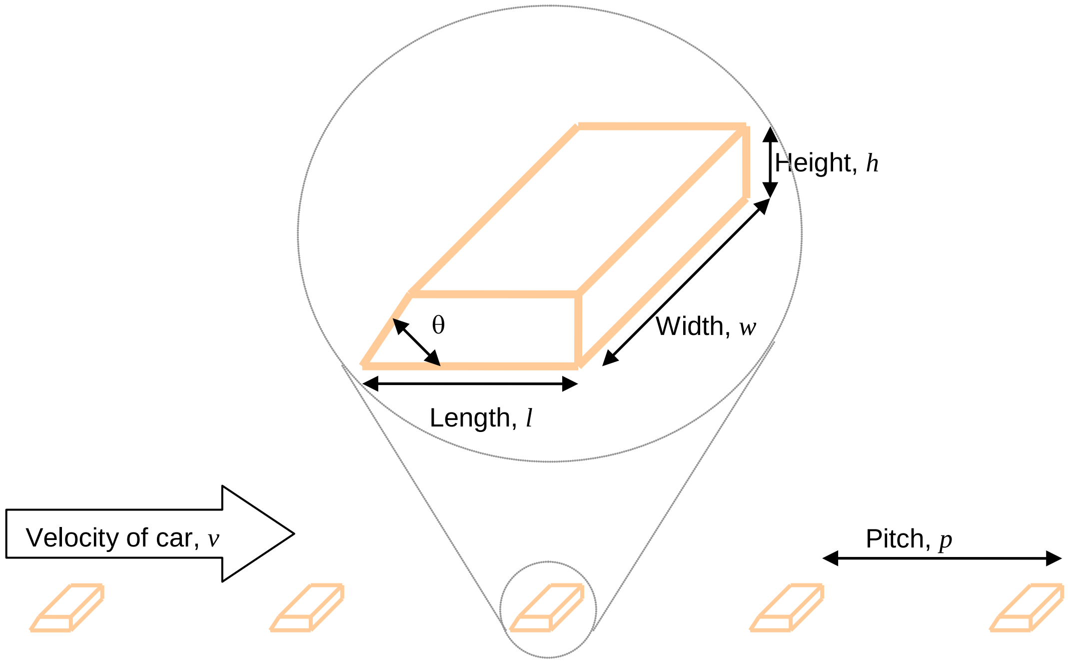
Abbreviations and terms

ATP roadmarkings	Audio tactile profiled roadmarkings
Grade 2 chip	Larger-sized aggregate, with chips of 19mm nominal diameter
Grade 6 chip	Smaller-sized aggregate, with chips of 7mm nominal diameter

Terms used for dimensions of the ATP roadmarking blocks



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Executive summary

This report describes a research project undertaken to establish the relationship of the dimensions of audio tactile profiled (ATP) roadmarkings to the noise and vibration generated inside a vehicle when it traversed the roadmarkings. This would identify the acceptability of new types and profiles of ATP roadmarkings and the minimum distances required for the roadmarkings to be effective. A second stage would then determine the effectiveness of the noise and vibration in alerting the driver. The research findings would allow noise and vibration levels for any ATP roadmarking and the resultant human response to be calculated from the relationships determined.

Method for noise and vibration effects

The physical effects of ATP roadmarkings were determined by measuring the noise (using sound level meters) and vibration (using accelerometers) inside a vehicle while it traversed a special test strip of ATP roadmarkings. The measurements were made on test strips of ATP roadmarkings made from test blocks which were positioned in a single line with block pitch (spacing length between consecutive blocks) at 250mm, 500mm or 750mm. The wooden test blocks were cut from pine timber into shapes to give variation to their height, width and length, and variation in the angle of the rising edge facing the oncoming vehicle.

The sound level and acceleration (vibration) inside the car were measured for each run over a test strip of ATP roadmarkings, while the driver controlled the speed to 40, 60, or 100km/h within a tolerance of ±5 km/h.

Results and issues

Considerable variability was found between repeat runs over a number of different ATP roadmarking test strips. The variability was such that it obstructed identifying the effects of the different test block dimensions. Investigations into the variability included using wider test blocks and multiple runs, measuring noise outside the vehicle rather than inside, and measuring the spectral content of the noise. It was found that a reliable method was to adhere the wooden or plastic blocks to the road, use average effects calculated from multiple runs, and establish trends through spectral analysis of the resultant noise.

The noise spectra of road-only travel were compared with the noise spectra of traversing the ATP roadmarkings. Particular changes at specific frequencies of the noise spectra were noted while traversing the ATP roadmarkings. The important frequency was the one at which the test blocks were impacted (depending on block pitch and vehicle speed) plus harmonics of that frequency, especially the second harmonic. For example, for a 500mm pitch and a test speed of 100km/h (27.8m/s), the impact frequency was 56Hz and the second harmonic was 112Hz.

The following investigations were carried out using the measurement techniques developed:

- The noise levels were measured outside and inside the vehicle. It was discovered the tonal peaks from contacting the ATP roadmarking were just as pronounced outside the vehicle as they were inside but the higher frequency components of the noise (300Hz and upwards) were much less prominent inside the vehicle compared with outside. This was probably a consequence of the sound-deadening insulation used for the interior of vehicles.

- The effects of the 250mm and 500mm pitch were investigated. The 250mm pitch (less distance between test blocks) generated about 2 dB(A) more noise than the 500mm pitch (more distance between test blocks) showing that the frequency of the dominant tone of contacting the ATP roadmarking moved in proportion to the difference in pitch.
- The effects of ATP roadmarkings over two different road surface types were examined using grade 2 (larger-sized 19mm) chipseal and grade 6 (smaller-sized 7mm) chipseal. Each time, the noise effect of traversing the ATP roadmarkings dominated and was about the same for both road surface types.
- In a comparison of the noise effects for trucks and cars traversing ATP roadmarkings, the trucks experienced the tonal peak of noise at the same frequency as cars but the trucks were much less responsive, with the noise level of the tonal peak for trucks being only about half that for cars.
- The effect of increased block height on tonal peak was greater than the effect of increased block height on total noise. As block height increased from 2mm to 6mm, the total noise increased by only 2dB(A); whereas the tonal peak increased by about 10dB(A).

Driver-response to ATP roadmarkings

Driver-response was investigated as a threshold effect. To determine the driver-response to ATP roadmarkings and to identify the threshold at which drivers detect the noise and vibration effects of ATP roadmarkings, a laboratory-based driving simulation was created, and a set of progressively increasing effects, from road-only to ATP roadmarkings at building block heights (from 2mm to 6mm,) was obtained for the threshold trials via a driving simulator.

Participants were played noise effects from a vehicle driving over the different ATP block heights and on the road only in controlled conditions. The accuracy of participants in detecting the difference between road-only noise and ATP roadmarkings noise was assessed using signal detection theory while the participant completed a distracter task (Stroop task; Stroop 1935) designed to replicate the cognitive demands of driving, with or without background music.

From these tests, the overall threshold block height was found to be between 3mm and 4mm. Based on the range of results, all participants, across different age groups, reliably identified ATP roadmarkings with a block height of 5mm. The results show some suggestion that age may be a factor in response to the threshold block height, particularly in the music task.

Conclusions

- The methodology described is a reliable method for measuring the level of ATP roadmarking noise and vibration noticed by drivers.
- Wooden or plastic blocks, adhered to the road, are a viable way to make ATP roadmarking lines for experimental purposes, such as identifying trends in noise and vibration effects in relation to the dimensions of the blocks. No difference was observed between wood or plastic blocks and thermoplastic blocks.
- When examining how the dimensions or type of ATP roadmarking may influence noise levels, emphasis should be placed on the tonal components of the noise rather than the total noise level.

- When measuring the noise and vibration of ATP roadmarkings, multiple measurements are needed which, when averaged, give a reliable measurement of the noise and vibration levels provided by a particular ATP roadmarking.
- Due to the restricted sample size of the research undertaken, reliable results were available only for rectangular block shapes.
  - Increasing block height increased the overall noise effect and the effect of the dominant tone of traversing the block. As block height increased, the increase in the effect of the dominant tone became greater than the increase in the overall noise effect.
  - Increasing the block width gave greater certainty that the vehicle made contact with the ATP roadmarking, but noise effects appeared unchanged relative to those from the standard 100mm block width.
  - Decreasing the block pitch, so there was less distance between blocks, increased the noise level by several dB(A) and increased the frequency of the dominant tone proportional to the change in pitch.
- The ATP roadmarking appeared to have a lower physical effect for trucks than it did for cars. This may have also resulted in the ATP roadmarkings having a lesser effect for truck drivers than for car drivers, but this was not tested.
- There was a particular level at which the ATP roadmarkings were noticed, but they did not become much more noticeable as the physical effects increased beyond that threshold. The method described in this report appears to be an effective way to test the threshold effect.
- Based on these findings, ATP roadmarkings were reliably detected by drivers when the block height was 4mm high. All participants in our study detected them at a block height of 5mm. The presence of music increased the required block height slightly, but was not enough to require the next block height (of 1mm higher).

Recommendations for further research

- Further research should use a larger sample of participants and extend the range of block shapes and pitch trialled. Research could test whether a higher frequency noise effect would alter the threshold block height at which the ATP roadmarking is reliably detected.
- The need for older people to have a higher block height for the same level of detection should be investigated.
- Identifying truck drivers' response to the threshold block height recommended for cars would assist in determining the value of ATP roadmarking treatment of an area where there is an issue with truck crashes.

Abstract

The research identified how the physical noise and vibration generated by traversing ATP roadmarkings was influenced by the properties of the roadmarkings, such as their height, width and pitch, as well as by other factors, such as vehicle speed. The research established the relationship of human response to the noise and vibration generated. The physical effects of traversing ATP roadmarkings were determined by measuring the noise (using sound level meters) and vibration (using accelerometers) inside the vehicle while the vehicle traversed a special test strip of ATP roadmarkings, the profiles of which were machined mainly from wood, or from plastic.

