Audio Tactile Profiled Roadmarkings:
Understanding how they work and when they are effective

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1 Introduction

This current project aimed to develop an economical method for determining whether a particular audio tactile profiled roadmarking meets acceptable performance standards, without the need for manufacturers and road agencies to run further complex human response tests for individual marking types and to establish minimum dimensions of the marking for performance and permissible application tolerances. This would be achieved by measuring the relationship of response to the noise and vibration levels generated by markings so that for new marking types, or for identifying minimum dimensions, noise and vibration levels could be determined by calculation then human response determined via the relationship of response to noise and vibration levels.

2 Background

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

Central Laboratories Report 03-527605 *Guidelines for Performance of New Zealand Markings* describes investigations of the in-vehicle noise experience created when trafficking upon ATP markings. This project was a preliminary study to identify methodologies for measuring the noise and vibration effects so as to consider the potential for performance-based measures. A clear pattern of difference between markings of different conditions was shown between the marking types and between the markings and the road.

The second project extended the work of the first project and sought to establish, in broad terms, the effect of dimensions on the noise and vibration levels and the extent that these were noticeable. The intent was to develop some initial "end of life" criteria.

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

Several issues arose out of this study.

- The difficulty of attempting to identify relationships between dimensions and effects when in-situ markings show considerable variation of critical dimensions.
- The likely bias in subjective response when evaluators are deliberately searching for the effect.
- The relevance of the vibration response when it appears less readily detectable subjectively and also appears, so far, to be strongly related to the more easily measured and detected noise response.

3 Measuring the physical effects of ATP roadmarkings

3.1 Method

In this current project, the physical response was determined by measuring in-vehicle noise (using sound level meters) and in-vehicle vibration (using accelerometers) while the vehicle traversed a special test section of ATP markings.

Measurements were made on test strips where the accuracy of the dimensions of test profiles is certain because the test profiles were machined, from wood mainly but also from plastic, then adhered with double sided preformed adhesive approx 1 mm thick to form the test strip. The test blocks were stuck to the road surface using double sided tape in a single line with block pitch of either all 250 mm, or all 500 mm, or all 750 mm. The wooden test blocks were cut from pine timber into shapes to give variation in height, width and length of the block and the angle of the rising edge facing towards the oncoming car (see Figure 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 an ideal ATP marking. These blocks too, were adhered to the road in the same manner as the wooden blocks.

Figure 1 The test car next to a line of test blocks on the Manfeild race track and a selection of four wooden test blocks and a thermoplastic test block that were used in the testing

The trends of the experiments with different block pitch, height, and test speeds were obscured by the variability of the noise produced when tracking over the markings, even though this was done with care.

Experimentation then used much wider blocks, which were easier to consistently hit for multiple runs (about five). Variability was sought to be further minimised by analysis of the tonal content of the noise and measurements outside of the car. It was found that the wider blocks did not reduce the variability. But, producing an average noise spectrum from about five runs produced reliable data that could be used to identify trends. This approach was then used to compare inside-car and outside-car noise levels, investigate the effect of ATP markings over different road surface types, and compare the relative effect of ATP markings on cars and trucks.

This work is described in the 2008 and 2009 papers to the NZRF/RIAA conferences.

This paper focuses on the driver response. While the previous work provides a method of obtaining a reliable measurement, it is recognised that drivers contact ATP markings is a far less controlled manner, yet the markings remain effective, so the approach to understanding driver response has been via a threshold effect. That is, a certain level of noise has to occur for the ATP markings to be noticeable but thereafter, increased noise does not greatly increase notice.

