

Balancing the needs of cyclists and motorists

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Executive Summary

Between 2002-2004 a four-part research programme was undertaken to identify hazards to cyclists from features of the road network that are designed to benefit motorists. Such features include, for example, profiled markings for wet/night visibility and flush medians that enable easy right turns but narrow the available lane width. The perspective of the research is to recognise and understand the conflicting needs of cyclists and motorists who share a road corridor. The outcome is to facilitate more informed decision-making in design, maintenance and management of the road corridor by balancing the needs of cyclists and motorists.

Study 1 examines the stability of cyclists encountering roadside obstacles including a variety of line-marking types. Lines examined included new types of marking that are of potential benefit to motorists because of the wet night visibility and extended service life. These are restricted in their use, despite their superior benefits to motorists, because of concerns for cyclists.

Studies 2 and 3 help define the amount and quality of space towards the lane edge needed for cyclists. Study 2 observes the effects of a passing truck on cycle stability by measuring the forces from the vehicle slipstream that cyclists are exposed to, and then measuring the cyclists' reaction to these forces using the methodology developed for measuring cyclists' stability. Study 3 involves the observation of cyclists as they negotiate roadside obstacles, including utility covers, pedestrian crossings, pinch points, line markings, parked vehicles and gravel.

Study 4 establishes to what extent the design of the road corridor is perceived by cyclists as hazardous and a consequent deterrent for cycling. This study also surveys parents of children in two groups: those who cycle to school, and those taken by car. It identifies the relationship between the two groups and how that affects whether they encourage their children to cycle to school.

Study 1: The effects of roadside obstacles on cycle stability

Participants completed multiple passes over 20 objects (1600 trials in all) on an instrumented racing cycle. Recordings were compared with a baseline of recordings of normal riding over smooth asphalt. New techniques of control for learning effects were used and the methodology proved to be reliable.

The analysis of the trials revealed a correlation between trends in increasing marking thickness and increasing instability, but this correlation was not consistent, indicating that selecting markings as safe for cyclists on the single criterion of marking thickness is not appropriate.

Some general findings of the trial are:

- Sixteen of the objects, including rough ground, a round utility access cover, oversized thermoplastic lines (7 mm thick), and an audio-tactile line show significant effects on the stability of cycles.

- Traditional painted road markings, chlorinated rubber lines, and a low profile thermoplastic marking show no significant impact on cycling. Relative assessment of the effect of the objects on cycle stability is reported and the validity and reliability of the method is discussed.
- A reliable method for assessing the impact of roadside obstacles on cyclists has been developed. This method can be used to assess new objects as new products are developed for the benefits of road users.
- The current practice of limiting markings to less than 4 mm thickness (and preferably 2.5 mm or less) in spaces shared by cyclists should continue.
- Where lines greater than 4 mm thickness are used, then there should be a site-specific study that identifies specific risks to cyclists. Measures could be to lessen these risks, for example not using these lines at the natural crossing point for cyclists.
- Thermoplastic lines equal to and above 4 mm produced effects on cyclists similar to those experienced when riding over lines that have been shown to be problematic by independent assessment, e.g. audio-tactile lines.
- Thermoplastic lines 3 mm thick produced effects on cyclist stability that are little different from existing paint markings.
- New structured markings produce effects that are equivocal, but the markings are thicker than the normal case.
- Cycle stability is actively managed by the cyclist, but seriously interfered with normal cycling activities such as looking back to assess traffic flow.

Study 1 specific recommendations

- Any new product considered for widespread use throughout the roading network should be assessed for its effects on cyclists using methods similar to those outlined.
- The current 'height-based' standard (Transit NZ Specification TNZ P/22) should be replaced by a performance-based standard, including a testing regime using a methodology similar to that used in this study.
- Wherever merging and conflict points are identified as necessary, additional attention should be given to removing other hazards such as cat's-eyes, thick line markings, utility covers and loose gravel.
- The concept of locking cyclists into a cycling space and locking motorists out of this same space with a continuous raised profiled marking, or another type of restricting device (e.g. close-spaced raised pavement marker) is strongly not recommended. Such a concept will mean the common method of avoiding hazards within the cycle space by entering into the vehicle lane would require the negotiation of an even more significant hazard.

Study 2: The effects of trucks passing on cycle stability

This study involved measuring the physical forces produced by a large truck as it passes by a cyclist, and included the measurement of the real impact trucks have on cyclists' stability, using the instrumented cycle from Study 1.

No 'wobble' effects due to these forces under normal riding conditions were detected. Also the force generated by the truck increases proportionally to the square of truck speed, but the separation distance within the 0.5 to 1.5 m tested has no significant effect.

Study 2 specific recommendation

- In areas with high numbers of cyclists, and where shoulder space for cyclists is narrow (e.g. <1 m), so they cannot accommodate momentary instability, truck speed should be limited to 50 km/h or less, or cyclists be accommodated by other provisions.

Study 3: The effects of roadside obstacles on cyclists' behaviour

Understanding how cyclists identified the natural cycling path even when unmarked, and their behaviour when encountering obstacles in their path, was established by observing cyclists riding around a 15 kilometre pre-identified course. The obstacles included a round utility access cover; a bull-nosed pedestrian crossing facility; a square utility access cover; a parked truck; a narrow bridge; drainage grates; a section of rough surface; a patch of loose gravel; and a baseline smooth asphalt section.

Key findings are:

- Cyclists manage hazards they encounter by 'occupying the space', even when this is in conflict with other vehicles. A roadside hazard such as a raised utility cover will, when combined with a cyclist, become a problem to be managed by motorists. Cyclists have a tendency to move out into the vehicle lane (and rarely look back) and rely on motorists to respond. Thus the influence of roadside hazards extends well beyond a limited interest group. Every road user is affected by and manages a roadside hazard.
- With reference to Study 1, a reasonable supposition is that cyclists occupy the space without looking back because either they forget to look, or the hazard of 'looking back' is greater than, or interacts with, the risk of occupying the traffic space and obliging motorists to manage the cycle/vehicle conflict. Communicating this idea to motorists would significantly improve cycle/vehicle interaction with the attendant benefits.
- The likelihood of a cyclist moving into conflict is modulated by the size of the available connected space. The indications of this study are that a connected pathway with a width of as little as 30 cm is sufficient to significantly reduce the likelihood of cycle/vehicle conflict. Although there are optimal design parameters for cycleways, no minimal design parameters have been specified to assist road designers. Further research is needed to develop minimum design parameters, and to test that this minimum space is consistent across most obstacles, or is obstacle-specific.

- Where edge lines are marked, cyclists have a tendency to ride on the shoulder near the left of the edge line, though the idea that they ride on the line to improve smoothness of ride was not supported in this research. The reasons for the tendency are unclear and require further research. This natural tendency of cyclists staying to the left of the edge line and motorists to the right, if consistent, could be exploited to allocate space where full cycle lanes are not practical.

Study 3 specific recommendations

- Guidelines are needed for road asset managers on how to interpret the natural cycling path and how to allocate space within the roadway. These guidelines should assist road managers to identify obstacles that cyclists will avoid, and develop maintenance plans to either remove these obstacles or create alternative road space for cyclists. The use of extensive flush medians to aid traffic manoeuvres needs to be balanced against an obstruction-free natural cycle pathway that is free of unexpected cycle/vehicle conflicts.
- Education is needed so that motorists have an appreciation of cyclist behaviour, and can scan the road ahead from a cyclist's perspective to identify cycle obstacles that will force the cyclist into their path. This is particularly important near intersections, or at pedestrian crossing facilities, where road managers often constrict the space available to cyclists.
- Further research is needed to identify a minimum cycle space around obstacles, and whether an edge line can effectively partition cycle and vehicle paths.

Study 4: Parents' perceptions of cycle safety for high-school children

This study was undertaken to identify whether perceptions of a lack of safety acted as a deterrent to cycling for high school children. Questionnaires were delivered to 204 parents of teenage children who lived within normal cycle-riding distance from their high school.

The parents occupied two distinct groups: those identified as allowing their child/children to regularly cycle to school, and those who were observed to drop their child/children at school by motor vehicle. Improving the attitudes of parents towards cycling by reducing anxiety regarding cycle safety, or improving their perceived enjoyment of cycling, is likely to encourage cycling behaviour among their children.

Key findings are:

- Overall, parents regard cycling to school as slightly dangerous. Parents who drive their children to school appear to be more risk-averse than parents who allow their children to cycle.
- Parents vary in their assessment of the riskiness of different modes of travel to school, with parents who drive their children to school perceiving cycling to be the riskiest mode.
- The perceived safety of the particular route relates to whether the child/children cycle or are driven to school. Around 7% of the choice to drive rather than cycle is explained by a perception of the safety of the cycle route.

1. Introduction

- Features of the road environment that create a safety concern include known factors associated with cycle injuries.

Whether or not parents used to cycle to school is related to the likelihood of their high school children cycling to school. Given the current decline in cycling, as a cohort effect, future efforts to encourage cycling to school will be further impeded by the absence of a cycling history in parents.

Study 4 specific recommendations

- Address the cohort effect concerning cycling experience and its likely influence on reducing cycling in school-aged children. This can be done by promoting cycling in schools, recognising that there will be a long-term benefit that is currently not recognised in the evaluation of such programmes.
- Address the heightened perception of the relative riskiness of cycling with information that targets parental concerns for safety of the roading context, and balances these concerns with information concerning the benefits of cycling.
- Any effort to improve the roading environment to reduce parental perception of cycling danger should address cycle/traffic conflict as this, more than road features in themselves, appears to be the basis of the heightened concern for the safety of cycling.

Abstract

Between 2002-2004 a four-part research programme was undertaken to identify hazards to cyclists from features of the road network that are designed to benefit motorists. The four studies were: 1: The effects of roadside obstacles on cycle stability; 2: The effects of trucks passing on cycle stability; 3: The effects of roadside obstacles on cyclists' behaviour; 4: Parents' perceptions of cycle safety for high-school children.

The perspective of the research is to recognise and understand the conflicting needs of cyclists and motorists who share a road corridor. The outcome is to facilitate more informed decision-making in design, maintenance and management of the road corridor by balancing the needs of cyclists and motorists.

1. Introduction

Cyclists are a vulnerable group because they have no usual dedicated space on which to travel, and must alter their path according to the best choice of route in the circumstances of their journey. There are a number of guidelines for dedicated cycle paths available from international sources (e.g. Austroads 1999; 2000; Transit 2003; Loder and Bayly Consulting Group 1989; Institute of Highway and Transportation 1996). However, on most New Zealand roads it is neither practical nor affordable to create a separate provision for cyclists, and the road space has to be shared by cyclists and motorists. Roading authorities face the challenge of building a road space that balances the needs of both cyclists and motorists. To do this, the needs of cyclists must to be better understood.

New Zealand cyclists compete with others for the surface over which they travel, whether this is the road shoulder or the very left-hand side of the road. Often this area is not designed or maintained to promote the interests of cyclists and the consequence is cyclists moving on to the roadway and into conflict with other traffic, effectively decreasing the safety of cyclists by increasing their exposure to hazards. Cyclists face a number of obstacles such as utility access covers, wind from passing trucks, gravel, and thermoplastic road markings. If an obstacle, such as gravel, affects cycle stability then a cyclist may lose control and suffer injury. Even if a cyclist does not lose control over the cycle, the ability of the cyclist to respond to other hazards may be compromised by deviating from the road shoulder into conflict with motor vehicle traffic and hence risk of injury. The presence of obstacles that affect cycle stability may also create concern for safety and this may in turn deter potential cyclists. An important requirement for understanding the needs of cyclists is knowing the effects of objects that commonly appear in their pathway.

This report investigates the effects that some common obstacles (Study 1) and wind generated by passing trucks (Study 2) have on cycle stability. Following this, the report studies the effects that path obstacles have on a cyclist's behaviour. The parents of potential cyclists are then surveyed (Study 4) to assess the extent to which concerns about road safety deters potential cyclists.

2. Study 1: The effects of roadside obstacles on cycle stability

2.1 Background

During the 1990s suggestions were made that thermoplastic road markings adversely affected cycle stability and hence contributed to loss-of-control accidents. Opus International Consultants (Munster et al. 1999, 2000a, b) were commissioned to investigate the effects of thermoplastic lines on cycle stability. In their study, cyclists rode over thermoplastic lines of a variety of different heights at an approach angle of between 0° and 10°. Both the cyclists and an observer assessed the effects of the line on cycle stability. Effects on cycle stability were absent with road markings below 2.1 mm, inconsistent on road markings around 4 mm, and consistent on road markings above 7 mm in height. The authors concluded that the risk of cycle instability could be significant with road markings of height more than 7 mm.