The driver-response was investigated as a threshold effect via a laboratory-based driving simulation. Participants were played noise effects in controlled conditions from a vehicle driving over different ATP block heights between 2mm and 6mm, and from a vehicle on the road only. The accuracy of participants in distinguishing between road-only noise and ATP roadmarking noise was assessed using signal detection theory while the participant completed a distracter task (Stroop task; Stroop 1935) designed to replicate the cognitive demands of driving. The overall threshold block height was found to be between 3mm and 4mm.

1 Introduction

This report describes a research project undertaken to:

1 establish the relationship of the dimensions of audio tactile profiled (ATP) roadmarkings to the noise and vibration generated inside a vehicle when it traverses the roadmarkings

2 determine the effectiveness of this noise and vibration in alerting the driver.

Prior to this research there was no accepted method for testing ATP roadmarkings for performance – either in terms of audio and tactile response or in terms of effective lifetime with respect to retaining key critical dimensions.

1.1 Background

Two previously completed projects identified methods by which the physical noise and vibration effects of ATP roadmarkings could be measured, and established broad relationships between physical dimensions and the noise and vibration generated by ATP roadmarkings.

Central Laboratories report 03-527605 *Guidelines for performance of New Zealand markings* (Dravitzki et al 2003) describes investigations into the noise experienced inside a vehicle when travelling on ATP roadmarkings. This project was a preliminary study to identify methodologies for measuring noise and vibration effects, as a basis for considering the potential for performance-based measures. The project included driving a test vehicle, instrumented with a sound level meter, on one design of ATP roadmarking. Differences were clearly observed between different markings of the same design (but with variations in their wear), and between the markings and the road. Tests included measuring good- and poor-condition markings, as well as measuring the noise and vibration effects of two types of road surface.

The second project extended the work of the first and sought to establish in broad terms the effect the dimension of the roadmarkings had on noise and vibration levels and the extent to which these were noticeable. The intention was to develop some initial 'end-of-life' criteria.

An instrumented test car was used to drive along ATP roadmarkings and record the sound and vibration levels inside the cabin. Subjective assessment of the audio and tactile effect of the ATP roadmarkings was also made by the two vehicle occupants as the roadmarkings were traversed. Physical measurement of the ATP roadmarking dimensions were taken on a separate occasion as this required partial road closure.

Identifying a relationship between noise (or vibration) effects and physical dimensions was complicated by the variability in dimensions of the in-situ ATP roadmarkings.

Several issues arose out of this study. These were the:

- difficulty of attempting to identify relationships between dimensions and effects because in-situ material showed considerable variation in the critical dimensions
- likely bias in subjective response because evaluators were deliberately searching for an effect
- relevance of the vibration response when it appeared less readily detectable subjectively and also appeared to be strongly related to the more easily measured and detected noise response.

1.2 Objective of the study

This project aimed to:

- develop an economical method for determining whether a particular ATP roadmarking meets acceptable performance standards, without the need for manufacturers and road agencies to run further complex human response tests
- establish minimum roadmarking dimensions for performance and permissible application tolerances.

The first stage of the research was to identify how the physical noise and vibration generated by traversing the ATP roadmarking was influenced by its properties, such as height, width and pitch, and by other factors such as vehicle speed. The second stage of the research was to establish the relationship of human response to the noise and vibration generated by traversing the ATP roadmarking. The relationships established could identify the acceptability of new ATP roadmarking profiles and types, or identify minimum dimensions required for effective ATP roadmarkings. The research findings would allow the calculation of the:

1 noise and vibration levels for any ATP roadmarking

2 level of human response to the established noise and vibration levels.

To overcome the issue of dimensional variability encountered in previous research, test ATP roadmarking lines would be formed by shaping blocks of material, mainly of wood, then adhering them to the road with double-sided adhesive tape.

2 Measuring the physical effects of ATP roadmarkings

2.1 Method

The physical response was determined by measuring the noise (using sound level meters) and vibration (using accelerometers) inside a vehicle while it traversed a special test strip of ATP roadmarkings.

Measurements were made on test strips of ATP roadmarkings where the accuracy of the dimensions of the test blocks was certain because the test profiles were machined, mainly from wood but also from plastic. They were attached to the road surface with double-sided adhesive tape, approximately 1mm thick, to form the test strips. The test blocks were positioned in single lines with a consistent block pitch (spacing length between consecutive blocks) of 250mm, 500mm or 750mm for each line. The wooden test blocks were cut from pine timber into shapes to give variation in height, width and length, and variation in the angle of the rising edge facing towards the oncoming vehicle (see figure 2.1).

Correlation to in-situ ATP roadmarkings was also provided. Traffic Safety Products Ltd made some additional blocks of thermoplastic by a screeding process over release paper to represent the profile section of an ideal ATP roadmarking. These thermoplastic blocks were also adhered to the road in the same manner as the wooden blocks.

Figure 2.1 The test car next to a line of test blocks on the Manfeild race track, and a selection of five test blocks, including four wooden test blocks and one thermoplastic test block

For road user safety purposes the experiment was carried out on private roads at the Manfeild race track near Palmerston North and at the Paraparaumu airstrip near Wellington. This use of hired test areas with attendant significant time and hire costs influenced how the experimentation was conducted. In particular, the available time was used to complete tests of as many parameters as possible, with the data being processed in the following days.

A test car was driven over wooden blocks of different sizes and shapes, representing the sizes and shapes of ATP roadmarkings, which were stuck to two flat, uniform road surfaces, at a range of pitches. The acceleration (vibration) and sound level inside a vehicle were measured for each run while the driver controlled the speed to 40, 60 or 100km/h within a tolerance of ±5km/h. The range of testing dimensions and conditions is shown in table 2.1 for the Manfeild race track and in table 2.2 for the Paraparaumu airstrip.

The test car was a 1996 Toyota Corolla GL Wagon (front-wheel drive) with fewer than 20,000km driven. Figure 2.1 shows the test car next to a line of test blocks at the Manfeild race track. Tyres were inflated to 32psi when cold.

Sound was recorded through a Rion NL-32 sound level meter mounted behind the driver's left ear. The sound meter output an analogue sound pressure signal which was logged on a multi-channel Logbook Data Logger at a rate of 12,500Hz. A tri-axial accelerometer was mounted in the passenger's footwell on the central partition below the gear lever. The driver and passenger of the test car assessed whether the wheels hit the full line of test blocks and only the successful runs were used for further analysis.

Table 2.1 Size, shape and pitch of blocks, and speeds used at the Manfeild race track

Height (mm)	Width (mm)	Length (mm)	Angle (deg)	Pitch (mm)	Speed (km/h)
6	100	40	90	250, 500, 750	40, 60, 100
10	100	40	90	250, 500, 750	40, 60, 100
14	100	40	90	250, 500, 750	40, 60, 100
10	100	40	70	250, 500, 750	40, 60, 100
10	100	40	45	250, 500, 750	40, 60, 100
10	100	40	25	250, 500, 750	40, 60, 100

Table 2.2 Size, shape and pitch of blocks, and speeds used at the Paraparaumu airstrip

Height (mm)	Width (mm)	Length (mm)	Angle (deg)	Pitch (mm)	Speed (km/h)
14	100	40	90	250	40, 60
10	100	40	30	250	40, 60, 100
10	100	40	45	250, 500	40, 60, 100
10	150	80	45	250, 500, 750	40, 60, 100
14	150	80	45	250	40, 60, 80
10	150	80	90	500	40, 60,100
10	150	80	90	750	40, 60
14	150	40	½ round	250, 500, 750	40, 60, 100
10	150	37	½ round	250, 500, 750	40, 60, 100

3 Results

There was considerable variability between repeat runs. This variability on the same block pitch and size obstructed identifying the effect the block dimensions might have on the generation of noise and vibration when traversing the simulated ATP roadmarking line. Table 3.1 shows the results for all rectangular blocks, with 90º as the angle of the rising edges, tested at the Paraparaumu airstrip. At this stage it was considered that the extent of variability meant there was little value in investigating any effects of rising edges sloping at other than 90º.

Table 3.1 Noise levels and range for repeat runs over rectangular blocks at the Paraparaumu airstrip

Speed km/h	Block width (mm)	Pitch (mm)	Average noise level dB(A)	Range dB(A)	Std deviation	Noise road only dB(A)
40	100	250	77.1	74.1–80.7	3.46	61
	150	250	77.6	69.8–79.9	4.34	
		500	77.9	73.9–81.5	0.48	
		750	73.8	69.5–76.0	2.61	
	200	250	77.3	77.0–77.7	2.24	
45	150	750	74.1	n/a		
50	100	250	77.5	n/a		
	150	750	72.4	n/a		
60	100	250	74.5	73.1–78.8	3.46	64
	150	250	77.2	74.1–80.6	3.25	
	100	500	71.4	n/a		
	150	500	75.6	74.0–79.0	2.12	
	150	750	74.3	70.1–77.6	2.59	
100	100	250	82.8	82.6–82.9	0.25	69
	150	250	85.3	82.8–87.1	1.85	
	100	500	78.9			
	150	500	81.6	79.0–83.5	1.69	
	150	750	80.9	78.6–82.3	1.78	

Before proceeding with the work, the key issue was to resolve this variability.

A significant lesson from this work was that a performance-based approach to the effect of ATP roadmarkings might not be appropriate because of the variability in noise effect. It helped confirm the validity of the intent of this research, which was to develop a knowledge of the dimensions/noise and vibration relationship through controlled experiments. Road controlling authorities could assure themselves the markings were still making adequate levels of noise and vibration simply by a field measurement of their dimensions.

4 Investigating the variability

Three possible influences on the variability were then investigated.