4 Measuring driver response to ATP markings

4.1 Noise samples

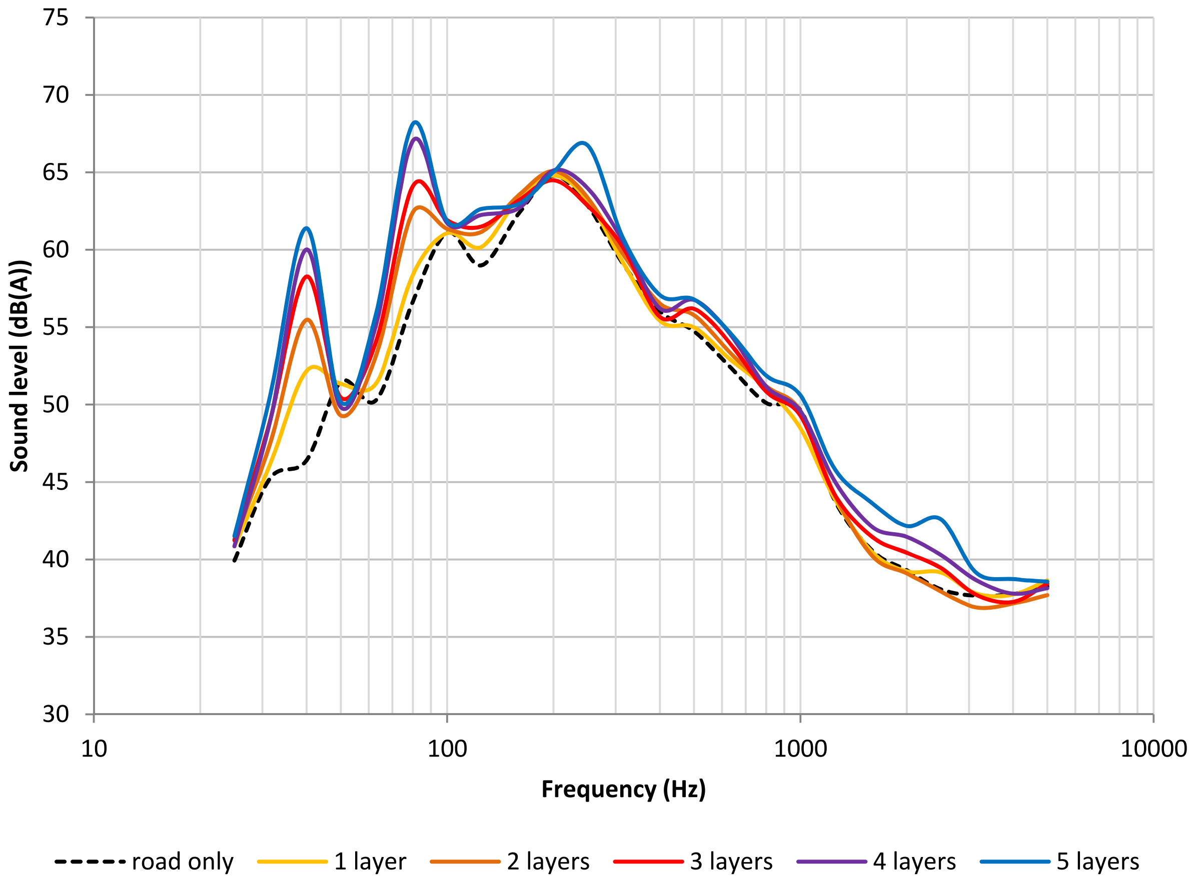
Actual noise and vibration samples from the interior of a vehicle were collected from the cabin of a vehicle in a real road setting, where plastic strips were attached to the road to simulate audio-tactile markings. Noise and vibration samples were recorded using sound level meters and accelerometers mounted within the car cabin following the same methodology as in Section 2 above. The plastic strips were placed at 250 mm intervals, and had the following dimensions 40 mm by 200 mm by 1 mm (vertical thickness). They were stacked on top of each other to create the five different ATP roadmarking heights between 2 and 6 mm (see Table 1) with double-sided tape to secure each layer. The test vehicle travelled at 70km/h over each of the ATP roadmarking conditions five times (for a total of 25 drives). The speed at which the bars were impacted was 19.4 m/s.