Cyclists also face a number of other obstacles in the cycle path that may affect cycle stability. Opus International Consultants was then commissioned by Transfund to identify causes of cycle-only crashes on New Zealand's public roads (Munster et al. 2001). A survey of cyclists who had been injured in a cycle crash found that 28% of cyclists attributed their crash to road features. The most common single road feature cited was loose gravel (34%), although a grouping of surface irregularities (e.g. potholes, uneven surface) were frequently cited (39%).

The present study ascertains the effect on cycle stability of loose gravel, a variety of road surface irregularities including round utility access covers, rough ground, reflectors, buttons and loose gravel, and a series of road markings. Road markings investigated included thermoplastic paint lines of heights ranging from 2 mm to 7 mm, with Visibeads or drop-on beads, and calcite. Also investigated were Rainline, Vibraline and structured markings, as well as waterborne paint and chlorinated rubber markings. Road markings also differ in terms of their base chemical composition (e.g. thermoplastic and chlorinated rubber), the presence of additives (e.g. Visibeads, drop-on beads and calcite) and their form (e.g. Vibraline and Rainline). There are advantages and disadvantages associated with types of line markings. For example, chlorinated rubber lines are thin and not known to present any real hazard to cyclists, but tend to be non-durable, discolour with wear and present inferior retroreflectivity for motorists. Thermoplastic lines are durable, present superior retro-reflectivity, but perhaps present a hazard to cyclists, most particularly when structured into a Vibraline designed to warn motorists crossing the edge line.

Cycle stability is a product of the behaviour of the cyclist as well as the physical characteristics of the cycle and the environment. The particular characteristic of the environment that we are interested in here is the type of obstacle the cyclist hits. In the present study, we will look at the cycle stability of a number of cyclists riding the same cycle over different obstacles and over no obstacle.

Cycle stability can be measured in a number of different ways. One of the ways is by quantifying the verbal reports of cyclists. Munster et al. (1999, 2000a,b) had cyclists talk about their experience of the road markings and afterwards categorised the responses. While their method enables wider and richer experiences to be described, it does not allow very good quantification of the experience of the cyclist. A better way of doing this, and the one used in this study, is to ask cyclists to rate the obstacle on a scale of 0 to 10 in terms of the obstacle's effect on cycle stability.

Verbal ratings by cyclists are a subjective measure and as such it is possible that they may not accurately reflect the actual effect the obstacle has on cycle stability. Munster et al. (1999) had observers record instability-related events to establish objective measurement of stability. A few researchers have used electronic equipment to measure the effect of objects on cycles and motorcycles (Martinez 1977; Bayer & Nels 1987; Outcalt 2001; Bachman 2001). Physical measures used have included handlebar torque, handlebar angle, vertical acceleration, and lateral acceleration. Of the studies that have used physical measures, one states that physical measures were not useful (Bachman 2001), two used the subjective experience of riders to make conclusions instead of the physical measures (Martinez 1977; Outcalt 2001), and one failed to find any effect of the object studied (Bayer & Nels 1987). Indeed Bucko & Khorashadi (2001) state that the subjective experience of the rider is more useful than physical measures. For the present study both subjective and physical measures were collected. Handlebar angle and lateral acceleration were measured because either or both of these will be affected if stability is compromised (Jones 1970).

Using human participants introduces factors that need to be controlled in an experimental study. One potential problem is that participants might learn how to ride over a particular obstacle so that its effects on cycle stability are unobservable. If this is the case then the results underestimate the obstacle's effect on cycle stability, and cannot generalise to a population of riders who have not learnt how to ride over the particular obstacles that were studied.

The tasks that cyclists were asked to perform before encountering the object were analogous to those that cyclists face in normal road conditions. Cyclists are asked to aim a laser on a target board, look back and tell the time from a clock (to stimulate the assessment of traffic), and to come to a stop by braking. The cyclists were told whether they passed or failed the task to maintain a standard of task performance. Making cycling over objects more difficult by requiring them to perform tasks associated with normal cycling tasks will distract participants from deliberate concentration on the line. Distraction tasks are commonly found to interfere with the performance of learnt behaviour (e.g. Strayer & Johnston 2001; Weerdesteyn et al. 2003), which in this case would be interfering with the learnt behaviour of crossing lines. In this way the tasks should reduce the influence of learning in the current study.

This study aims to successfully model the influence of 15 types of line markings and five common surface irregularities on the stability of cycling. Some of the 15 line markings considered have individual characteristics, such that some are beyond current

specifications (e.g. a 7 mm thermoplastic line) and would not be useful in actual road conditions, but are thought to produce the most instability. Other lines are considered hazardous because of their characteristics but are used only on motorways, away from cyclists (e.g. Vibraline, see Plant 1995). The waterborne paints and chlorinated rubber paints have been used for a very long time without any noted impact on cyclists. These are used as comparisons along with a baseline of a non-marked smooth asphalt surface. Munster et al. (1999) noted that the angle of approach to the line was a factor in cycle stability, with narrower angles appearing to increase the effect of a line on cycle stability. In the present study, cyclists were guided onto lines at a 5° angle using cones and by aiming a cycle-mounted laser at a target board.

2.2 Method

2.2.1 Participants

Seventeen cyclists participated in the study. Six of the cyclists were exposed to all object types and, due to the time this entailed, were paid for their time. The remaining eleven participants were enthusiastic cyclists who volunteered their time to be exposed to a selection of objects. Table 2.1 shows the median days cycled per week, median kilometres cycled per week on sealed roads, median speed when cycling on sealed roads, number of males and females, median age, median height, and median weight for the two groups of participants. Man Whitney U tests found that cycle enthusiasts cycled significantly more days per week ($U = 7.5$, $p < .05$), a greater distance per week ($U = 7$, $p < .05$), cycled faster ($U = 1$, $p < .05$), and were significantly older than paid participants. There were no significant differences between paid and enthusiast participants on gender ($U = 22.5$, $p > .05$), height ($U = 25$, $p > .05$), and weight ($U = 17$, $p > .05$).

Table 2.1 Median days cycled per week, median kilometres (km) cycled per week, median speed when cycling in kilometres per hour (km/h), number of males and females, median age in years, median height in centimetres (cm), and median weight in kilograms (kg) for paid and enthusiast participants.

Cycling demographic	Paid Cyclists	Enthusiasts
Median days cycled per week	0	3
Median km per week	0.5	45
Median speed (km/h)	18	28
Number of males	3	9
Number of females	3	2
Median age	20	45
Median height (cm)	175	170
Median weight (kg)	65	75

2.2.2 Equipment

Figure 2.1 shows the test racing cycle. The cycle had general purpose racing tyres of dimension 700 x 22/23C¹. The tyres were inflated to 70 psi. Attached to the frame (Figure 2.1, A) was a potentiometer which varied a voltage supplied by a battery. The potentiometer was fixed to the pivot point for the handlebars. The potentiometer was calibrated prior to testing to allow an accurate conversion of the measured voltage to the measure of handlebar angle. It also had a high quality red laser pointer (C on Figure 2.1) visible in daylight at a distance of 100 m. Attached to the handlebars (B) was a speedometer that displayed the cycle's speed in kilometres per hour (km/h). Attached to the carry tray at the rear of the cycle was a receiver (H), a MultiLog Pro data logger (G), an accelerometer (E) set perpendicular to the frame, a power supply for the potentiometer (J), and a connector box (F).

The potentiometer measured the position of the handlebars in volts. The accelerometer measured acceleration perpendicular to the direction of travel of the cycle's rear wheel in gravities (g). An increase in g indicates acceleration to the right of the cycle, and a decrease in g indicates acceleration to the left of the cycle. Both handlebar position accelerations were measured 10 cycles per second. These measurements were recorded on the data logger and downloaded to the notebook PC periodically. As the cycle travelled down the course (Figures 2.2) towards the target board the three laser beams would be broken. These beam breakings were recorded on the computer. In addition the breaking of laser beam 2 was transmitted to the cycle and recorded by the logger. This enabled the logger and computer data to be matched during data analysis.



Figure 2.1 The instrumented test cycle used by all participants.

¹ Tyre dimensions: 700 = circumference, 22 = 622 mm inner diameter, 23 = 623 mm outer diameter, C = continental racing tyre.

2.2.3 Objects

Twenty-three lines were laid in a disused car park in Upper Hutt (Figures 2.2, 2.3, 2.4). After an initial phase of pilot testing fifteen lines were chosen for experimentation. An area without a line was used as a baseline and is termed 'Line No. 3' hereafter. Table 2.2 shows the British Pendulum Number for the lines, the height of the lines, and presence of beads on the line, whether the line had calcite on it, and what type of line it was. Cycles approached the lines at an angle of 5°. All lines were ridden over when wet.

Five objects were investigated in a sealed access way. These were a manhole cover, rough ground, gravel, reflectors, and buttons. Figure 2.5 shows the objects and provides their dimensions. Cycles approached these objects at right angles. Except for the gravel, all objects were wet when ridden over.

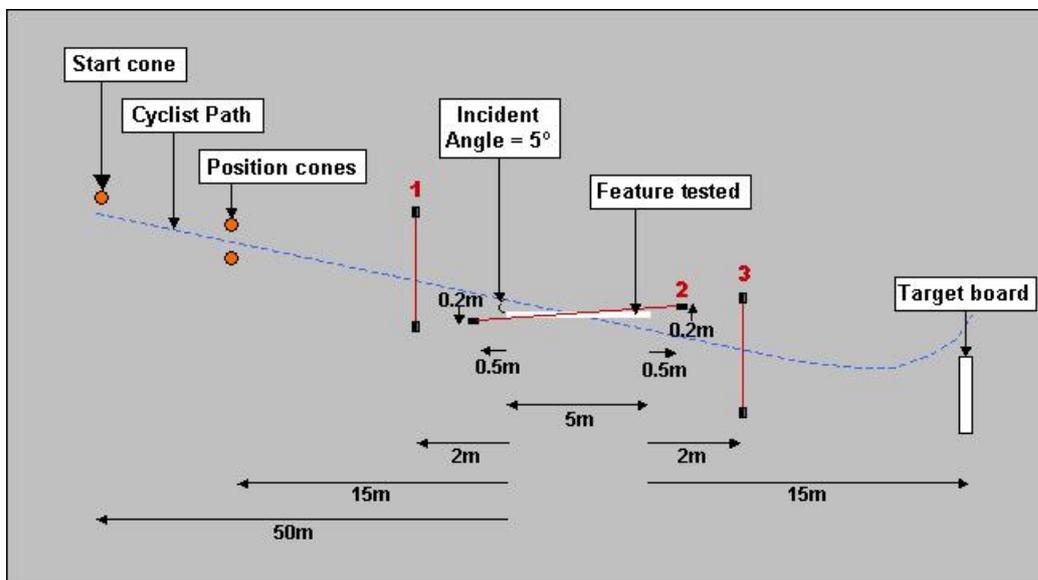


Figure 2.2 General layout of cycle course with measurements.

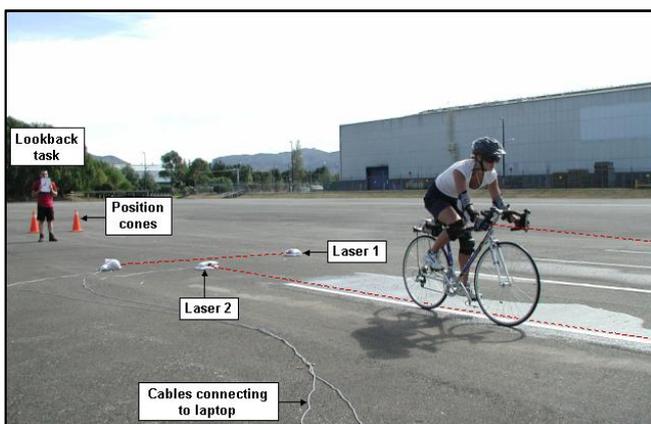


Figure 2.3 (left) Layout of the approach path of the cyclist.

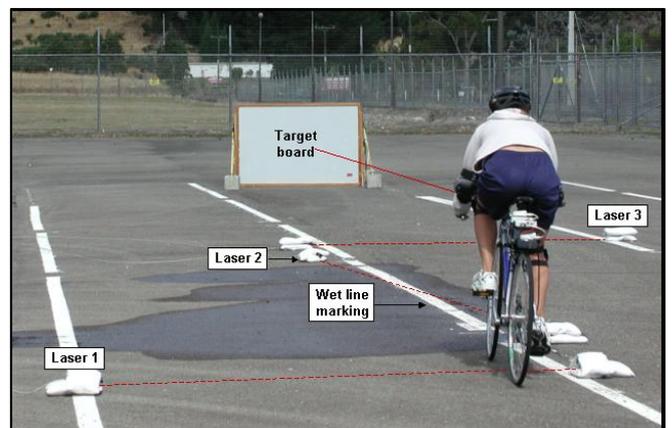


Figure 2.4 (right) Layout of the laser set-up and target board around the test feature.