The variability could be the result of not being able to keep the tyre in a consistent position on the line. The blocks tested were usually only 100mm in width, though some runs were done with blocks 150mm or 200mm wide. However the tyre was approximately 150mm wide so there could easily have been some sideways wander along the line. A possible solution was therefore not to attempt to accurately simulate ATP roadmarking lines of standard width but examine the effects using wider blocks, eg up to 300mm, so that consistent tyre contact was certain. If this was successful it would identify that the narrower the block (and line), the more uncertain its effect in practice.

A second factor could be that the measurement of noise inside the car was inherently variable. Therefore three to five runs of each variation in block configuration and selection were undertaken to produce a stable average for comparison with similar stable average results.

The main emphasis in the work until this point had been on total noise level but then the emphasis was broadened to focus on changes in noise at specific parts of the noise spectra where ATP roadmarkings had an effect. This was the frequency at which the blocks were impacted plus the harmonics of this frequency, especially the second harmonic. For example, for a 500mm pitch and a test speed of 100km/h (27.8m/s) they would be 56Hz and 112Hz.

Another approach was to study the effect of the dimensions of the blocks when the noise was measured outside the car. For that part of the noise spectra where the blocks had an effect, there could be significant variation because of mechanical engine noise and car body vibration. Therefore by measuring outside the car, the influence of these variables might be less.

4.1 Wider test blocks

A series of runs was undertaken with wider test pieces. For each variant of spacing and speed five replicate runs were made. The results are shown in table 4.1 where it can be seen there is an overall pattern for ATP roadmarking lines to generate more noise when the block pitch is shorter and the blocks are more closely spaced. The table shows there is no pattern to the noise range from each set of five runs. A range of 3 or 4dB(A) across the five runs on each width/pitch combination is common but in several instances the range across the five runs is from only 1 to 2dB(A).

Table 4.1 Noise level and range for five repeat runs over very wide blocks

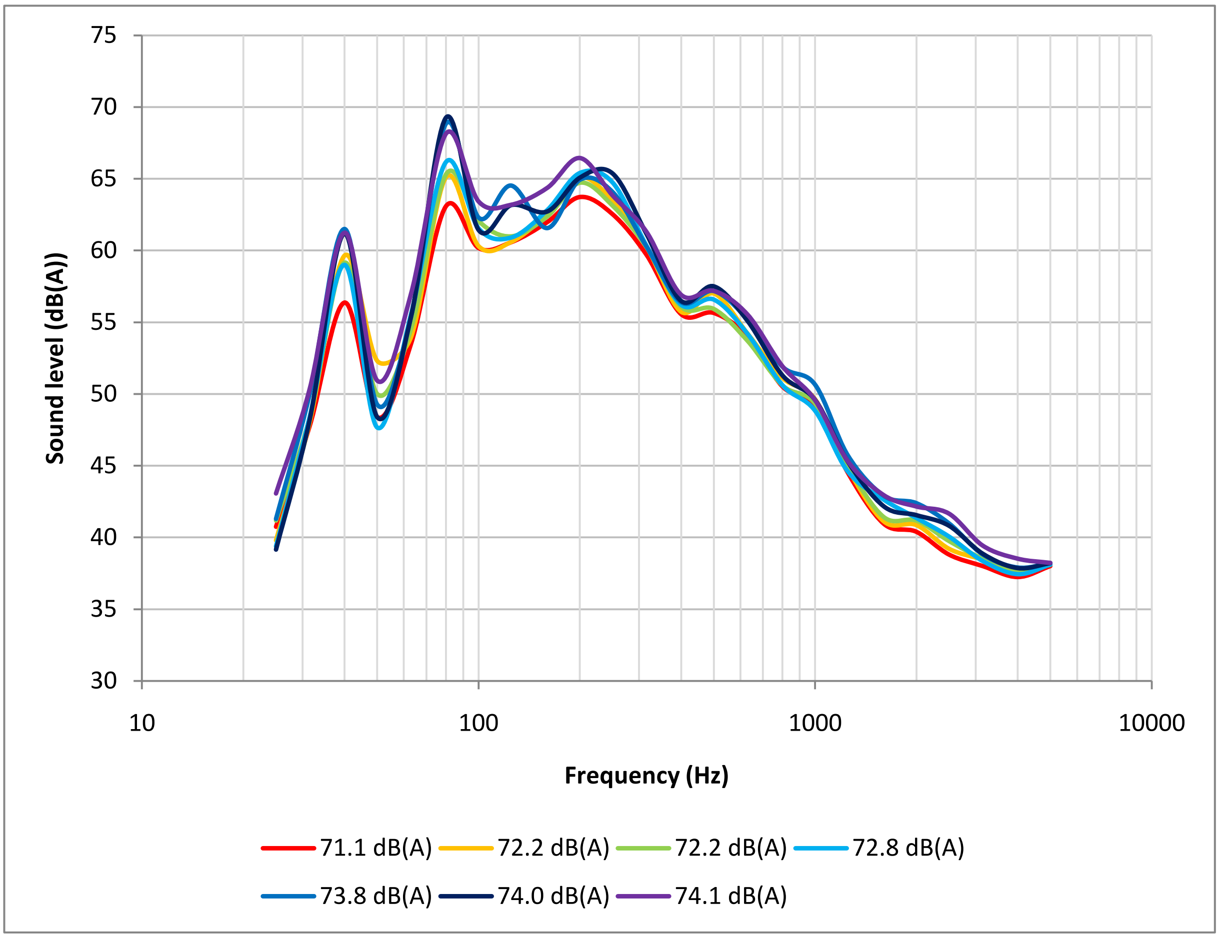
Block width (mm)	Speed (km/h)	Pitch (mm)	Average noise level (dB(A))	Range (dB(A))
200	60	250	67.4	2.3
		500	65.7	1.8
	100	250	74.4	4.4
		500	73.3	4.9
250	60	250	66.0	2.9
		500	65.3	4.9
	100	250	74.9	7.2
		500	71.4	1.3
300	60	250	68.9	3.9
		500	66.2	0.7
	100	250	71.9	3.8
		500	73.3	3.5

4.2 Spectral analysis of tonal effects

This method gave much more emphasis to the tonal content of the noise, especially the portion of the noise spectra that arose from the rate at which the ATP roadmarking blocks were traversed; which at 100km/h with a 500mm block pitch was 56 blocks per second, or at 100km/h with a 250mm block pitch was 112 blocks per second.

Figure 4.1 shows the results of seven repeat runs over an ATP roadmarking with a block height of 5mm, block pitch of 500mm and vehicle speed of 70km/h. The dominant peaks are, as expected, at 40Hz and 80Hz. There is considerable variability between the seven repeat runs, both in total noise and the levels of the tonal peaks. Figure 4.1 also shows there is correspondence between the total noise from a run and the levels of that run’s tonal peaks.

Figure 4.1 Noise spectra from seven repeat runs over ATP roadmarkings



Noise spectra can be added together to produce an average spectra. After further experimentation, as shown below, the preferred method was to take the spectral content, as shown above, then average that for five repeat runs to produce an average noise spectrum for each experimental condition.

This method was trialled for increasing block height, as shown below.

4.2.1 Trialling repeat runs and investigating the effect of block height

Plastic blocks, 40mm long by 200mm wide, were placed at 500mm block pitch. Each plastic block was 1mm thick and progressively stacked on top of each other to create five different ATP roadmarking block heights between 2mm and 6mm. A thick double-sided tape was used to attach the first layer of plastic blocks to the road surface so that the block height with one plastic block was 2mm. Another thinner type of double-sided tape was used to secure each stacked layer on top of the first, so that the block height increased by 1mm for each subsequent stacked layer of plastic.

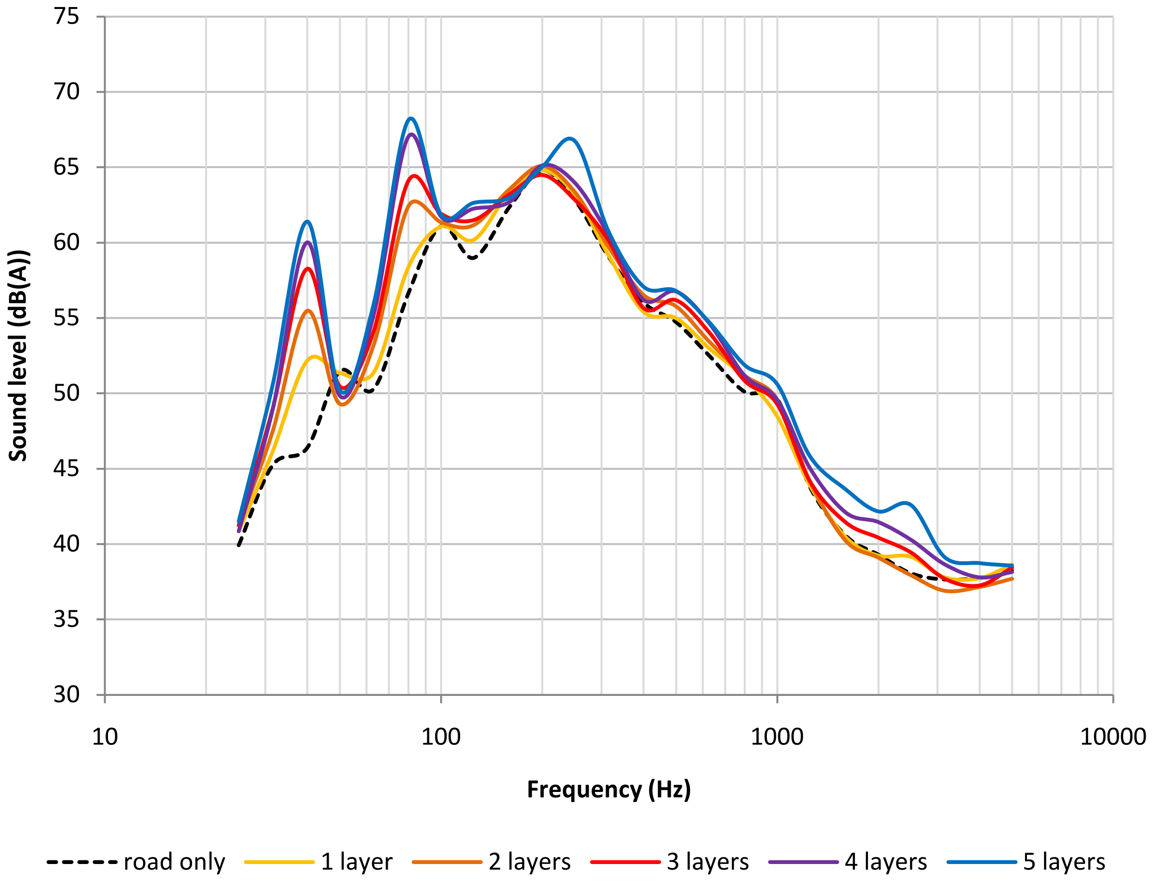
The test vehicle was a car and it travelled at 70km/h over each of the ATP roadmarking conditions five times (for a total of 25 drives). The speed at which the ATP roadmarkings were impacted was 19.4m/s.