The driving simulator was calibrated to ensure the noise samples taken from the vehicle going over the test track matched the conditions received by participants.

Table 1 Audio-tactile line heights at each experimental level

Experimental level, or number of layers	Height (mm)
1	2
2	3
3	4
4	5
5	6

Figure 2 Average noise level of multiple (five) runs over each block thickness (from Wainui trials)



As Table 2 and Figure 2 shows, there is a steady increase in noise at the tonal peaks in the 63 and 80 Hz third octave bands. The noise increase for these tonal peaks is about 3 to 4 times the actual change in total noise level.

Table 2 Average noise levels obtained from repeated runs for increasing block heights

	Noise level (dB(A)) at 40 Hz		Noise level (dB(A)) at 80 Hz		Total noise level (dB(A)) across all frequencies
		Increase relative to road only		Increase relative to road only	
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

5 Driver response threshold measurement

To determine the minimum height of ATP markings required for reliable detection by motorists, a laboratory simulation was created. Subjects were played back noise effects from different ATP markings in controlled laboratory conditions. The accuracy of their detection responses between road noise and ATP markings was assessed using signal detection theory while completing a distracter task (Stroop task[1]) designed to replicate the cognitive demands of driving.

Participants were trained in completing the Stroop task and to identify the ATP markings noise from road noise before completing the main tasks that examined their ability to perceive markings of different heights both with the distracter task alone and the addition of music to create a more realistic scenario.

5.1 Method

5.1.1 Participants

Fifteen participants (9 male and 6 female) were all 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 hearing ability less than average, the remaining participants all rated themselves average or above. The vast majority (80%) suggested they drive most days.