2. *Study 1: The effects of roadside obstacles on cycle stability*

Table 2.2 The lines used in the experiment. Shown is the British Pendulum Number (BPN) (according to British Standard BS EN 1436:1997), height in millimetres (mm), bead type, presence of calcite, and type of line.

Line No.	BPN	Height (mm)	Bead	Calcite	Line type
	72	Baseline asphalt with no line			
2	58	3.5	Visibeads	Yes	Thermoplastic
4	59	0.5	Visibeads	Yes	Waterborne Paint
8	63	2	None	No	Thermoplastic
9	52	0.5	Visibeads	No	Waterborne Paint
10	46	0.2	None	No	Chlorinated Rubber
11	67	7	None	No	Thermoplastic
12	54	3	Dropon	Yes	Thermoplastic
13	70	3.5	None	No	Thermoplastic
14	50	0.5	Dropon	No	Waterborne Paint
16	57	7	Dropon	Yes	Thermoplastic
17	58	4.5	Dropon	Yes	Thermoplastic
19	68	3	Dropon	No	Structured Marking
21	91	N/a	None	No	Rainline
22	59	N/a	None	No	Vibralline
24	41	0.2	None	No	Waterborne Paint

2.2.4 Procedure

The broad outline of the study was explained to participants. All cyclists completed a consent form and pre-experiment survey (see Appendix 1). The details of the procedure were then explained to participants, who familiarised themselves with the equipment and course.

Before each participant's ride, water was applied to both the object and the 2 m of the cycle path in front of the object.

Upon instructions to begin, participants left the start cone and rode at a speed of over 20 km/h with their laser aimed at the target board. They were instructed that they could use the position cones to help keep in line with the target. When participants broke laser beam 1 they would either be told to do one of three tasks or told nothing. They proceeded towards the target until they had broken all three laser-beams and then they proceeded back to the start cones outside the laser-beams. On the way back to the start they were asked, "On a scale of 0-10 (with 0 being not noticeable and 10 being caused dangerous instability), how much effect did the line/object have on your ride stability?" The entire procedure constituted a completed trial.

Each participant had 12 trials of the object, three trials with each task and three trials with no task. The tasks were presented in 20 different orders (as shown in Appendix 2). Before each participant's cycle, an order of task presentation for each of the 12 trials was randomly selected from this list.

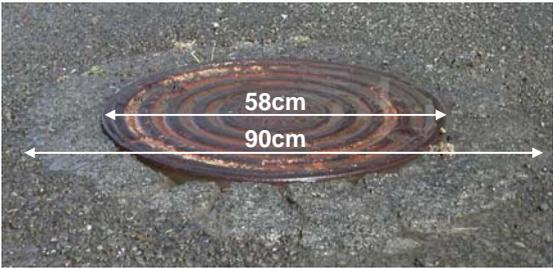
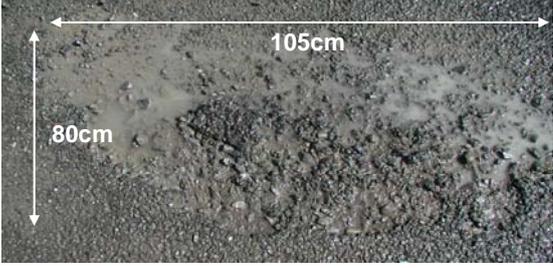
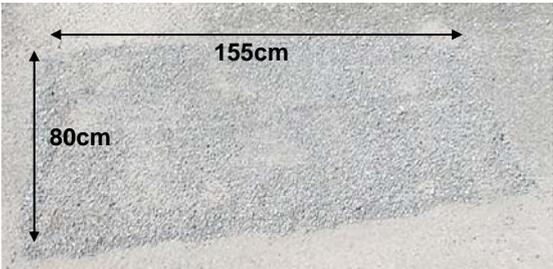
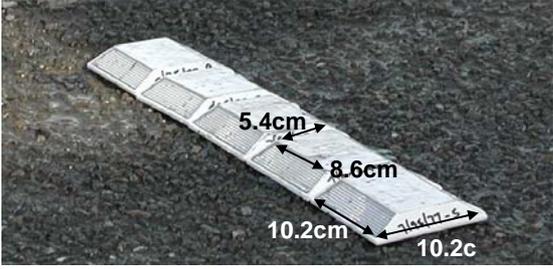
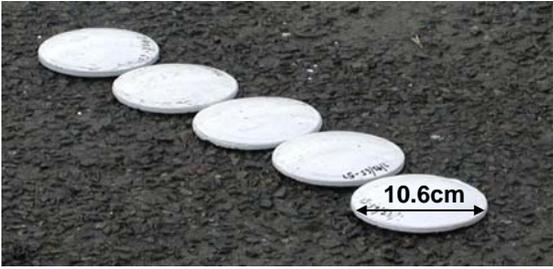
<p>Object 1: Utility Cover</p> <p>Dimensions: The recessed rings on the cover were each 6 mm in height</p>	
<p>Object 2: Rough Ground</p> <p>Dimensions: ~8 mm depth</p>	
<p>Object 3: Gravel</p> <p>Dimensions: ~7 mm in height</p> <p>Grade 4 seal chip (meaning 75% of the chip is between 3 mm and 10.5 mm size)</p>	
<p>Object 4: Reflectors</p> <p>Dimensions: 19 mm in height</p>	
<p>Object 5: Buttons</p> <p>Dimensions: 22.5 mm in height</p>	

Figure 2.5 The five surface irregularity objects studied at the access way site.

The three tasks that participants were asked to do are as follows:

(1) Target: After breaking the first laser beam, participants were told to "Target". This meant to aim the laser as close to the centre of the target as possible and keep it there. They were also told that they only had a short period of time in which to get the laser onto the target so that it was important that they responded to the instruction 'target' as soon as possible. At the end of the run, a judge determined whether the participant 'passed' or 'failed' the task and the participant was told accordingly. The cyclist scored a 'pass' if the laser appeared on the target board prior to the cyclist reaching the object (i.e. laser beam 2).

(2) Lookback: After breaking the first laser beam participants were told to "Lookback". This meant to look back and tell the time from a clock on a card. They were also told that the time would always be different and would only be shown for a short period, so it was important to look back when given the instruction. After breaking the third laser beam, the participants stated the time and then heard whether they had 'passed' or 'failed' the task. The participant scored a pass if the time stated matched the time on the clock card. Clock times were in hours and were chosen arbitrarily.

(3) Brake: After breaking the first laser beam participants were told to "Brake". This meant to come to a complete stop and put a foot down. They were also told that they would only have a short period of time to stop, so it was important to respond when given the instruction. After breaking the third laser beam, the participants stated the time and then heard whether they had 'passed' or 'failed' the task. The participant scored a pass if the cycle braked on or before the line/object (i.e. laser beam 2).

When participants had completed all the line objects they completed Survey Part 2, as shown in Appendix 1.

2.3 Results

2.3.1 Calculation of combined measure of cycle stability

The data collection method used here permits separate analysis of four measures: the average handle bar position; the average lateral acceleration; the range of handle bar positions; and the range of lateral acceleration². Such an analysis would not give an assessment of the overall effect of an object on cycle stability and hence not enable objects to be ranked in terms of their effect on cycle stability. To do so requires these measures to be combined into one measure of cycle stability.

When cycling on a level piece of asphalt, such as in front of the object, presumably a cycle is in a normal and stable state. The relative contribution of the four measures to cycle performance under this stable state can be ascertained by forcing the derivation of one factor, using a principal components factor analysis, and looking at the factor coefficients of the measures. These factor coefficients can be used to combine the

² Analysis of the effects of objects on individual measures has been performed and is available from the authors on request.

measures taken before the object into one measure of cycle stability. Assuming that the four measures contribute the same degree to cycle performance in an unstable state as they do in a stable state, the factor coefficients from before the object can also be used to combine the measures after the object into one measure of cycle stability.

The factor coefficients from a principal component analysis performed on the before object data are shown in Table 2.3. The before object data were regressed against the after object data for each measure to obtain residuals free of variance due to differences before the object. The residuals for each measure were then multiplied by their respective coefficient and the results were added together to obtain the combined measure.

Table 2.3 Component score coefficients from principal component analysis for average handle bar position, average acceleration of cycle, range of acceleration of cycle, and range of handle bar positions collected before the objects.

Component	Coefficient
Average handlebar position	-.458
Average acceleration of cycle	.386
Range of acceleration of cycle	.427
Range of handlebar positions	.348

2.3.2 Comparison of effects of objects with baseline

Table 2.4 shows the results of univariate Analysis of Variance (ANOVA) comparing the combined measure for each object with that from the baseline condition. It shows that 16 of the 20 objects resulted in a significantly higher mean of the combined measure compared with the baseline.

The means are ordered by the difference between the baseline and object means from negative to positive. A negative number indicates that an object has an adverse effect on stability. It can be seen that line markings are ranked below the other objects. It can also be seen that, although the 7 mm-high line markings create some of the greatest instability in comparison to other line markings, 3 mm- and 3.5 mm-high lines also appear to create considerable instability. Instability does not appear to be a simple function of height.

2. *Study 1: The effects of roadside obstacles on cycle stability*

Table 2.4 ANOVA comparisons for the combined measure, with each object compared to baseline. Shown is the difference when each mean is subtracted from baseline, the standard error, and significance. Objects are ordered by mean difference from negative to positive.

Line No.	Object type	Height	Beads	Calcite	BPN	<u>M_{Diff}</u>	<u>SE</u>
17	Rough Ground					-.462***	.039
16	Round Utility Access Cover					-.231***	.024
20	Domes	22.5				-.230***	.034
18	Loose Gravel					-.212***	.031
19	Raised Pavement Markers	19				-.189***	.042
6	Thermoplastic	7	None	No	67	-.179***	.035
1	Thermoplastic	3.5	Large beads	Yes	58	-.120***	.028
10	Thermoplastic	7	Dropon	Yes	57	-.118**	.039
14	Audio-tactile		None	No	59	-.104**	.034
7	Thermoplastic	3	Dropon	Yes	54	-.103**	.034
11	Thermoplastic	4.5	Dropon	Yes	58	-.100*	.041
9	Waterborne Paint	0.5	Dropon	No	50	-.099***	.024
8	Thermoplastic	3.5	None	No	70	-.076*	.033
12	Structured Marking	3	Dropon	No	68	-.066**	.019
13	Profiled Thermoplastic		None	No	91	-.062*	.024
4	Waterborne Paint	0.5	Large beads	No	52	-.062*	.026
3	Thermoplastic	2	None	No	63	-.026	.027
15	Waterborne Paint	0.2	None	No	41	-.012	.017
2	Waterborne Paint	0.5	Large beads	Yes	59	.032	.016
5	Chlorinated Rubber	0.2	None	No	46	.039	.021

* $p < .05$, ** $p < .01$, *** $p < .001$

2.3.3 Comparison of effect of road markings with audio-tactile line

Table 2.5 shows comparisons for the combined measure with each line marking compared to the audio-tactile line, and is ordered by the difference between this line and the individual line markings from negative to positive. A negative number indicates that a line marking causes more instability than the audio-tactile line. Rough ground, the round utility access cover, domes, and loose gravel create more instability than the audio-tactile line. The conventional paints (waterborne paint lines 15 and 2, and the chlorinated rubber line 5) cause less instability than the audio-tactile line. The remaining obstacles cause a similar level of instability to the audio-tactile line.

Table 2.5 ANOVA comparisons for the combined measure, with each object compared to the audio-tactile line. Shown is the difference when each mean is subtracted from the audio-tactile line, the standard error, and significance.

Line No.	Object type	Height	Beads	Calcite	BPN	\underline{M}_{Diff}	\underline{SE}
17	Rough Ground					-.358***	.05
16	Round Utility Access Cover					-.127**	.039
20	Domes	22.5				-.127*	.048
18	Loose Gravel					-.108*	.044
19	Raised Pavement Markers	19				-.086	.051
6	Thermoplastic	7	None	No	67	-.075	.046
1	Thermoplastic	3.5	Large beads	Yes	58	-.016	.042
10	Thermoplastic	7	Dropon	Yes	57	-.014	.05
7	Thermoplastic	3	Dropon	Yes	54	.000	.046
11	Thermoplastic	4.5	Dropon	Yes	58	.004	.051
9	Waterborne Paint	0.5	Dropon	No	50	.004	.039
8	Thermoplastic	3.5	None	No	70	.027	.045
12	Structured Marking	3	Dropon	No	68	.038	.036
13	Profiled Thermoplastic		None	No	91	.042	.039
4	Waterborne Paint	0.5	Large beads	No	52	.042	.04
3	Thermoplastic	2	None	No	63	.077	.043
15	Waterborne Paint	0.2	None	No	41	.092*	.035
	Baseline Asphalt				72	.104**	.034
2	Waterborne Paint	0.5	Large beads	Yes	59	.136***	.035
5	Chlorinated Rubber	0.2	None	No	46	.142***	.037

* $p < .05$, ** $p < .01$, *** $p < .001$

2.3.4 Effects of object type on participant rating

Table 2.6 shows the results of ANOVAs for the participant rating of each object compared with that of the baseline, ordered by the difference between the baseline and object means from negative to positive. A negative number indicates that an object had an adverse effect on the participants' rating of stability. Across all objects, participant ratings and the combined measure were moderately correlated ($r(498) = .488, p < .05$). The rankings of objects by the combined measure and the participant ratings were strongly correlated ($r_s(20) = .880, p < .05$).