Noise and vibration samples were recorded using sound level meters and accelerometers mounted within the car cabin.

Table 4.2 The number of plastic blocks stacked and the effective ATP roadmarking block heights

Number of plastic blocks stacked	Block height (mm)
1	2
2	3
3	4
4	5
5	6

Figure 4.2 Average noise level of multiple (five) runs over each block height[1] (from Wainuiomata trials)



As figure 4.2 and table 4.3 show, there is a steady increase in noise at the tonal peaks in the 40Hz and 80Hz third octave bands. The noise increase for these tonal peaks is about three to four times the actual change in total noise level.

[1] Noise measurements were made on Moores Valley Road, Wainuiomata, Lower Hutt, as described in section 2.1.

Table 4.3 Average noise levels obtained from repeated runs for increasing block heights

	Noise level at 40Hz		Noise level at 80Hz		
		Increase relative to road only		Increase relative to road only	Total (all frequencies)
Road only	46.4		56.7		70.6
1 layer	52.2	5.8	58.4	1.7	71.1
2 layers	55.5	9.1	62.4	5.8	71.8
3 layers	58.3	11.9	64.1	7.4	72.0
4 layers	60.0	13.6	67.0	10.4	73.0
5 layers	61.4	15.0	68.1	11.5	73.9

The results showed the success of the technique of using the average result from five repeat runs. This preferred technique was then used to develop an understanding of a number of issues, such as noise inside the car compared with noise outside the car, the effects of road surface type and block pitch, and the effect of ATP roadmarkings on trucks compared with the effect on cars.

4.3 Noise inside the car versus noise outside the car

While the overall intention had been to use controlled test blocks, the practicalities of hiring either the Manfeild race track or Paraparaumu airstrip meant this was not always possible. To examine the differences between inside and outside car measurements, on-road tests were made on a section of in-situ ATP roadmarkings at Kaitoke on State Highway 2 just north of Wellington. Ten runs were made with simultaneous inside and outside car noise measurements. The outside measurement was via a fixed microphone. Cones were spaced on the road 20m before and 20m after the fixed microphone point so researchers both inside and outside the car could ensure the car’s position would coincide with the interior measurement in their recordings. In addition, corresponding measurements were made with the car driving on the road surface only and not on the ATP roadmarking.

The noise spectra shown in figures 4.3 and 4.4 were processed by taking each of the 10 runs and combining them to produce an average effect.

Figure 4.3 shows the ATP roadmarking causes a 6dB(A) increase in outside noise. The two pronounced peaks will give this noise a distinctive tonal character (which can be a source of annoyance for any residents nearby). Compared with travel on the road surface only, these tonal peaks at 100Hz and 200Hz are 13 to 15dB(A) noisier. Note that these distinct tones are a lower noise level than the main part of the spectra near 1000Hz but note also that this is shown as the A-weighted dB(A) where the lower frequencies, such as 100Hz and 200Hz, are weighted by subtracting about 20dB and 10dB respectively. Examining the individual spectra shows that road-only spectra are more consistent for each run. The spectra when traversing the ATP roadmarking shows about an 8dB(A) variation in the size of the 100Hz tonal peak over the 10 individual runs made.

Figure 4.3 Noise outside the car for ATP roadmarkings and for road only

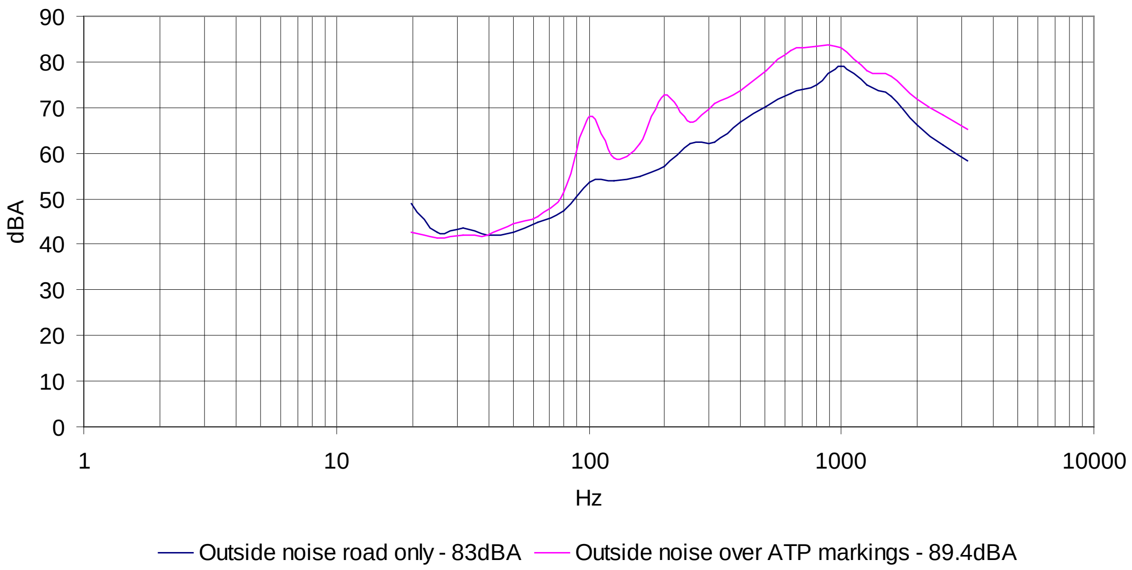


Figure 4.4 shows the noise inside the car. The noise increase inside is the same as outside, that is 6dB(A), helping to confirm that the noise measured comes from contact with the ATP roadmarking rather than from another spurious source. The distinctive tonal peaks are also present with the 100Hz peak being about 13dB(A) greater than for the road only, but the 200Hz peak is reduced.

Figure 4.5 shows the noise inside and outside the car when in contact with the ATP roadmarking, and repeats components of figures 4.3 and 4.4. The noise outside the car is much louder than inside (11dB(A)) but it should be remembered that car bodies and interiors use sound-deadening insulation which is designed around the dominant noise frequencies. The tonal components of the noise inside and outside the car coincide, and inside the car the tonal component is dominant.