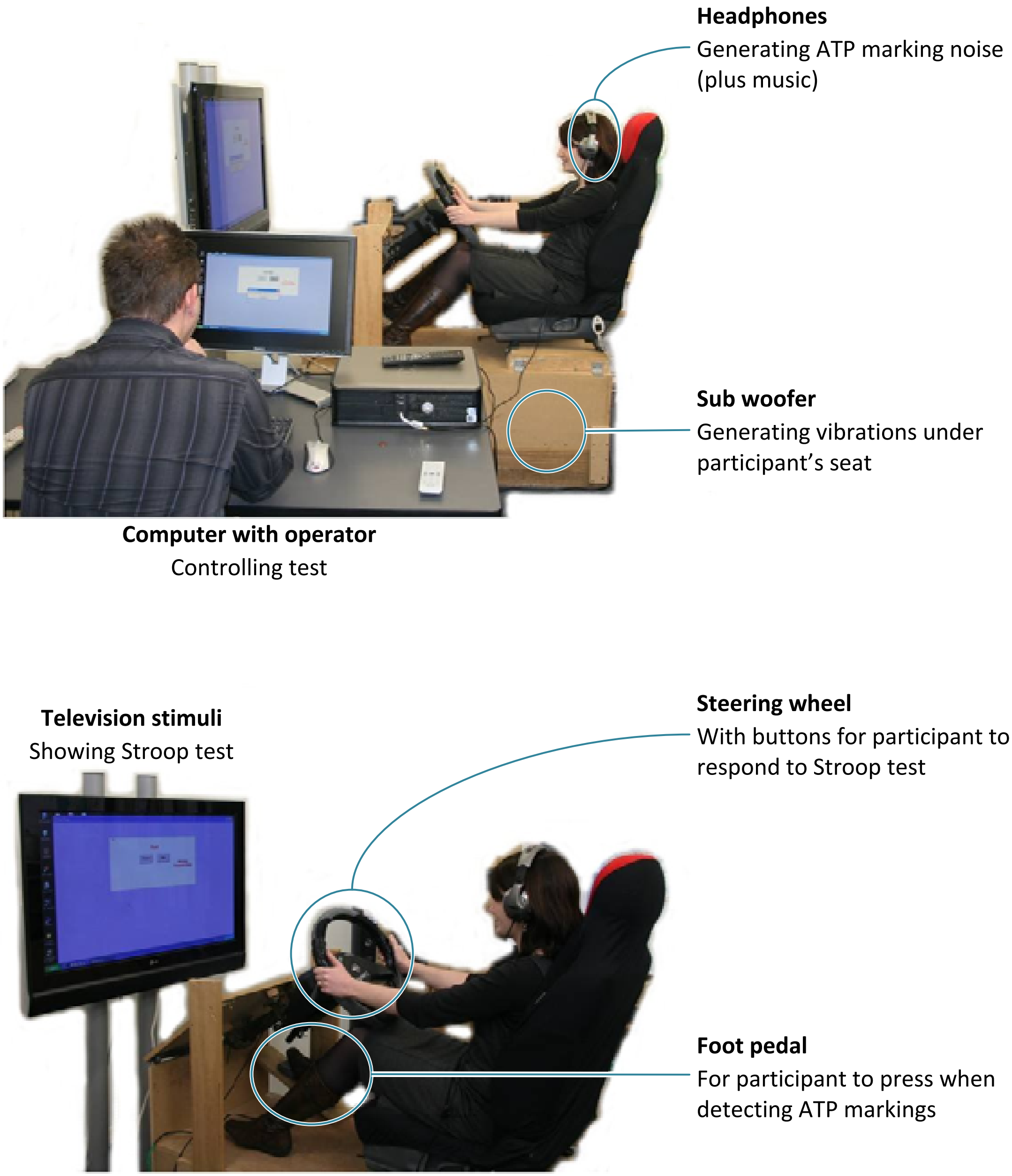
5.1.2 Simulator setup

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 1,250 mm long by 600 mm wide by 500 mm 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 all 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 distracter task.

[1] Stroop, J. R. (1935). Studies of interference in serial verbal reactions. Journal of Experimental Psychology, 18, 643-662.

Figure 3 A participant seated in the simulator during piloting, with labels describing simulator equipment setup



5.1.3 Procedure

Training tasks

Prior to undertaking the main task, participants first had to complete two training tasks to a minimum level of accuracy. The first of these two tasks was the Stroop task, followed by the ATP marking 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 3 for definitions and examples.)

Table 3 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 to the neutral and congruent conditions and significantly better in the congruent condition[2].

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) and a high-quality ATP marking that meets current specifications. Responses were made using a foot pedal attached to the simulator that participants pressed once when they detected the ATP marking. Again, this task was repeated until the line was detected with at least 90 percent accuracy on twenty trials.

Main task

In the main task, participants completed both a longer set of trials of the distracter task while also asked to identify the audio-tactile lines when they were presented. Participants were given prompts to maintain their performance on the distracter to an acceptable level, and to tap the foot pedal whenever they heard an audio-tactile line. The audio-tactile recordings were all made from one vehicle over markings of different heights, as presented in Table 1.

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 marking without significantly dropping in their performance of the distracter task, based on the method of Sadaghiani, Hesselmann, and Kleinschmidt[3]. All participants started at the highest level (condition 5, 6 mm ATP marking) and were gradually exposed to each condition down to 1 once they completed 3 successful trials at the level above. If they were incorrect on a trial, they dropped back to the level prior. Each movement up or down a level was described as a “reversal”. A participant’s threshold was found when either:

- They identified the ATP marking three consecutive trials at the lowest level (condition 1);
- They completed 16 reversals across the conditions, or;
- They were unable to identify the ATP marking across three consecutive trials at the highest level (condition 5).

Music distracter condition

Following the main task an additional music audio distraction condition 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

[2] MacLeod, C. M. (1991). Half a century of research on the Stroop effect: An integrative review. Psychological Review, 109, 163-203.