Table 2.6 ANOVAs for the mean participant rating of each object compared with the baseline. Shown is the difference when each mean is subtracted from baseline, the standard error, and significance.

Line No.	Object type	Height	Beads	Calcite	BPN	\underline{M}_{Diff}	\underline{SE}
17	Rough Ground					-2.503***	.231
19	Raised Pavement Markers	19				-2.285***	.219
16	Round Utility Access Cover					-2.111***	.247
18	Loose Gravel					-2.111***	.253
20	Domes	22.5				-1.825***	.217
10	Thermoplastic	7	Dropon	Yes	57	-1.444**	.467
14	Audio-tactile		None	No	59	-1.347***	.348
11	Thermoplastic	4.5	Dropon	Yes	58	-1.306**	.443
1	Thermoplastic	3.5	Large beads	Yes	58	-1.292**	.415
8	Thermoplastic	3.5	None	No	70	-1.097**	.383
6	Thermoplastic	7	None	No	67	-1.083**	.344
7	Thermoplastic	3	Dropon	Yes	54	-1.042*	.408
13	Profiled Thermoplastic		None	No	91	-.917**	.311
15	Waterborne Paint	0.2	None	No	41	-.705*	.347
3	Thermoplastic	2	None	No	63	-.658*	.314
9	Waterborne Paint	0.5	Dropon	No	50	-0.556	.316
5	Chlorinated Rubber	0.2	None	No	46	-0.5	.264
12	Structured Marking	3	Dropon	No	68	-0.486	.259
4	Waterborne Paint	0.5	Large beads	No	52	-0.278	.185
2	Waterborne Paint	0.5	Large beads	Yes	59	-0.111	.139

* $p < .05$, ** $p < .01$, *** $p < .001$

2.3.5 Effects of physical characteristics on cycle stability

The physical characteristics of all the road markings were regressed stepwise against the combined measure to find out the relative effects of the characteristics on stability. The BPN ($t(372) = 1.183$, $p > .05$), the presence or absence of beads ($t(372) = -1.444$, $p > .05$), and the presence or absence of calcite ($t(372) = 1.635$, $p > .05$) did not account for a significant amount of the variance of the combined measure. Height accounted for a significant amount of the variance ($t(372) = 5.085$, $p < .05$). A similar regression was performed for the thermoplastic road markings only (lines 6, 8, 1, 10, 7, 11, and 3), and again height was the only measure to account for a significant amount of the variance ($t(163) = 2.366$, $p < .05$).

2.3.6 Effects of tasks on cycle stability

An ANOVA found that the combined measure differed significantly across tasks ($F(3, 492) = 5.942$, $p < .05$). A Games-Howell post-hoc showed that the braking ($M_{Diff} = .0891$, $p < .05$) and lookback ($M_{Diff} = .0514$, $p < .05$) tasks produced more instability than the no-task condition. There was no significant difference between the no-task and target task conditions ($M_{Diff} = .0313$, $p > .05$), or between the braking and lookback task conditions ($M_{Diff} = .0337$, $p > .05$).

2.3.7 Reliability of results across paid participants

The data analysis above was performed on the aggregate data from the six paid participants. The objects were also ranked by their effect on the combined measure for each individual participant, with the degree of consistency between participant rankings indicating reliability. A Friedman test found no significant difference in rankings for the combined measure across participants ($\chi^2(19) = 1.861, p > .05$). Individual rankings strongly correlated with the rankings of the aggregate measure ($\bar{r}_s = .828, SD = .064$) and with each other ($\bar{r}_s = .699, SD = .09$).

2.3.8 Generalisation to experienced cyclists

Experienced cyclists rode over objects 5, 6, 14, and the baseline. ANOVAs found no significant difference between paid and experienced participants for the combined measure ($F(1,188) = .120, p > .05$) or for the subjective rating ($F(1, 189) = 3.749, p > .05$). There was no significant interaction between participant type and object type for the combined measure ($F(3, 188) = 2.395, p > .05$) or the subjective rating ($F(3, 189) = 1.702, p > .05$).

2.3.9 Angle of approach

The angle of approach to road markings was planned to be 5°. If participants maintained this angle of approach then the cycle laser should have been on the target board for trials where there was no task and where the task was to target the laser on the board. Paid participants' lasers were on the target board in 88.5% of these trials.

2.4 Discussion

This study aimed to establish a reliable and valid method for investigating the effect of different objects on cycle stability. The physical measures collected generated clear and orderly differences between objects. The fact that physical measures are useful here contrasts with the literature on bicycle and motorcycle stability (e.g. Bachman 2001; Bayer & Nels 1987; Bucko & Khorashadi 2001; Martinez 1977; Outcalt 2001). It is likely that the use of repeated measures design, as well as the investigation of object effects relative to a baseline, were important improvements in methodology. The use of tasks to prevent interference from learning effects, and the use of a bike-mounted laser to achieve high consistency of angle of approach, may also have helped to obtain clear differences between objects.

Strong correlations were found between the rankings for the combined measure and the subjective measures of the different objects. Research suggests that verbal reports are made more accurate by the presence of physical measuring apparatus. This is true whether the apparatus measures anything or not, because the perceived capacity of the physical measure to detect subjective bias reduces its occurrence (Jones & Sigall 1971). The accuracy of the subjective measures in the present study is likely to have been improved by the collection of physical measures, explaining differences between findings

here and those of previous research (e.g. Munster, et al. 1999, 2000a,b) that relied mainly on the subjective impressions of the cyclists.

The data from each paid participant can be regarded as separate replications of the same experiment. Analysis revealed that the results were consistent across paid participants, suggesting that the results are highly replicable. In addition, no difference was found between the results for the paid participants and the results for the sample of experienced cyclists, suggesting that the results are reliable over a range of individual differences between cyclists. Such participant reliability forms part of the assessment of the generality of the results. Further enhancing the generality of the results was the use of tasks analogous to on road cycling, such as the braking and looking-back tasks. These tasks generated instability above that of the 'no-task condition' increasing the sensitivity of the measures to detecting differences between objects.

Among the road markings, four types did not create a detectable instability relative to baseline. These were a 2 mm thermoplastic line with no beads or calcite, waterborne paints lines of 0.2 mm and 0.5 mm in height (one with large glass beads and calcite, and one without beads and calcite), and a 0.2 mm chlorinated rubber line. Because these lines create no more instability than asphalt, they do not represent a hazard to cyclists.

All objects were compared to the audio-tactile line, an object thought to cause significant hazard to cyclists. Rough ground, the round utility access cover, domes, and loose gravel created more instability than the audio-tactile line, and twelve other objects were found to create a similar level of instability to the audio-tactile line. These latter objects include commonly used line markings, which suggest that changes might be made to standards that guide road marking practices.

The only physical factor found to account for a significant amount of variance in cycle stability was the height of the object. However, because a line marking of as low as 0.5 mm can induce a similar level of cycle instability to an audio-tactile line, regulating line markings by height cannot ensure cyclist safety. Comprehensive testing of line markings, and other objects placed in cyclist's path, for effects on cycle stability needs to be undertaken for accurate standards for objects to be established.

One disadvantage with the present method is the inability to assess the degree of risk associated with a particular object when an object's effect differs significantly from that of the baseline asphalt. To assess the degree of risk for such objects would require the relationship between the combined measure and the probability of accident to be quantified. The risk to participants precluded this in the present study. However, future technological developments may enable participant risk in the experimental setting to be minimised, and hence enable experiments to be conducted to quantify this risk.

2.5 Conclusions

The method used here establishes the relative physical effects different objects have on cycle stability, and seems robust under statistical assessment. Commonly used roadmarkings were not significantly different from the audio-tactile lines that are considered by independent investigations to represent a hazard to cyclists. The height of the line marking influenced cycle stability, but not enough to enable specifications based on height to ensure cyclist safety. Future work is necessary to establish the effects on cycle stability of the full range of road objects, and to establish a relationship between the combined measures of cycle stability and the probability of accident. Such research will enable precise specifications to be developed for the design and maintenance of cycle-safe environments.

2.6 Recommendations

- Any new product considered for widespread use throughout the roading network should be assessed for its effects on cyclists using methods similar to those outlined.
- The current 'height-based' standard (Transit NZ 2003b) should be replaced by a performance-based standard, including a testing regime using a methodology similar to that used in this study.
- Wherever merging and conflict points are identified as necessary, additional attention should be given to removing other hazards such as cat's-eyes, thick line markings, utility covers and loose gravel.
- The concept of locking cyclists into a cycling space and locking motorists out of this same space with a continuous raised profiled marking, or another type of restricting device (e.g. close-spaced raised pavement marker) is strongly not recommended.

Such a concept will mean the common method of avoiding hazards within the cycle space by entering into the vehicle lane would require the negotiation of an even more significant hazard.

3. Study 2: The effects of passing trucks on cycle stability

3.1 Introduction

There are many stories of cyclists being knocked off their bikes by the wind generated from passing trucks, but such anecdotal evidence has not been backed up by scientific study. In fact, there appear to be no such studies relating truck-generated wind to bicycle safety, though vehicle cross-wind effects have been investigated (Baker 1991). It was the purpose of this experiment to go some way in rectifying that gap, by determining how passing trucks disturb the air in regard to the variables of truck speed, and the distance between cyclist and truck.

Once the relationship between induced wind speed, truck speed, and the separation distance had been identified, attempts were made to identify which situations, if any, may pose a hazard to the cyclist. Solutions, in the form of suggested restrictions on truck speed and separation distance, will be applied where they are considered to be both effective and reasonable.

The purpose of this study is to:

1. determine the wind levels generated by moving trucks;
2. determine how changes of truck speed, and the distance between truck and cyclist affect these wind levels;
3. identify situations within the speed-separation categories that may be dangerous to cyclists; and
4. suggest solutions relating to truck speed and separation distance.

3.2 Method

3.2.1 Overview

Two propeller anemometers were mounted on a tripod, one facing down the road, the other across. These were logged using portable data loggers at eight samples per second. A 17 m-long truck was driven past the instrumentation. The truck speed and distance of the instrumentation from the left hand wheel track were varied in a controlled manner.

The typical surface area of a cyclist was estimated from frontal and side-on photos of a cyclist, using a scaled geometric overlay. This was combined with the wind speed measurements to predict the force exerted on the cyclist by the wind.

3.2.2 Wind measurement instrumentation

Two four-blade polystyrene propeller anemometers (23 cm diameter) were mounted on a sturdy tripod for purposes of wind measurement. A two-anemometer design was used because bicycles are reasonably stable in their longitudinal axis (forward and backward rotation, where the pivot is about the front or rear tyre contact patch), but quite unstable about their lateral axis (left-right tilting about the imaginary line of travel on the ground). The use of two anemometers allowed for the separation of the two dimensions of rotation.

The anemometers were set perpendicular to one another, each in a horizontal plane (i.e. facing northerly, and easterly directions). To minimise interference effects from the wakes, the anemometers were vertically offset by 30 cm, and each was extended 20 cm from the tripod's vertical axis (Figure 3.1). In this arrangement, the across-road anemometer is 20 cm closer to the wheel path of the truck than the centre of the down-road anemometer, causing a small systematic error in the distance variable. This is a necessary compromise to avoid wake interference, and for the stability of the equipment mounting. Distance measurements were taken relative to the across-road propeller. A pair of small 10 bit IQ Loggers logged the voltage output of the anemometers at a rate of eight samples per second. Response time of the anemometers was estimated to be of the order of 0.1 seconds, similar to the sampling rate.

At the site, the tripod was mounted so that one anemometer faced along the road towards the on-coming truck, and the other faced straight across the road. The height of the tripod was set such that the point midway between the anemometers was 1.2 m above the ground, a reasonable approximation of the height of the centre of drag for a typical cyclist.



Figure 3.1 Close up of the anemometer arrangement, showing the offset in vertical and horizontal position to minimise wake interference.