Figure 4.4 Inside car noise for ATP roadmarkings and for road only

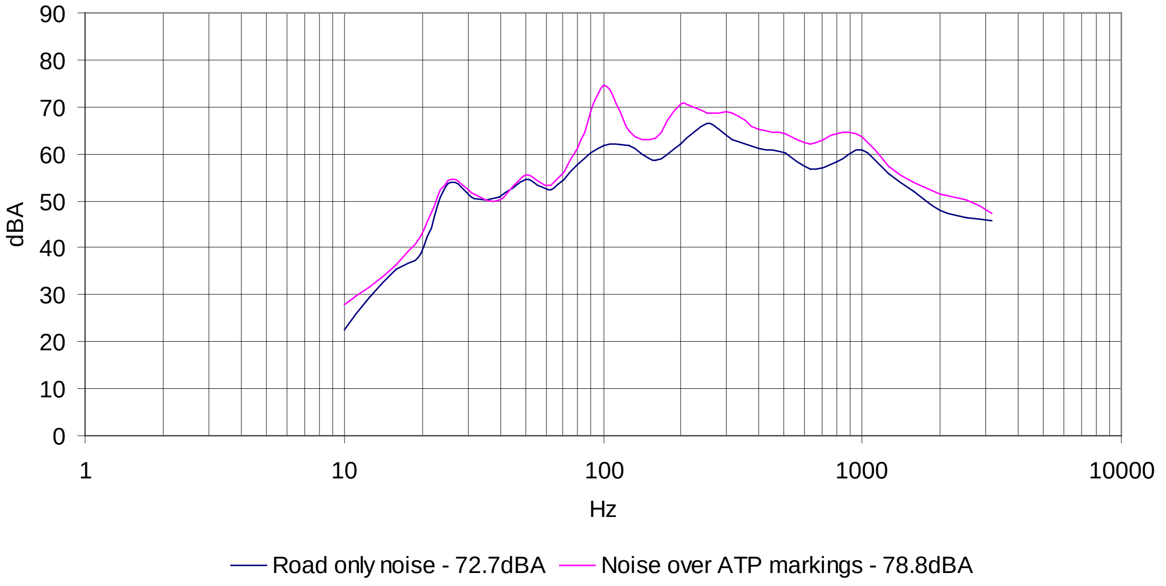


Figure 4.5 Noise for ATP roadmarkings for inside and outside the car

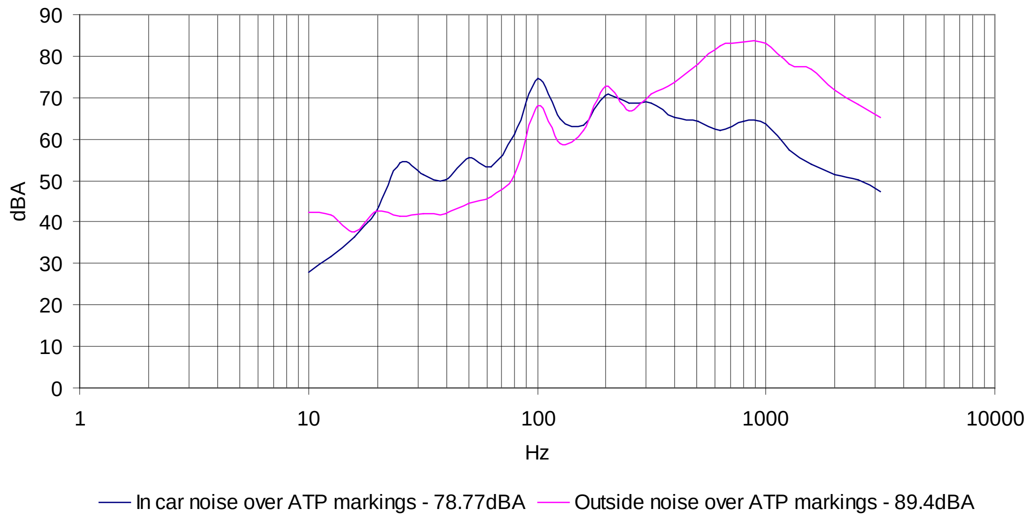


Table 4.4 shows the range in noise levels measured, the standard deviation and the total noise for each cluster of runs. It also demonstrates there is no additional reliability benefit in measuring noise outside the car. However, as figure 4.5 shows, there is a marked difference in the effect of ATP roadmarking noise inside and outside the car.

Table 4.4 Range and standard deviation between 10 consecutive runs on the ATP roadmarking

		Outside car	Inside car
Range	ATP roadmarking	6.2	5.4
	Road only	1.5	0.7
Standard deviation	ATP roadmarking	1.79	1.30
	Road only	0.49	0.22
Total noise (dB(A))	ATP roadmarking	89.4	78.8
	Road only	83.0	72.7

Note that the tonal peaks, such as at 100Hz, show a similar variation.

5 The effect of different road surface types, block pitch, and trucks versus cars

This part of the study established the extent to which the road surface type might influence the effectiveness of ATP roadmarkings, the effect of different block pitch, and the effect of the ATP roadmarkings for trucks compared with for cars.

5.1 Testing carried out

Two vehicles, first, a 2006 Toyota Corolla GL Wagon (front-wheel drive) and, second, a truck, were driven over ATP roadmarkings on road surfaces of two types: grade 6 chipseal (using a smaller 7mm size chip) and grade 2 chipseal (using a larger 19mm size chip).

In the car, a micro accelerometer (EK3l02AQ) was mounted in the front-passenger's footwell on the central partition below the gear lever. Sound was recorded via a Rion NL-32 sound level meter mounted behind the driver's left ear. For the truck, the accelerometer and sound level meter were placed in equivalent positions.

The outputs of the two instruments were logged by a multi-channel Logbook 360 data acquisition system. The sample length was fixed at two seconds, and a 'pass' over a ATP roadmarking was considered valid if the car remained on the ATP roadmarking for the entire two seconds of the sample and if the car held a constant speed. For each pass, the location, speedometer reading, direction of travel and time of day were recorded, along with subjective assessments of the effectiveness of the roadmarking in terms of, separately, its audio and tactile response.

A consistent repeat of the each pass was difficult so each pass was repeated four more times in order to extrapolate average runs. In total 70 samples were recorded.

5.2 The experience inside a vehicle

The subjective experience of driving over these ATP roadmarkings in a car was that they all caused noise and vibration to varying degrees. The most notable change was caused by the pitch between the blocks of the ATP roadmarkings. The ATP roadmarkings with a block pitch of 250mm had a noticeably greater effect than the ATP roadmarkings with a 500mm block pitch. This assessment was based on the noise and vibration experienced inside the car.

The effect inside the car of the various speeds was a change in noise and vibration frequency, but there was no discernible difference in total noise for different speeds. A difference in the noise of ATP roadmarkings over the two different road surfaces was not discernible.

When travelling in the truck, the subjective experience was that the noise and vibration response was less than in the car. This was due to the noise heard in the truck being lower in frequency and, although audible, at times it was difficult to distinguish this noise from general road noise.

5.3 Results of measurements

5.3.1 The effect of the road surface

Figure 5.15.1 and 5.2 compare the total noise from a car travelling over ATP roadmarkings on the two road surface types with the total noise from travelling on the road surface only. Figure 5.1 shows the noise measurements made on a grade 6 (smaller chip of a nominal 7mm size) chipseal surface, and figure 5.2 the measurements made on a grade 2 (larger chip of a nominal 19mm size) chipseal. Measurements for both road surface types were made with the car travelling at 100km/h and on both road surface types the ATP roadmarkings were of the same type, laid with the same nominal dimensions and characteristics.

Figure 5.1 Noise of ATP roadmarkings over grade 6 chipseal vs noise of grade 6 chipseal road surface only, for car travelling at 100km/h

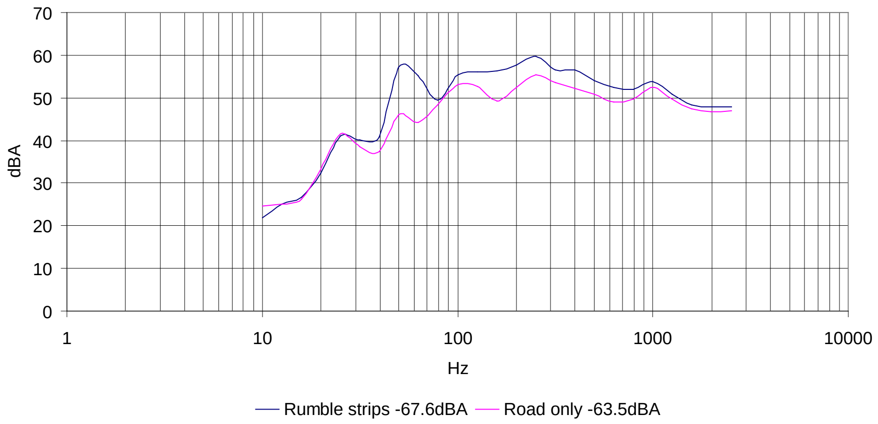
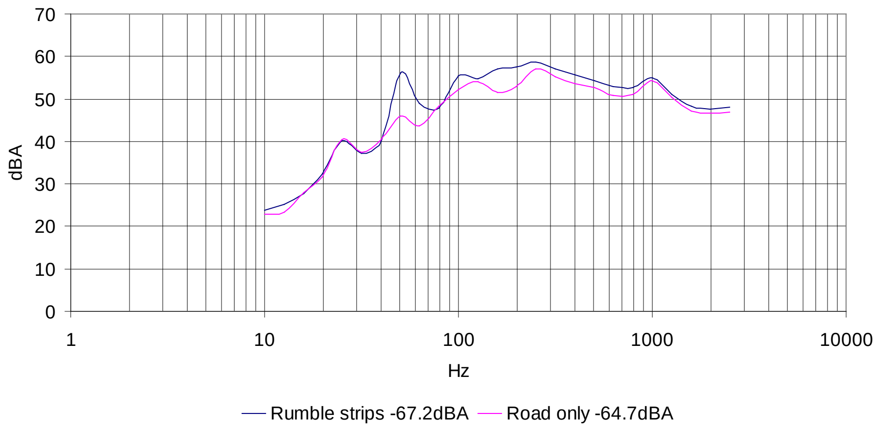


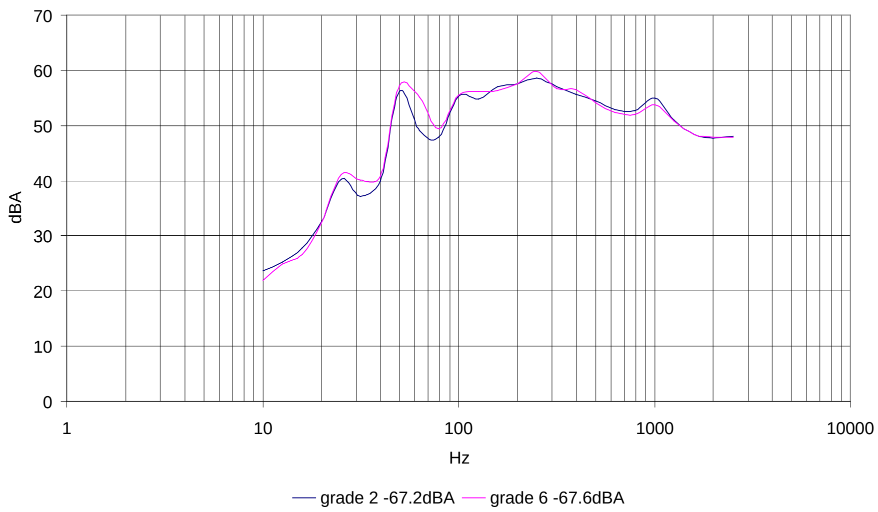
Figure 5.2 Noise of ATP roadmarkings over grade 2 chipseal versus noise of grade 2 chipseal road surface only, for car travelling at 100km/h



The noise increase from ATP roadmarkings over grade 2 chipseal is 2.5dB(A) above the road-only noise compared with 4.1dB(A) above the road-only noise for the grade 6 chipseal, but these overall noise level differences are less relevant to understanding the ATP roadmarking effect than is consideration of the tonal content. The noise spectra show pronounced peaks for the ATP roadmarkings especially at about 50Hz (as expected by the combination of car speed and block pitch). There is a significant difference in the tonal effects when driving on the ATP roadmarkings compared with driving on the road only. This again matches the subjective impressions. For both road surface types, these tonal peaks are about 12dB(A) noisier when driving over the ATP roadmarking compared with driving on the road only.