[3] Sadaghiani S, Hesselmann G, Kleinschmidt A (2009) Distributed and antagonistic contributions of ongoing activity fluctuations to auditory stimulus detection. Journal of Neuroscience, 29(42): 13410-7.

conditions, as there are often competing sources of sound in the vehicle, including passenger conversation and music.

Demographics

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

5.2 Results

Table 4 shows the results of the two main tasks. As can be seen in the table, the overall threshold in both conditions is a ATP marking height of between 3 and 4 mm. Based on the range presented, all participants reliably identified markings at a height of 5mm.

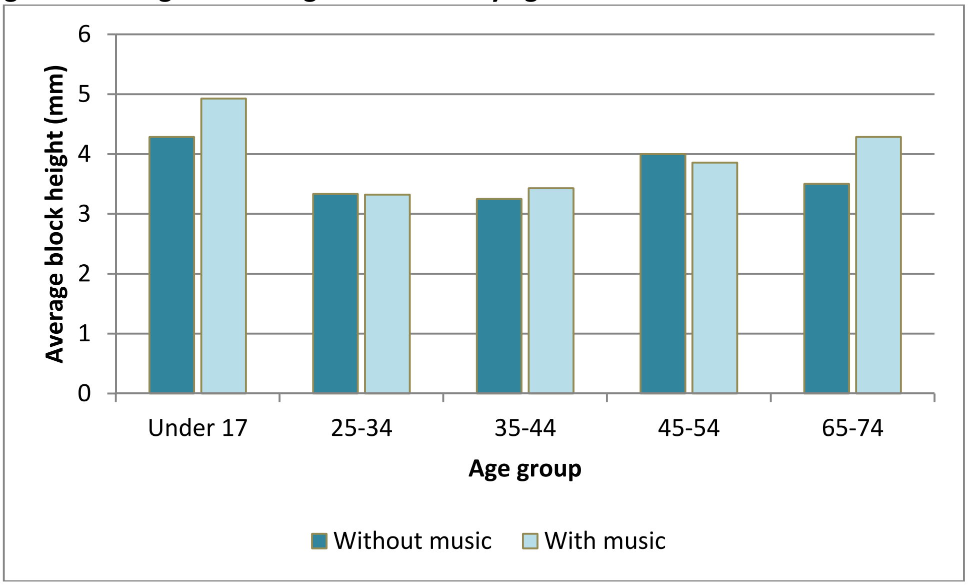
Table 4 Mean, SD and range of the key variables in the two main tasks. Overall threshold measure is presented in bold.

		Main test			Music distractor test		
		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 N	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 RT	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-.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 we would have expected.

Figure 4 shows the relationship between the average threshold 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 distracter task condition.

Figure 4 Average block height threshold by age across the two main tasks



6 Conclusions

- When measuring the noise and vibration effect of ATP markings, multiple measurements are needed which, when averaged, provide a reliable measurement of the noise and vibration levels provided by a particular ATP marking.
- Wooden or plastic blocks, adhered to the road are a viable way to make audio-tactile lines for experimental purposes such as when wanting to identify trends in noise and vibration effect in relation to dimensions.
- When examining how the dimensions or type of ATP marking may influence noise levels, emphasis should be placed on the tonal components of the noise rather than the total noise level.
- The effect of the ATP marking on trucks appears to be a lower physical effect which probably also results in the markings having a lesser effect on truck drivers than for car drivers, but this has not been tested.
- A threshold approach to ATP markings’ effectiveness appears appropriate. That is, there is a particular level at which the markings are noticed, but they do not become much more noticeable as the physical effects increase beyond that threshold.
- Based on these findings, audio tactile profiled markings are reliably detected by drivers when they are 4 mm high, and all participants in our study detected them at 5 mm. The presence of music increased the required block height slightly, but was not enough to require the next block height (of 1 mm higher) in marking.
- The methodology described is a reliable method to measure the level of noise and vibration from audio-tactile markings that people find noticeable in a driving setting.