3.2.3 Test vehicle

A tractor unit and a 13 m semi-trailer, along with an experienced driver, were hired from a local haulage contractor. The length of the cab was 1.9 m, followed by a 2.2 m gap, after which was the 13 m-long trailer. The trailer had a height of 3.6 m, with the cab being somewhat lower at about 2.5 m in height. The width of the truck and trailer was about 2.5 m. The semi-trailer was of the 'Taut-Liner' variety, with canvas and strapping on both sides, and solid front, rear, and roof sections (Figure 3.2).



Figure 3.2 The truck used in the experiment was a tractor unit with a 'Taut-Liner' 13 m long semi trailer.

The driver was required to maintain a straight line past the instrumentation, with the left wheel passing over the dotted yellow 'no parking' line on the left-hand road edge. The centre of this was taken as the second reference point for the distance measurements. The driver was also required to maintain a constant and accurate speed for the 50 m before, and 50 m following the instrumentation. No external checks were made to verify the accuracy of the speed of the truck.

3.2.4 Procedure

The experiment required the variation of two variables: the speed of the truck, and the distance between the truck and the instrumentation. The speed of the truck could take the values 30, 50, 70 and 80 km/h, while suitable distances were selected from 0.5, 1, 1.5, 2, and 3 m (see Appendix C).

3.2.5 Cyclist information

To calculate the force exerted on a cyclist by the wind, it is necessary to know the surface area for the cyclist. Photographs of a cyclist were taken from front and side perspectives. The cycle and cyclist were overlaid with simple geometric shapes, of which the area was found. The coefficient of drag was obtained by estimates found in related literature. By

summing the product of the area of each shape and the distance from its centre to the ground, then dividing by the combined area of the shapes, the centre of drag was calculated.

3.3 Analysis

3.3.1 Data treatment

The output of the two anemometers was downloaded into an Excel spreadsheet and converted from volts to wind speed, in metres per second. The period starting approximately 5 seconds before, and ending 20 seconds after, each passing truck was extracted and the data inserted into a separate worksheet for each speed-distance combination. Thus each worksheet contained three runs of about 25 seconds each.

3.3.2 Wind profiles

A relatively calm day was selected for testing, so that the interference of the ambient conditions with the truck-induced wind would be minimised. At the start of the measurements a 1 m/s breeze was coming from the south, which gradually increased to a steady 3 m/s breeze by the end of the experiment. A few runs occurred during gusts of wind (up to 6 m/s), but this was not considered to be a significant issue because of the repeated measures. All values quoted here have had the ambient wind vector removed from them, and can be interpreted as purely truck-induced wind velocities.

The basic shape of the wind profile remained fairly similar across all truck speeds, and separation distances (Figure 3.3).

3.3.2.1 Along-road wind profile

As the front of the truck passed the instrumentation, along-road wind speed spiked into a well-defined positive peak before rapidly decreasing into a lower 'plateau' region. This region had wind speeds of about 2 or 3 m/s and lasted between 5 and 20 seconds.

As the air immediately in front of the truck travelled at a similar speed to the truck, some of this air spillage caused the peak. The plateau region is likely to be the remnants of the column of air set into motion by the truck.

3.3.2.2 Across-road wind profile

The across-road wind profile showed a positive (towards the instrumentation) peak immediately before the front of the passing truck, followed by a rapid decrease into a negative peak, which always occurred at, or soon after, the time the rear of the truck had passed.

The positive peak is another result of the front of the truck blocking air, with some of that air spilling off the side of the truck towards the instrumentation. The negative peak, or trough, is due to the suction effect from the rear of the truck. Often one positive peak and several negative peaks occur, perhaps caused by the gap between the tractor and trailer or from eddies generated by the wheels.

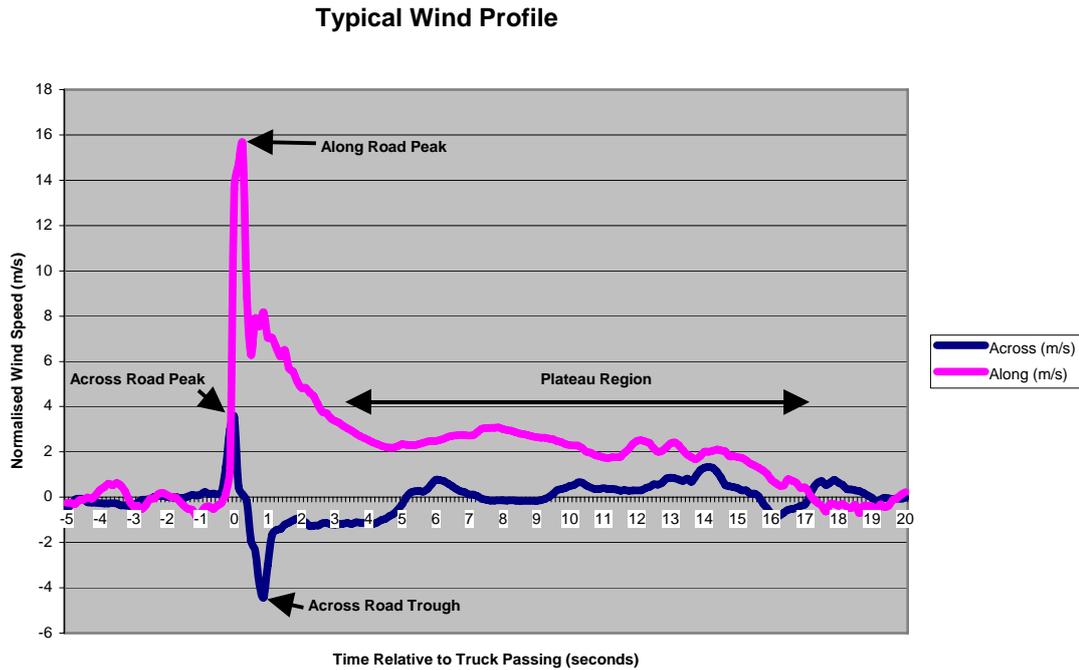


Figure 3.3 A typical wind profile from one of the 80 km/h runs, placed at 1.5 m from the truck's path. Both along-road and across-road time series have been normalised (adjusted so that the ambient condition has a mean of zero).

3.3.3 Along-road peak velocity

Regression analysis shows that the along-road peak is strongly dependent on truck speed ($r^2 = .66$, $F = 37.4$ (2,39), $p < .001$), while being independent of the separation distance ($p = .2$). Figure 3.4 displays this relationship, with a linear regression line given by $v = .157u + 1.58$, where u is truck speed in km/h, and v is peak wind speed in m/s.

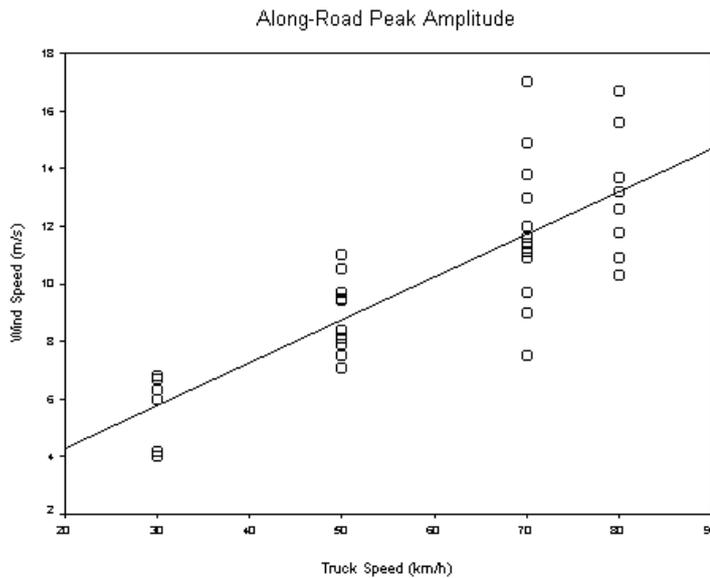


Figure 3.4 Scatter diagram showing the linear relationship between truck speed (u , in km/h) and along-road peak wind speed (v , in m/s).

3.3.4 Across-road positive peak velocity

Regression analysis shows that the across-road positive peak velocity is dependent on both truck speed and separation distance ($r^2 = .49$, $F = 18.3$ (2,39), $p < .001$). The standardised beta coefficients for truck speed, and separation distance respectively are: $\beta_{\text{speed}} = .58$ ($p < .001$) and $\beta_{\text{distance}} = -.66$ ($p < .001$). This means that the peak across-road velocity increases with truck speed, and decreases with separation distance at a similar rate. The truck speed (u , in km/h) and distance (d , in metres) as a predictor of the peak across-road wind velocity (v , in m/s) yields the equation, $v = .035u - .95d + 2.0$.

3.3.5 Across-road negative peak velocity

Regression analysis shows that the across-road negative peak velocity is inversely dependent on truck speed only ($r^2 = .33$, $F = 9.8$ (2,39), $p < .001$). The lower r^2 value indicates a high degree of scatter in the results, meaning that truck speed is not a particularly good predictor of the negative peak velocity.

3.3.6 Plateau time

The plateau time was defined as the time taken between the trailing edge of the along-road peak, and the point at which the wind velocities returned to ambient. A weak negative relationship with truck speed alone was identified ($r^2 = .20$, $F = 4.71$ (2,38), $p < .05$).

3.3.7 Across-road inter-peak time

The Inter-peak time is defined as the time between the across-road positive and negative peaks. A reasonably strong negative relationship exists between truck speed and inter-peak time ($r^2 = .61$, $F = 25.7$ (2,33), $p < .001$). This makes physical sense, as the faster the truck is moving, the briefer the period between its arrival and departure from the instrumentation. This is likely to vary directly proportional to the length of the truck.

3.3.8 Forces on cyclists

The aerodynamic drag force (F_D) represents the force exerted on the cyclist by the wind. This depends on the quantities of air density ρ , surface area (A) and type, and wind speed (v) (Equation 3.1).

$$F_D = \frac{C_D A \rho v^2}{2} \quad \text{Equation 3.1}$$

The frontal surface area of the test cyclist was $A_{\text{front}} = 0.55 \text{ m}^2$, and the side-on area was $A_{\text{side}} = 1.33 \text{ m}^2$. The coefficient of drag (C_D) for the cyclist is estimated at $C_D = 0.9$, and the rotating spoked wheels at $C_D = 0.1$.

3.3.9 Longitudinal force

The maximum longitudinal forces on the cyclist occurred during the 70 and 80 km/h runs, and approached 100N at maximum, equivalent to the weight of about 10 kg pushing on the cyclist's back. The full width at half maximum (FWHM) of the peak is typically only 0.5 second, implying that the cyclist would experience an impact, rather than a steady push.

3.3.10 Lateral force

The lateral forces on the cyclist were much lower than the longitudinal force, even though the effective surface area was higher. This was due to the lower lateral wind velocities. The maximum leftward force on the cyclist was 11N, occurring when the separation distance was lowest; the maximum rightward force on the cyclist was 23N, occurring when truck speed was highest. The highest combined lateral forces on the cyclist were an 11N 'push' to the left, followed 0.9 seconds later by a 20N 'pull' to the right, occurring at 70 km/h and 0.5 m separation distance.

Although the forces are seemingly quite low, the rapid rate of change in the direction of these forces may cause balance problems for cyclists. Since the force on the cyclist scales as the square of wind speed, which is directly proportional to truck speed, and the time between peaks is inversely related to truck speed, the rate of change of force on the cyclist is proportional to the something near the cube of truck speed, at least approximately so for most real-life situations. This is borne out by the regression of the rate-of-change-of-force (defined as the difference between positive and negative peaks, divided by the inter-peak time) against truck speed, which finds the power of truck speed to be 2.989 ($r^2 = .84$, $F = 176 (1,34)$, $p < .001$), exceptionally close to that which could be derived using the reasoning above.

3.3.11 Sources of error

The most obvious source of error is the variability of the ambient wind conditions. To help combat this, as stated above, the experiment was carried out on a relatively calm day, and each wind speed measurement had the ambient wind speed subtracted from it. Because air movement is highly chaotic, three readings of each condition were taken in an attempt to avoid untypical measurements significantly distorting the analysis.

Another source of error was the accuracy of the distance from the measurement 'point' to the nearside of the truck. Two factors influence this. The first is a systematic error because the placement of the across-road anemometer was 20 cm closer to the truck than the along-road anemometer. This is negligible, as all measurements were taken relative to the across-road anemometer, and the along-road wind flows were not significantly altered by distance from the road. The second factor was the driver's ability to maintain a consistent and accurate line along the no-parking lines. Observations during the experiment revealed that the error was at maximum plus or minus 20 mm, centred on the line.

The remaining source of error was in the driver's ability to consistently hold the correct speed, as well as the reading given on his speedometer. Without external checks it is impossible to comment with certainty on the level of accuracy, but the strict standards imposed on the truck fleet in New Zealand should ensure a reasonable level of accuracy of the speedometer, which is assumed to be the larger error.