Comparing the noise level for the same type of ATP roadmarking on two different chipseal road surfaces shows little difference between total noise and frequency distribution for the ATP roadmarkings on each of the surfaces. Measurement of the dimensions of the ATP roadmarkings shows the ATP roadmarkings on the grade 2 chipseal are consistently a little lower in height, by about 1mm to 1.5mm. This is because some of the block profile height is ‘lost’ below or in the highly textured surface of the grade 2 (larger 19mm) chip. However, as shown in figure 5.3, this change in effective block height has little impact on the noise levels produced. Compared with ATP roadmarkings over grade 6 chipseal, the total noise of the ATP roadmarkings over grade 2 chipseal is only 0.4dB(A) less. The peak at 50Hz on grade 2 chipseal is 2dB(A) less than on grade 6 chipseal. Comparing the incremental effects of the ATP roadmarkings relative to their respective road-only effects, for each chipseal road surface, the ATP roadmarkings have a tonal increase of 12 to 13dB(A) over the respective road only, and this matches subjective impressions of the noise.

Figure 5.3 ATP roadmarkings on grade 2 chipseal and grade 6 chipseal, for car travelling at 100km/h

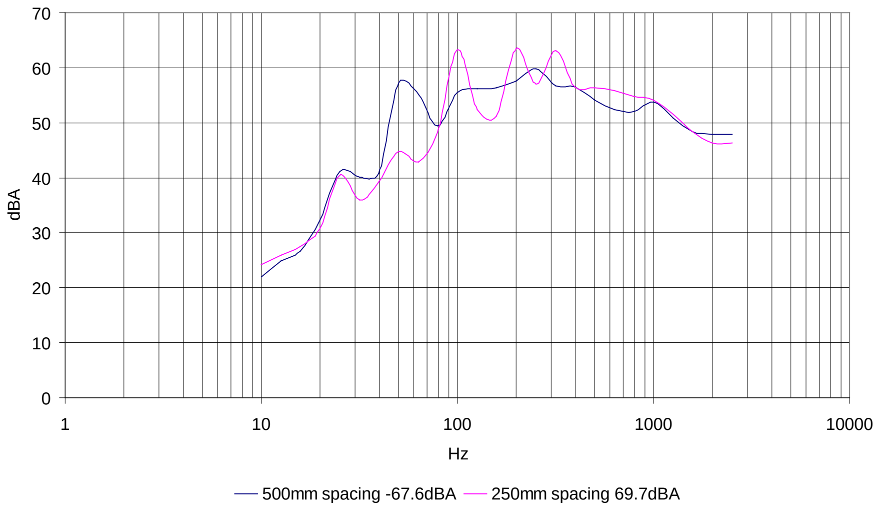


Based on this work, the effectiveness of ATP roadmarkings should be independent of the road surface type so long as the ATP roadmarking block height is not degraded when being applied on coarser textured road surfaces.

5.3.2 The effect of pitch

The characteristic observed to have greatest effect was the ATP roadmarking block pitch and the measurement results were consistent with observations made in the car. Changing block pitch had a significant effect on the total noise and frequency distribution. The total noise for the ATP roadmarkings with a 250mm block pitch was a little over 2dB(A) noisier than ATP roadmarkings with a 500mm block pitch. The block pitch effect on the frequency distribution was similar to the effect of varying speeds, with the 250mm block pitch creating a series of defined peaks in the higher frequency range compared with the peaks defined by the 500mm block pitch. Compared with road only, these noise increases were 10dB(A) at 100Hz, 10dB(A) at 200Hz, and 9dB(A) at 300Hz. For the driver and assistant undertaking the test, the block pitch appeared to be a strong factor in the effectiveness of the ATP roadmarkings, but this was not verified by a wider group of observers.

Figure 5.4 Noise of ATP roadmarkings with block pitch 250mm and 500mm, over grade 6 chipseal, for car travelling at 100km/h



Based on this work, establishing effective ATP roadmarkings needs to take account of the different tones and noise levels generated by different block pitch.

5.3.3 The effects for trucks versus cars

Table 5.1, and figures 5.5 and 5.6 show the noise effects of ATP roadmarkings when travelled over by a truck compared with being travelled over by a car.

As has already been discussed for cars, table 5.1 and figure 5.5 demonstrate the significant noise level and distinct tonal effects for cars on ATP roadmarkings compared with those for cars on the road only. However, apart from the tonal effect, the noise levels for trucks on ATP roadmarkings appear very similar to the noise levels for trucks on the road only. The changes in noise and vibration levels when trucks travel on ATP roadmarkings compared with changes when trucks travel on a road only are significantly less than the corresponding changes for cars travelling on ATP roadmarkings or on road only.

Table 5.1 Noise differences

		Noise levels, all dB(A)	
		Grade 2 (19mm) chipseal	**Grade 6 (7mm) chipseal**
Car	ATP roadmarkings	66.5	66.7
	Road only	62.0	60.2
	Increase in total noise	+4.4	+6.5
Truck	ATP roadmarkings	60.6	60.4
	Road only	59.1	59.1
	Increase in total noise	+1.5	+1.3

Figure 5.5 Truck and car noise comparison on grade 2 chipseal

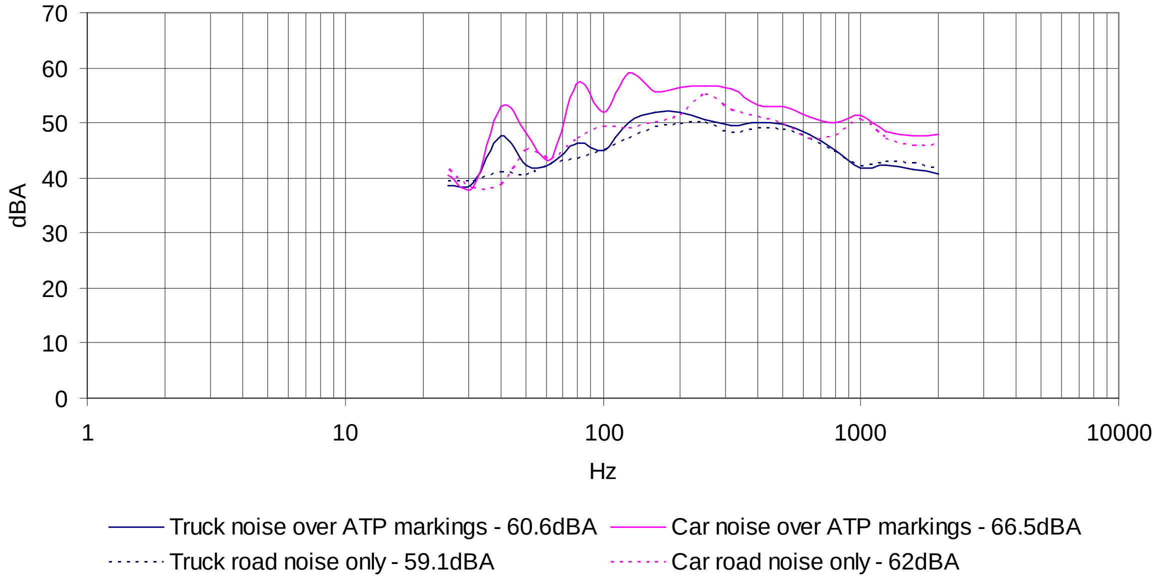
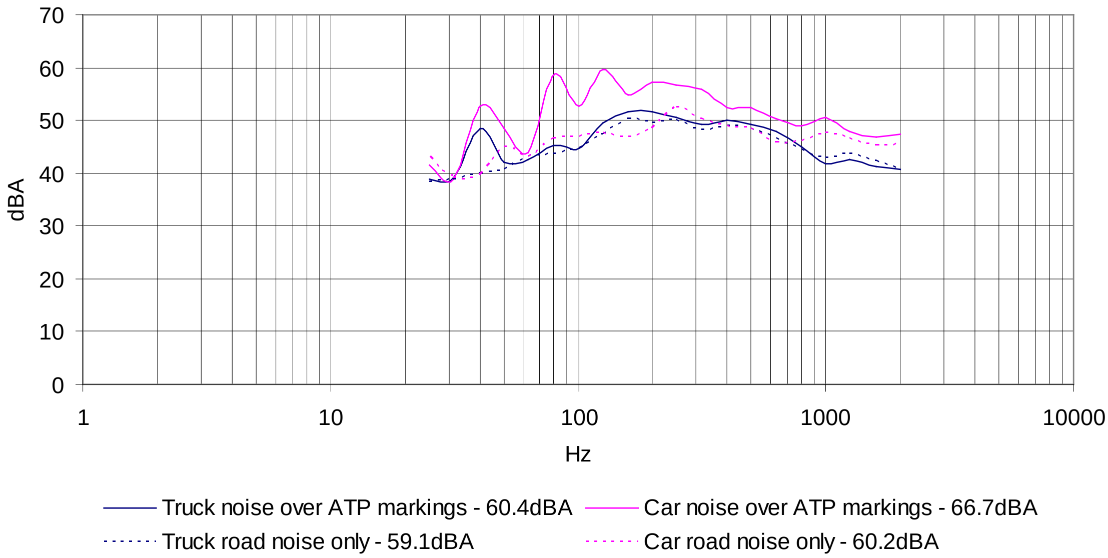


Figure 5.6 Truck and car noise comparison on grade 6 chipseal



In tonal effects, trucks travelling on ATP roadmarkings show an increase of about 8dB(A) at 40Hz compared with trucks travelling on road only. For cars, this ATP roadmarking increase at 40Hz is about 12 to 13dB(A) compared with travelling on road only. (Note that the test speed of the truck was lower than the test speed of the car: 80km/h compared with 100km/h.)