No account has been taken of the fact that the cyclist will have some velocity in the same direction as the truck. This velocity is likely to be between 10 km/h and 30 km/h depending on wind speed and direction, gradient, and the cyclist. As a consequence, it is

reasonable to subtract the cyclist's speed from the longitudinal wind speed generated by the truck. The lateral truck-generated wind speed will not alter.

3.3.12 Possible problems and suggested solutions

The longitudinal force on the cyclist, while large and sudden, is unlikely to cause significant problems on its own, as it is directed in a direction in which the bicycle is relatively stable. Longitudinal accelerations are also favoured by the wheel arrangement, so any sliding is unlikely, even in slippery conditions. It is possible, however, that the longitudinal acceleration, occurring immediately after the initial lateral acceleration, could further destabilise an already unstable cyclist. A reduction in truck speed would be the only reasonable solution to this problem, as separation distance does not have a significant effect on the along-road gust.

The lateral forces experienced by the cyclist while being passed at high speed, and narrow separation distance by large trucks, may constitute a hazard to cyclists. Here the bow and wake of the trucks throw the cyclist first away from, and then towards, the path of the traffic. The rate of change of the forces in this instance, combined with their magnitude, may cause a problem. Because a cyclist's centre of gravity is relatively high, they are particularly sensitive to lateral tilt. While the cyclist can control some degree of variation in side forces (cyclists can ride in quite windy conditions), a very rapid change from side-push-to-pull could cause destabilisation.

While this may be ultimately recoverable, the primary means for stabilising a bike is to change its direction (Jones 1970) through the influence of correcting centrifugal forces (weight shifting would take too long to smooth out very rapid changes of force). This may mean venturing further towards the path of following traffic. Because the force rate of change scales as the cube of truck speed, a reduction in truck speed will cause a rapid decrease in the risk of lateral gust-induced instability. Increasing the distance between traffic and cyclist will have a much weaker effect on induced instability, but should give the cyclist more room to manoeuvre before moving into danger of veering into traffic. It is worth noting that the lateral force rate of change is inversely proportional to the length of the truck.

3.4 Conclusion

Peak longitudinal force on the cyclist occurs as the front of the truck passes the cyclist and is strongly dependent on truck speed. Within the range 0.5 to 3 m, it is independent of the separation distance between cyclist and truck. Derived forces of up to 100N occurred during the high truck speed runs. While this exerts a considerable impact on the cyclist, it comes from directly behind him/her, and is unlikely to cause severe destabilisation on its own. To minimise this force on the cyclist, the only option is to reduce truck speed (force increases proportional to square of truck speed), as separation distance has no significant effect.

The two main lateral forces on the cyclist are: the initial 'bow wave', which pushes the cyclist away from the truck, and the following 'wake', which sucks the cyclist towards the truck. The peak forces involved here are smaller than the longitudinal force addressed previously, being between 10N and 20N. However, the force rate of change is very rapid (and is proportional to the cube of truck speed), which may cause destabilisation of the cycle.

The obvious solution is to reduce the speed of the truck, which will indeed make the most significant difference in the magnitude and rate of change of force on the cyclist.

Another solution is to increase the separation distance between truck and cyclist, which will have the combined effects of reducing the force somewhat, and providing the cyclist with more room to safely recover from any 'wobbles' induced by the truck.

3.5 Recommendation

- In areas with high numbers of cyclists, and where shoulder space for cyclists is narrow (e.g. <1 m) so they cannot accommodate momentary instability, then truck speed should be limited to 50 km/h or less, or cyclists be accommodated by other provisions.

4. Study 3: The effects of roadside obstacles on cyclists' behaviour

4.1 Introduction

There are three main behaviours or reactions available to a cyclist when they encounter an obstacle. The cyclist can choose to ride over the object, avoid the object by moving towards the kerb, or avoid the object by moving towards the driver lane and into potential conflict with a motor vehicle.

To facilitate better design of cycling facilities, it is important to examine which road features are perceived as hazards by cyclists and what avoidance strategies are employed to negotiate these perceived hazards. Most importantly, an avoidance strategy may lead to conflict with other road users, including motor vehicles. A roadside feature may be an actual hazard to a cyclist and cause a level of instability if traversed (hazardous features were identified in Study 1, Chapter 2 of this report). However, a cyclist need not traverse a feature if they *perceive* it to be a hazard. It has already been anticipated that cyclists will swerve out of their dedicated cycle lane to avoid surface irregularities, resulting in increased exposure to conflict with motorists (Austroads 1999; 2000).

Conflict between a cyclist and a motorist can only occur when a cyclist or cycle and a motor vehicle simultaneously occupy a space. The primary antecedent for conflict of this nature is a lack of path continuity. Cynecki (1980) defines traffic conflict as a measure of the potential for a traffic accident, and states that a traffic conflict occurs when a driver takes action to avoid a collision. For the purposes of this study, cyclists would be in a position of conflict when they expose themselves to a motorist's space, as this would require the motorist to swerve in order to avoid them. Cyclists would be in conflict when they cycle in the motorist's driving lane. Cyclists would also be in conflict when riding on the white line separating the cycle and driver lanes, because part of their body and their bike would be infringing on the driver lane, therefore occupying the same space.

Previous research examining the acceptability of cycle paths used the technique of cyclists riding over actual road sites in single file at their normal cycling speed, and getting them to rate how good the path was compared with other surfaces, and whether or not the path was acceptable (Cairney 2003). In this present study a similar technique was used, where participants cycled over an actual road, past naturally occurring obstacles, using their own cycling equipment, maintaining their normal cycling speed, under normal traffic conditions. This method of observation had the benefit of reducing participant bias, as participants were not aware of what was being measured. Cyclists reacted as they would naturally when encountering potential obstacles. Rather than subjective ratings, measures of actual cycling behaviour were used to gain a more objective measure of what cyclists perceived as hazardous.

The aim of this study was to identify the common roadside obstacles that cause cyclists to alter their cycle path. A further aim was to identify which features caused cyclists to leave

the cycle lane, and enter into a situation of conflict with motor vehicles. It was expected that observations would reveal tendencies for cyclists to avoid perceived and actual obstacles in the cycle lane. It was also expected that cyclists would mitigate potential conflict with motorists by using strategies such as looking back over their shoulder to check for traffic. There is likely to be a correlation between the obstacles identified as hazardous by quantitative methods in Study 1, and the actual roadside obstacles that cyclists choose to manoeuvre around in an on-road cycling situation.

4.2 Method

4.2.1 Participants

Thirty cyclists participated in this study. Participants were gained through advertisements in local newspapers, and posters placed at local gymnasiums, cycling shops, and shopping centres. Participation was voluntary. The age of the cyclists ranged between 16 and 75 ($M = 39.17$, $SD = 14.1$), with 23 males and 7 females. The cyclists typically cycled an average of four days in a week ($SD = 1.9$ days), cycling 126 km per week ($SD = 77$ km), and cycling at an average speed of 28 km/h ($SD = 5.2$ km/h). Participants were given cycling gift tokens as a sign of appreciation for their participation.

4.2.2 Potential obstacles

The study featured 13 potential obstacles for the cyclists to negotiate as well as a baseline cycle lane to gauge each cyclist's typical cycling position. The main cycling behaviours were categorised into variables of Hit, Avoidance, Look, and Position. The variables measured at each location altered depending on the obstacle under examination.

- The Hit variable measured whether the object being examined was hit or missed.
- The Avoidance category measured whether the cyclist deviated from their standard cycle path with the intention of avoiding the obstacle. The measure of Avoidance also examined whether the cyclist avoided the obstacle by moving right, increasing the potential for conflict with traffic in the driver lane, or whether the obstacle was avoided by moving left, decreasing the potential for conflict with traffic in the driver lane.
- The Look variable measured whether those cyclists who did move into conflict looked over their shoulder to check for traffic before moving into conflict.
- The Position variable measured the position of the cyclist when parallel with or on top of the obstacle. Positions were broken into left, middle or right of the cycle lane, on the white line at the right of the cycle lane, or in the left, middle, or right of the driver lane. Cyclists were deemed to be in potential conflict with drivers of motor vehicles when they were positioned in the driver lane or on the white line.

To gain a baseline of each cyclist's typical lane position a standard smooth surface road was used and the cyclist's position was recorded (Figure 4.1).

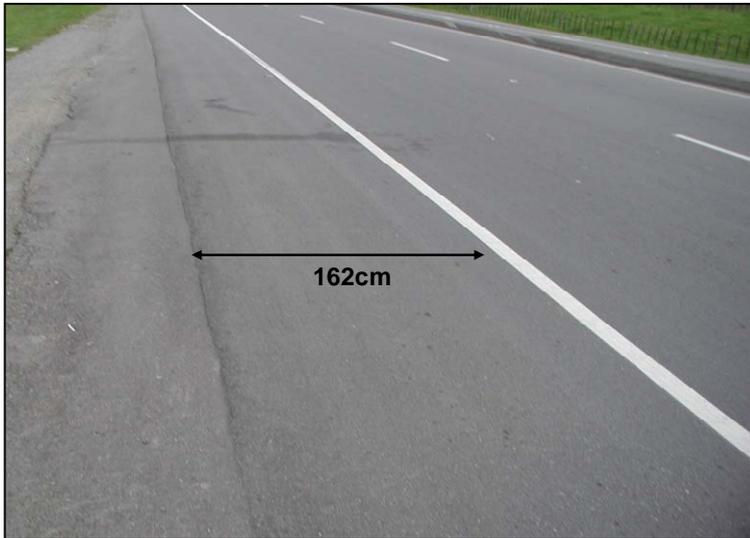


Figure 4.1 Standard smooth surface road.

The first obstacle encountered was a raised utility access cover (Figure 4.2). The cover was raised above the surrounding road surface by approximately 1.5 cm. The cycling behaviours examined at this object were Hit, Avoidance, Look, and Position.

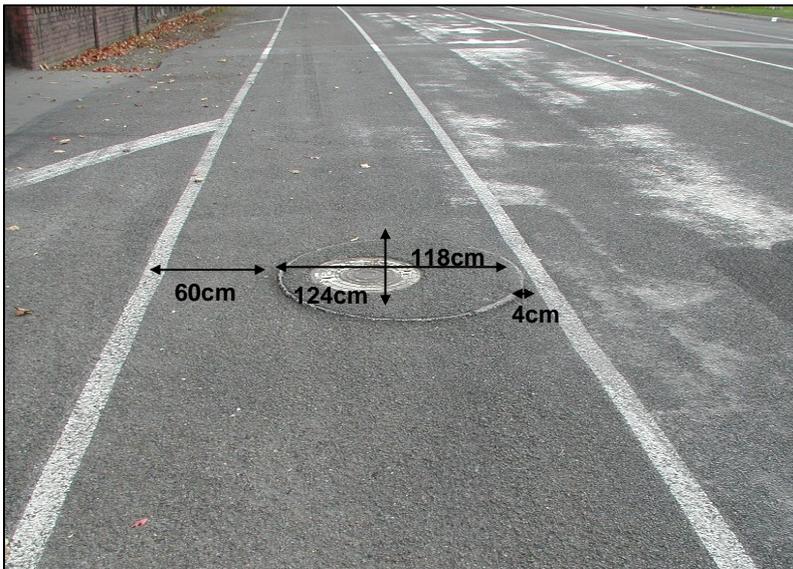


Figure 4.2 Raised utility access cover.

4. *Study 3: The effects of roadside obstacles on cyclists' behaviour*

Obstacle 2 was a pedestrian crossing (Figure 4.3). Behaviours measured at obstacle 2 were: whether the cyclist moved left (the 85 cm gap on the right of Figure 4.3) or right around the pedestrian island, whether they hit the thermoplastic crossing lines (Hit), whether they moved into conflict by entering the driver lane (Avoid), and whether they looked before moving into conflict (Look).

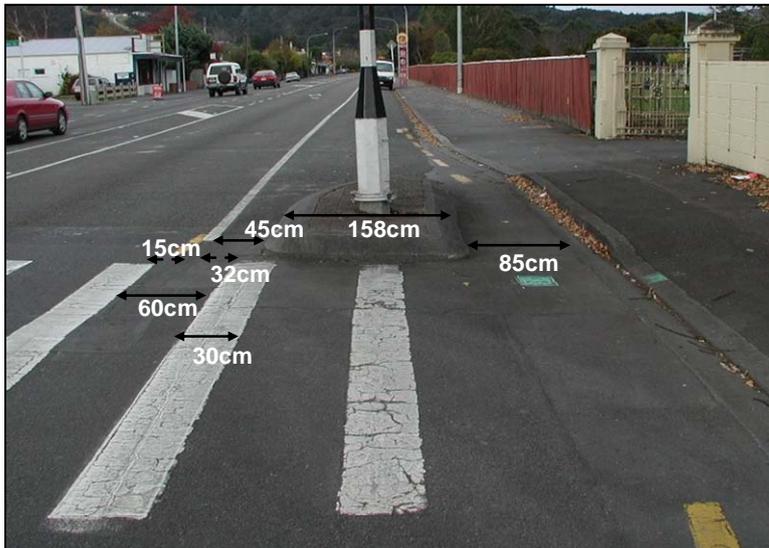


Figure 4.3 Pedestrian crossing.

Obstacle 3 was a square utility access cover (Figure 4.4). The cycling behaviours examined at this object were Hit, Avoid, Look, and Position.

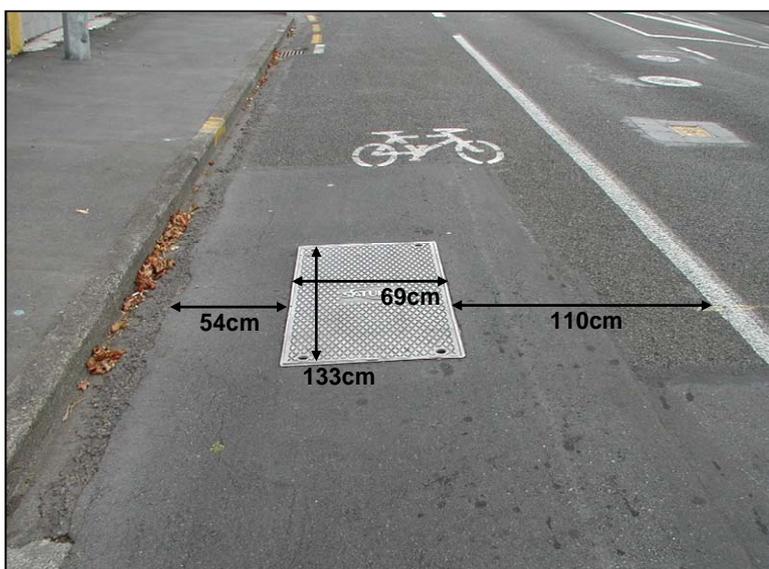


Figure 4.4 Square utility access cover.

Obstacle 4 was a pedestrian crossing at a corner (Figure 4.5). The cycling behaviours measured for this object were as follows: whether the cyclist attempted to miss the thermoplastic pedestrian lines, whether the cyclist pulled in after the corner or maintained width, cyclist position at the corner, and cyclist position after the corner.



Figure 4.5
Pedestrian
crossing at corner.

Obstacle 5 was a truck parked in the cycle lane (Figure 4.6). Cyclist behaviours measured were whether the cyclist was in conflict approximately 20 m before the parked truck, whether the cyclist moved into further conflict with the driver lane when passing the truck, whether they looked before moving into conflict, and cyclist position when parallel to the truck.



Figure 4.6 A truck
in the cycle lane.

Obstacle 6 was a cycle lane that ended abruptly at a vehicle-turning bay, so that cyclists were forced into the turning bay. The cycling behaviour measured was the point at which the cyclist moved into the turning bay (Zones 1, 2, or 3 in Figure 4.7), and whether they looked before entering into conflict.

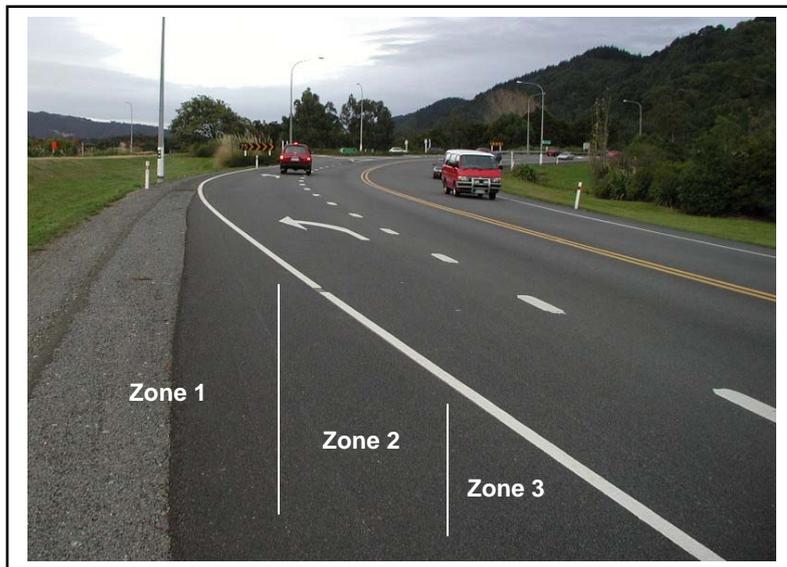


Figure 4.7 Lane ending at turning bay.

Obstacle 7 was a reflector (Figure 4.8). Cyclist behaviours measured at the reflector were Hit, Avoidance, and Look.



Figure 4.8 (above) Reflector.

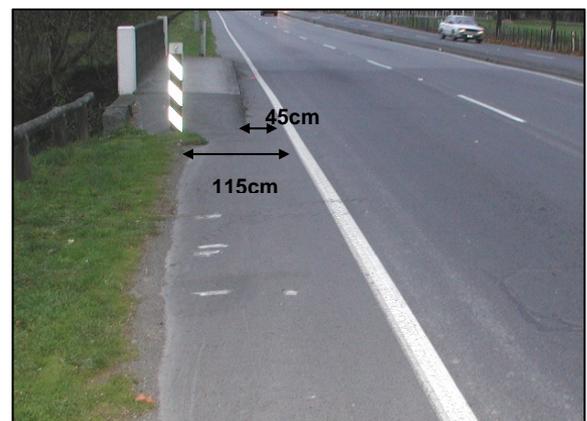


Figure 4.9 (right) Lane narrowed by bridge.

Obstacle 8 was a narrowing of the cycle lane due to a small bridge (Figure 4.9). Cyclist behaviours measured at the narrow bridge were Avoidance, Look, Position, and whether the cyclist pulled out of conflict after the bridge or whether they maintained their width.

Obstacle 9 was a pair of metal drainage grates at a corner (Figure 4.10). The cycling behaviour measured at the metal drainage grates was whether the cyclist was at conflict when rounding the corner parallel to the grates.

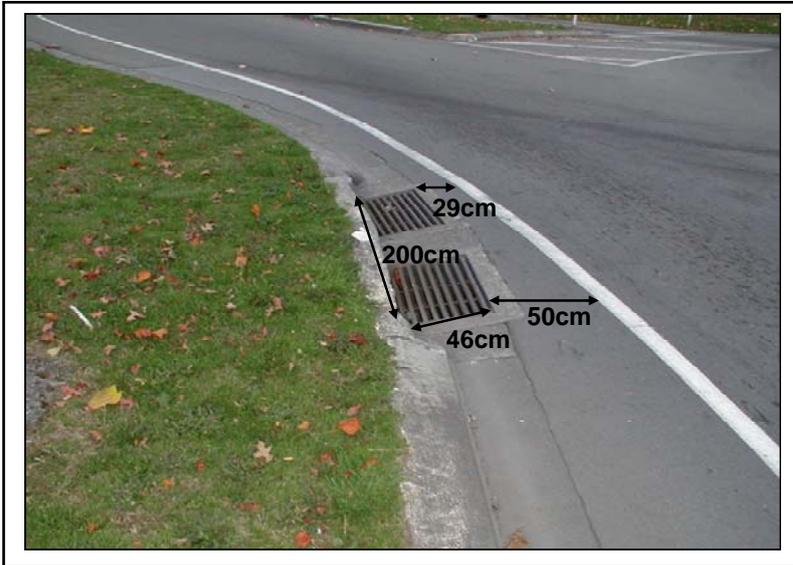


Figure 4.10 Metal drainage grates at a corner.

Obstacle 10 was a piece of plaster that probably fell off a truck (Figure 4.11). The behaviours measured at the piece of plaster were whether the plaster was hit, whether the cyclist was in conflict at the object, and whether the cyclist remained in conflict after the object.

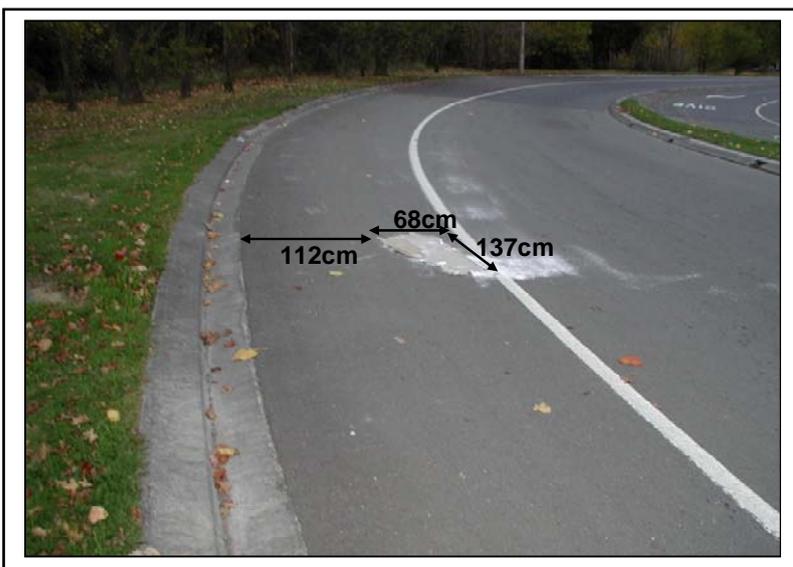


Figure 4.11 Road debris: Plaster board.

Obstacle 11 was a length of road that contained both rough and uneven surfaces as well as smooth asphalt road surface (Figure 4.12). The smooth surface was the 82 cm section of road on and to either side of the line marking separating the cycle lane from the driver lane. Position was measured, as well as whether the cyclist kept to the smooth or rough section of road.

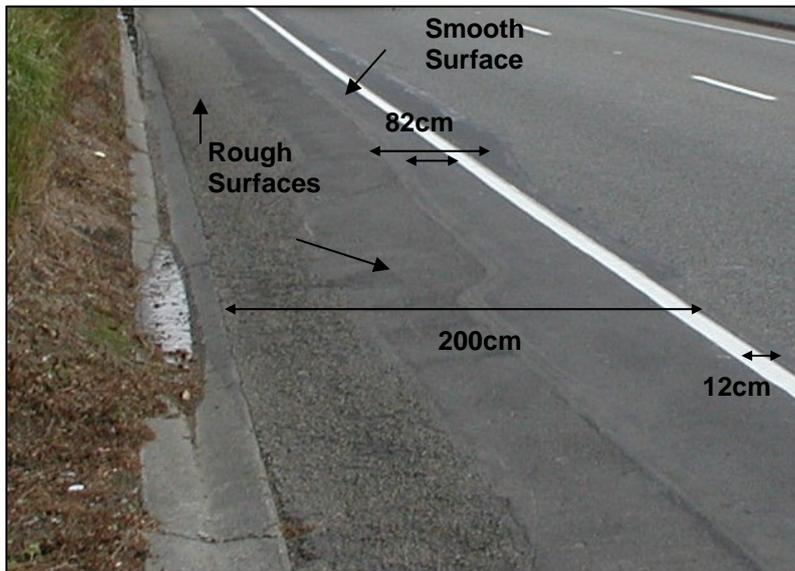


Figure 4.12
Rough and smooth
road surfaces.

Obstacle 12 was some loose metal (gravel) that covered a length of the cycle lane (Figure 4.13). Hit, Avoid, Look, and Position were measured at the loose metal.



Figure 4.13
Loose metal.

Obstacle 13 was a section of road at an underpass that narrowed the width of the cycle lane at a corner (Figure 4.14). Cyclist behaviours measured were whether the cyclist was in conflict to begin with, whether the cyclist moved into conflict before or at the corner, whether they looked before moving into conflict, and whether they moved out of conflict after the corner.



Figure 4.14
Narrow cycle lane
at corner.

4.2.3 Procedure

Naturally occurring obstacles in the cycle path were selected to represent a cross-section of the potential hazards a cyclist may typically encounter. Two separate cycle routes were chosen for their variation in available obstacles, and close proximity to one another. The first route was 11 km in length and the second route was 6 km in length. Video cameras and operators were set up in viewing positions of the potential obstacles, and were contacted by mobile phone when the cyclists began riding so they could begin recording.

Cyclists were given instructions on where they were to cycle for each of the two routes. A car park served as the same start and finish point for both circuitous routes. They were told to cycle as they normally would, and to ignore any cameras on the route. Cyclists all used their own bicycle and cycle safety gear, so that they were comfortable with the equipment they were using. All cycles were road bikes, with tyres less than 1 inch (2.5 cm) in width. Cyclists were given numbers to wear, one on their left upper arm, and one on their back, so that they could be easily identified on camera as they passed each obstacle. Cyclists were given a short survey with items concerning demographic information as well as items concerning the cyclist's typical speed and distance travelled in a week.