Table 5.2 Vibration comparisons inside a car and truck travelling over ATP roadmarking and road only

	Vibrations, all m/s^2	
	Car	**Truck**
Grade 2 ATP roadmarkings	0.0793	0.0638
Grade 2 road only	0.0328	0.0537
Increase in vibration	0.0466	0.0101
Grade 6 ATP markings	0.0898	0.0636
Grade 6 road only	0.0379	0.0554
Increase in vibration	0.0519	0.0082

Table 5.2 shows the vibration effects of ATP roadmarkings for cars and trucks compared with road only for the two chipseal road surface types. The main pattern is the truck on road only appears to provide more vibration than the car on road only, but on the ATP roadmarking, the car appears to provide more vibration than the truck, showing that trucks are much less sensitive to the tactile response of ATP roadmarkings.

It is also noted that the car footwell vibrations increase by about 15% when driving on the coarser grade 2 chipseal on the road only, compared with driving on the grade 6 chipseal. In comparison, the change in truck footwell road-only vibrations is an increase by about only 3% on the coarser grade 2. This gives further support for the conclusion from the noise measurements inside the vehicle, that the inside of trucks is less sensitive to road surface characteristics than cars.

Based on this work, the effectiveness of ATP roadmarkings for car drivers needs to be determined separately from their effectiveness for truck drivers.

6 Determining the threshold of driver response

At the outset of the project, it was assumed that driver response to ATP roadmarkings would be a dose-response effect. That is, if the block height was higher and the ATP roadmarking made more noise, then it would be more noticeable to the driver and consequently more effective. However, the high variability found in ATP roadmarking effects required the original approach to be reconsidered. Clearly, the great care in tracking along the ATP roadmarking line, which was needed to deliver any consistent experimental result, was quite different from how ATP roadmarkings would be experienced in practice, where drivers usually contact the ATP roadmarking briefly and in a variety of ways.

Therefore, the assumption of a dose-response effect was revisited and adjusted to examine for driver response around a threshold effect. That is, a certain level of effect is needed for the ATP roadmarking to be noticeable; after this, increases in noise or vibration do not increase the noticeability of the ATP roadmarking. This is analogous to the visibility of road signs. A certain visual level is needed for the sign to intrude into the driver's vision, but thereafter, being bigger or brighter does not make the sign more noticeable as the driver has already noticed it.

To determine the driver response to ATP roadmarkings and to identify the threshold at which drivers detect the noise and vibration effects of ATP roadmarkings, a set of progressively increasing effects, from road-only effects to ATP roadmarking effects, with block heights ranging from 2mm to 6mm in 1mm increments, was obtained (as described in section 4.2) which would be used in the threshold trials via a driving simulator.

The noise and vibration samples from inside the vehicle were used as inputs to a driving simulator. The driving simulator was calibrated to ensure the characteristics of the noise samples matched the characteristics of the noise received by the driving simulator participants.

6.1 Method

To determine the minimum block height required for reliable detection of ATP roadmarkings by car drivers, a laboratory driver simulation was created. The noise and vibration obtained for a car travelling on road only, then travelling on ATP roadmarkings with block heights 2mm to 6mm, were used to provide the effects used in the driving simulator. Participants were played noise effects from the different ATP block heights (and from the road only) in controlled conditions. The accuracy of participants in detecting between road-only noise and ATP roadmarkings noise was assessed using signal detection theory while the participant completed a distracter task (Stroop task; Stroop 1935) designed to replicate the cognitive demands of driving.

Participants were trained in completing the Stroop task and in identifying the ATP roadmarkings noise as different from the road-only noise before commencing the main tasks that examined their ability to perceive ATP roadmarkings of different block heights both with the Stroop distracter task alone and with the addition of music to the Stroop distracter task to create a more realistic driving-like scenario.

6.1.1 Participants

Fifteen participants (nine male and six female) were recruited from Opus Central Laboratories staff and their friends and family. Participants ranged in age from under 17 to 75 years of age with the majority of participants between 25 and 34 (n=6) or 45 and 54 (n=5). Two participants suggested they had some form of hearing disorder and ranked themselves as having a lower hearing ability than average; the remaining participants all rated themselves average or above. The vast majority (80%) said they drove most days.

6.1.2 Materials

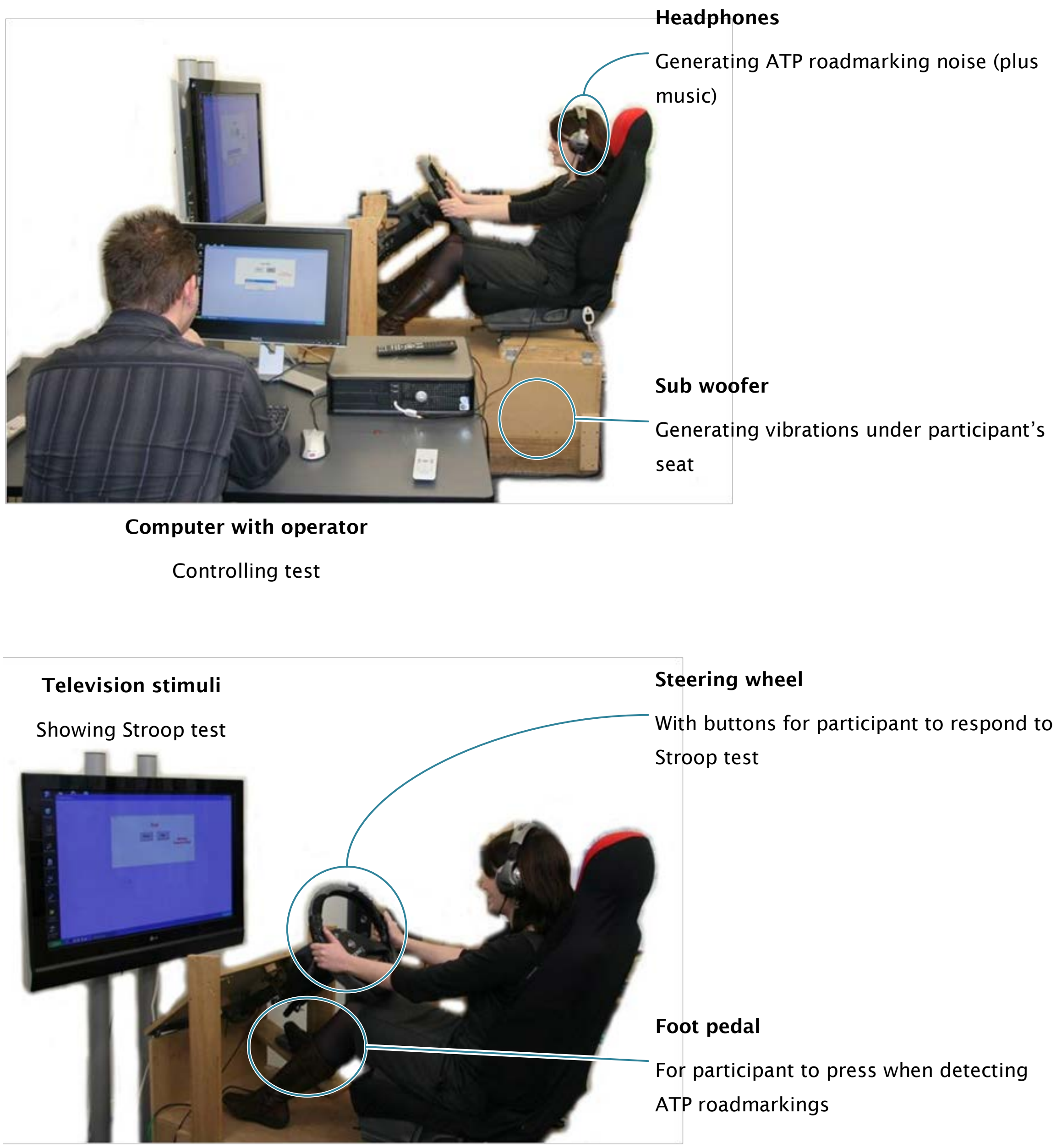
6.1.2.1 Vibration simulator setup

Participants sat in a quiet room at a specially designed simulator, run from a personal computer. A car driver's seat and steering wheel were mounted on a wooden box (with dimensions 125cm long by 60cm wide by 50cm high). A Denon stereo system with sub-woofers was used to simulate vibration, with the sub-woofers contained under the driver (within the box) facing upwards.

The visual distraction task was presented on a 42-inch plasma screen in front of the simulator and the audio was presented through personal headphones. Participants responded using either two buttons mounted to the steering wheel or a foot pedal mounted to the simulator and connected to a Velleman box that triggered records in the computer programme. Software was developed in Visual Basic to run the randomised schedule of audio sounds and the Stroop distracter task.

Figure 6.1 A participant seated in the vibration simulator during piloting

Figure 6.2 Simulator equipment setup from a side profile view and a rear profile view



6.1.3 Procedure

6.1.3.1 Training tasks

Prior to undertaking the main task, participants had to complete two training tasks to a minimum level of accuracy. The first of these two tasks was the Stroop task (Stroop 1935), followed by the ATP roadmarking identification task.

In the Stroop task, participants were presented with the name of a colour printed in one of three colours on the screen in front of them, along with two possible answers. The aim of the task was to identify the colour of the print, rather than the word that was written. Three conditions were used: congruent, incongruent and neutral (see table 6.1 for definitions and examples)

Table 6.1 Stroop test conditions and examples

Condition	Description	Example	Response choices	Correct answer
Congruent	The word and the print colour are the same	GREEN	Green or Red	Green
Incongruent	The word and the print colour are different	GREEN	Green or Red	Red
Neutral	The word and the print colour are different but the incorrect answer is not one of the two options provided	GREEN	Red or Blue	Red

A large body of research suggests that participants generally show poorer performance and slower reaction times in the incongruent condition compared with the neutral and congruent conditions and significantly better in the congruent condition (MacLeod 1991).

For the Stroop task, participants were presented with a minimum of 20 trials and were required to perform with a minimum of 90% accuracy before they could progress to the next task. Responses were made by pressing one of two buttons on the steering wheel that related to the two answer options presented on the screen.

Participants were then required to develop task proficiency until they could accurately detect the difference between a baseline condition (road only) and a high-quality ATP roadmarking that met current specifications. Responses were made using a foot pedal attached to the simulator that participants pressed once when they detected the ATP roadmarking. Again, this task was repeated until the ATP roadmarking was detected with at least 90% accuracy on 20 trials.

6.1.3.2 Main task

In the main task, participants completed a longer set of trials of the Stroop distracter task while also noting when the ATP roadmarkings were presented. Participants were given prompts to maintain their performance on the Stroop distracter task to an acceptable level, and to tap the foot pedal whenever they detected an ATP roadmarking. The ATP roadmarking recordings were all made from one vehicle over ATP roadmarkings of different block heights, as presented in table 4.2.

This task continued until the individual threshold of each participant was established. This threshold was determined by the condition at which the participant reliably identified the presence of the ATP roadmarking without significantly dropping in their performance of the Stroop distracter task, based on the method of Sasaghiani et al (2009). All participants started at the highest level (condition 5: 6mm block height) and were gradually exposed to each lower block height condition (down to condition 1: 2mm block height), once they had completed three successful trials at the previous condition. If the participants were incorrect on a trial, they returned to the previous condition. Each movement up or down a condition was described as a ‘reversal’. A participant’s threshold was found when they:

- identified the ATP roadmarking line three consecutive trials at the lowest block height (condition 1), or
- completed 16 reversals across the conditions, or

- were unable to identify the ATP roadmarking across three consecutive trials at the highest block height (condition 5).

6.1.3.3 Music task

Following the main task an additional music audio stimulation was introduced. The music task progressed in exactly the same way as the main task; however, the participants were also played music at a moderate level. This condition was included to more accurately simulate actual driving conditions, as there are often competing sources of sound in the vehicle, including passenger conversation and music.

6.1.3.4 Demographics

Following the completion of all the tasks, participants were asked to note their age, driving experience, hearing ability or disorder, and gender.

6.2 Results

Table 6.2 shows the results of the main task and the music task. As can be seen in the table, the overall threshold in both tasks is a block height of between 3mm and 4mm. Based on the range presented, all participants reliably identified ATP roadmarkings with a block height of 5mm.

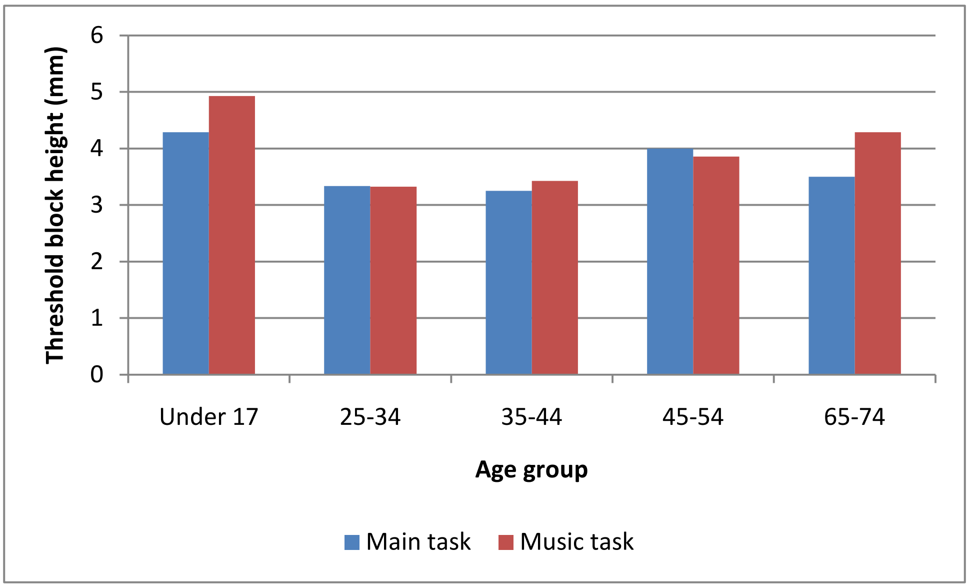
Table 6.2 Mean, standard deviation and range of the key variables in the main task and the music task (overall threshold measure is presented in bold)

		Main task			Music task		
		Mean	SD	Range	Mean	SD	Range
Threshold		**3.62**	**0.59**	**2-4.5**	**3.69**	**0.68**	**2-4.93**
Overall Stroop correct		265.2	63.24	93-330	537.27	144.82	120-737
Overall Stroop incorrect		21.07	9.84	11-50	35.27	19.69	18-93
Overall Stroop trials	Congruent	137.73	30.09	57-173	280.33	72.64	73-385
	Incongruent	127.47	34.55	36-164	256.93	74.18	47-352
Overall Stroop reaction time	Congruent	1.05	0.24	0.69-1.59	1.00	0.21	0.69-1.48
	Incongruent	1.31	0.31	0.82-1.89	1.23	0.26	0.82-1.72
Overall Stroop effect		0.26	0.11	0.09-0.47	0.23	0.09	0.12-0.44

The expected Stroop effects were seen across the results, and a small effect of music on the average threshold was seen, although this difference was less than expected.

Figure shows the relationship between the average threshold block height in the two tasks across age groups. There is some suggestion in the graph that age may be a factor in the average threshold, particularly in the music task condition.

Figure 6.3 Average threshold block height in the main task and the music task, by age group



7 Conclusions

- The methodology described is a reliable method for measuring the level of ATP roadmarking noise and vibration noticed by drivers.
- Wooden or plastic blocks, adhered to the road, are a viable way to make ATP roadmarking lines for experimental purposes, such as identifying trends in noise and vibration effects in relation to the dimensions of the blocks. No difference was observed between wood or plastic blocks and thermoplastic blocks.
- When examining how the dimensions or type of ATP roadmarking may influence noise levels, emphasis should be placed on the tonal components of the noise rather than the total noise level.
- When measuring the noise and vibration of ATP roadmarkings, multiple measurements are needed which, when averaged, provide a reliable measurement of the noise and vibration levels of a particular ATP roadmarking.
- Due to the restricted sample size of the research undertaken, reliable results were available only for rectangular block shapes.
  - Increasing block height increased the overall noise effect and the effect of the dominant tone of traversing the block. As block height increased, the increase in the effect of the dominant tone became greater than the increase in the overall noise effect.
  - Increasing the block width gave greater certainty that the vehicle made contact with the ATP roadmarking, but noise effects appeared unchanged relative to those from the standard 100mm block width.
  - Decreasing the block pitch, so there was less distance between blocks, increased the noise level by several dB(A) and increased the frequency of the dominant tone proportional to the change in pitch.
- The ATP roadmarking appeared to have a lower physical effect for trucks than it did for cars. This may have also resulted in the ATP roadmarkings having a lesser effect for truck drivers than for car drivers, but this was not tested.
- A threshold approach to the effectiveness of ATP roadmarkings appears appropriate. There was a particular level at which the ATP roadmarkings were noticed, but they did not become much more noticeable as the physical effects increased beyond that threshold. The method described in this research appears to be an effective way to test this threshold effect.
- Based on these findings, ATP roadmarkings were reliably detected by drivers when the block height was 4mm high. All participants in our study detected them at a block height of 5mm. (Block height and block height measurement is defined in NZTA M24.) The presence of music increased the required block height slightly, but was not enough to require the next block height (of 1mm higher).

8 Recommendations

- Our findings suggest, for a 500mm pitch, a minimum ATP block height of 4mm (or 5mm if a more conservative approach is taken) should be used. The conservative approach is probably preferable given the small sample size within this study, and also that the result is for only one block pitch and one travel speed. Now that an effective method is available, further research should use a larger sample and extend the range of block shapes and pitch trialled. Research could test whether a higher frequency noise effect alters the threshold block height at which the ATP roadmarking is reliably detected.
- Section 5.3 describes results of ATP roadmarkings with pitches of 500mm and 250mm. The closer spaced 250mm pitch was found to have a noise effect that was several dB(A) greater overall, and in addition there was an increase in the dominant tonal noise frequency from travelling over the ATP roadmarking. This was expected as the vehicle tyre would contact the blocks at a 250mm pitch twice as often as it would those at a 500mm pitch.
- The issue of pitch versus effectiveness is of interest because, informally, some drivers have reported the closer pitch to be more effective. However, the closer pitch uses more material and so is more expensive.
- The driver response study was based on a 500mm pitch. The research constraints did not permit the study of driver response to a 250mm pitch. However, as previously mentioned, the closer pitch increases the frequency of the dominant tonal component of the noise effect. People are more sensitive to higher frequencies, with their peak sensitivity being centred around 1000Hz. The dominant frequency of road-only noise is closer to that of 250mm pitch ATP roadmarkings than it is to that of 500mm pitch; so the difference in noise between road only and 250mm pitch ATP roadmarkings will be less than the difference in noise between road only and 500mm pitch ATP roadmarkings. But the response to ATP roadmarkings is believed to be a threshold response, so while the 250mm pitch may have a higher noise level and therefore be noticeable to a wider number of people, for those who have already noticed it, being even louder still should not make it more noticeable.
- The benefit of the closer pitch is likely to be that the ATP roadmarking will be noticeable at a lower block height, and the benefit of this is that the life of ATP roadmarkings with a closer pitch may be extended considerably. It is strongly recommended that research be undertaken to address this issue.
- It should also be noted that some simple analyses of this data suggest age could have an effect with older people requiring a higher block height for the same level of detection. The sample size of this study was not large enough to determine this definitively. This is an area that should be examined in further research.
- It was found that the noise and vibration effect for trucks was considerably less than for cars, yet other sources have reported truck drivers' complaints about ATP roadmarkings interfering with their driving task. An understanding of how truck drivers would respond to the recommended threshold block height for cars would assist in identifying the value of ATP roadmarking treatment of an area where truck crashes are an issue.

9 References

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