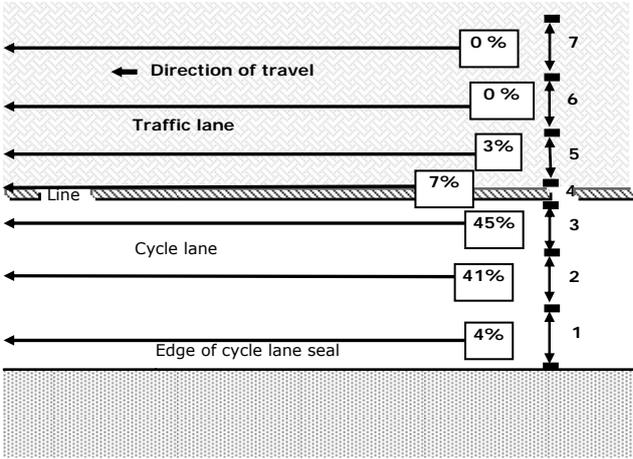
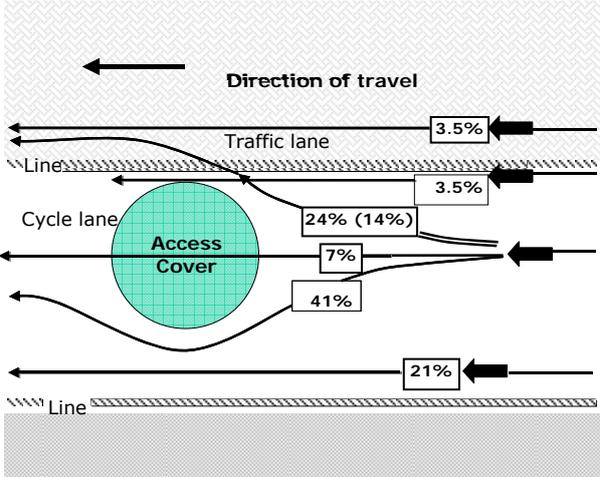
Cyclists were let go from the start point one at a time, and were spaced one minute apart to minimise overtaking. After all cyclists completed the first cycle course the camera operators were moved into position on the second 6 km cycle course and cyclists began riding again. After both courses were completed cyclists were given a post-riding survey. This survey contained items examining whether the cyclists thought their cycling

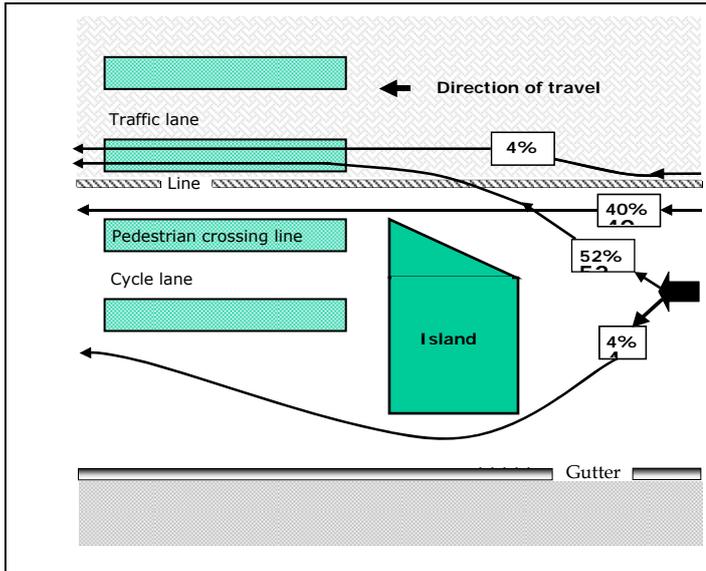
4. Study 3: The effects of roadside obstacles on cyclists' behaviour

behaviour during the study was typical of their normal cycling behaviour, how and why it differed from normal behaviour, and were also asked what they believed the study was trying to observe.

All video data were analysed separately by two individuals to ensure consistency in the results. The two observers recorded whether the object was run over, missed or avoided. They also recorded whether the cyclist avoided the object by moving away from the motor vehicle lane towards the side of the road, or by moving into the motor vehicle lane, and potential conflict. Whether the cyclist looked for traffic before moving into the vehicle lane was also recorded.

4.3 Results

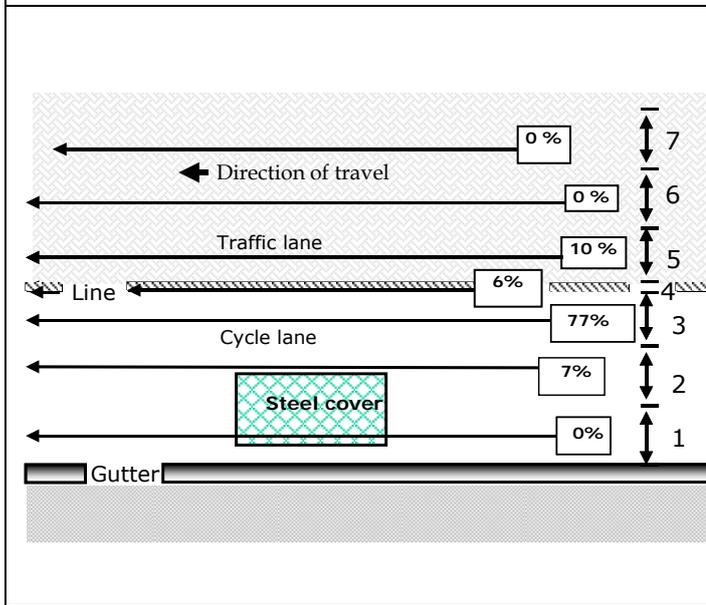
 <p>The diagram shows a cross-section of a road with a traffic lane and a cycle lane. The traffic lane is on the left, and the cycle lane is on the right. The cycle lane is separated from the traffic lane by a line. The edge of the cycle lane seal is marked. The distribution of cyclists is as follows:</p> <table border="1"> <thead> <tr> <th>Position</th> <th>Percentage</th> </tr> </thead> <tbody> <tr> <td>Direction of travel</td> <td>0%</td> </tr> <tr> <td>Traffic lane</td> <td>0%</td> </tr> <tr> <td>Line</td> <td>3%</td> </tr> <tr> <td>Cycle lane (right side)</td> <td>45%</td> </tr> <tr> <td>Cycle lane (centre)</td> <td>41%</td> </tr> <tr> <td>Edge of cycle lane seal</td> <td>4%</td> </tr> </tbody> </table>	Position	Percentage	Direction of travel	0%	Traffic lane	0%	Line	3%	Cycle lane (right side)	45%	Cycle lane (centre)	41%	Edge of cycle lane seal	4%	<p>Baseline</p> <p>Description: The baseline site was taken on a straight asphalt road with no debris or surface irregularities.</p> <p>Analysis: Only 10% of cyclists regularly ride in conflict. Of the remaining 90% that ride in the cycle lane 45% ride to the right of the cycle lane, 41% ride in the centre of the cycle lane, and 4% ride on the left of the cycle lane.</p>
Position	Percentage														
Direction of travel	0%														
Traffic lane	0%														
Line	3%														
Cycle lane (right side)	45%														
Cycle lane (centre)	41%														
Edge of cycle lane seal	4%														
 <p>The diagram shows a raised utility access cover (a green circle) positioned on the right side of the cycle lane. The distribution of cyclists is as follows:</p> <table border="1"> <thead> <tr> <th>Position</th> <th>Percentage</th> </tr> </thead> <tbody> <tr> <td>Traffic lane</td> <td>3.5%</td> </tr> <tr> <td>Line</td> <td>3.5%</td> </tr> <tr> <td>Cycle lane (avoided)</td> <td>24% (14% looked back)</td> </tr> <tr> <td>Cycle lane (hit cover)</td> <td>7%</td> </tr> <tr> <td>Cycle lane (avoided cover)</td> <td>41%</td> </tr> <tr> <td>Line</td> <td>21%</td> </tr> </tbody> </table>	Position	Percentage	Traffic lane	3.5%	Line	3.5%	Cycle lane (avoided)	24% (14% looked back)	Cycle lane (hit cover)	7%	Cycle lane (avoided cover)	41%	Line	21%	<p>Object 1: Raised utility access cover</p> <p>Description: A raised utility access cover positioned in the right (road) side of the cycle lane.</p> <p>Analysis: 24% of cyclists avoided the cover moving into conflict, and of those only 14% looked back for traffic. 41% of cyclists avoided the cover by moving out of conflict, and 7% hit the cover. The cover was not in the cycle path of the remaining 28% of cyclists.</p>
Position	Percentage														
Traffic lane	3.5%														
Line	3.5%														
Cycle lane (avoided)	24% (14% looked back)														
Cycle lane (hit cover)	7%														
Cycle lane (avoided cover)	41%														
Line	21%														



Object 2: Pedestrian crossing with island

Description: A pedestrian crossing with an island that cyclists could avoid by going to the right (road side) or left.

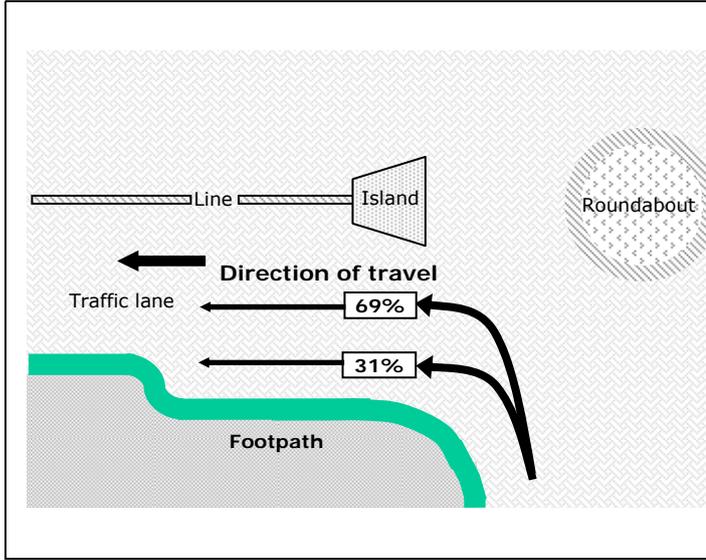
Analysis: 52% of cyclists chose to avoid the island into conflict, and of those only 13% looked back for traffic. Only 4% of cyclists avoided the island out of conflict (to the left of the island), and the island was not in the path of the remaining 44% of cyclists.



Object 3: Steel utility access cover

Description: A steel utility access cover in the centre-left of the cycle lane.

Analysis: The cover was not avoided or hit by any of the cyclists. Cyclists in conflict with traffic were 16%, 77% were in the traffic lane side of the cycle lane (zone 3), and 7% were in the middle of the cycle lane. These cycle positions are a shift from baseline, even though no avoidance behaviour was observed.

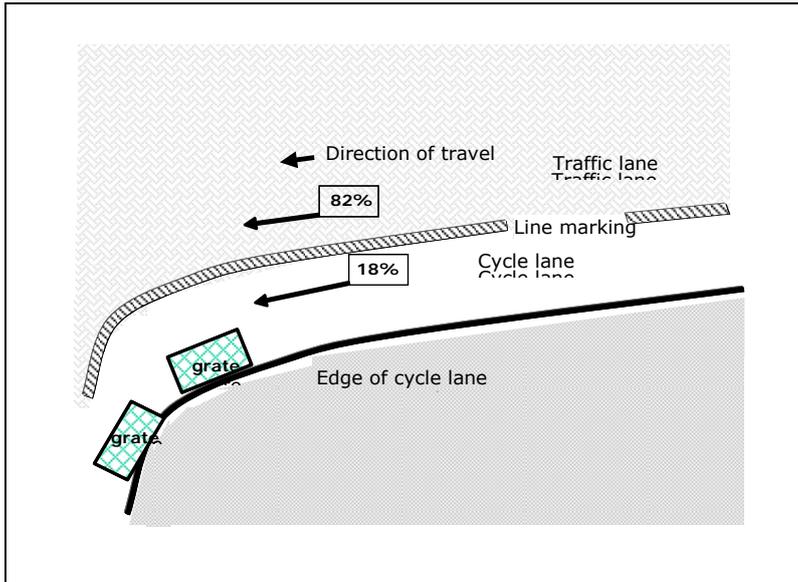


Object 4: Corner

Description: This corner was a left turn corner at a roundabout.

Analysis: After rounding the corner, 69% of cyclists maintained their width and 31% of cyclists moved over to the left of the road.

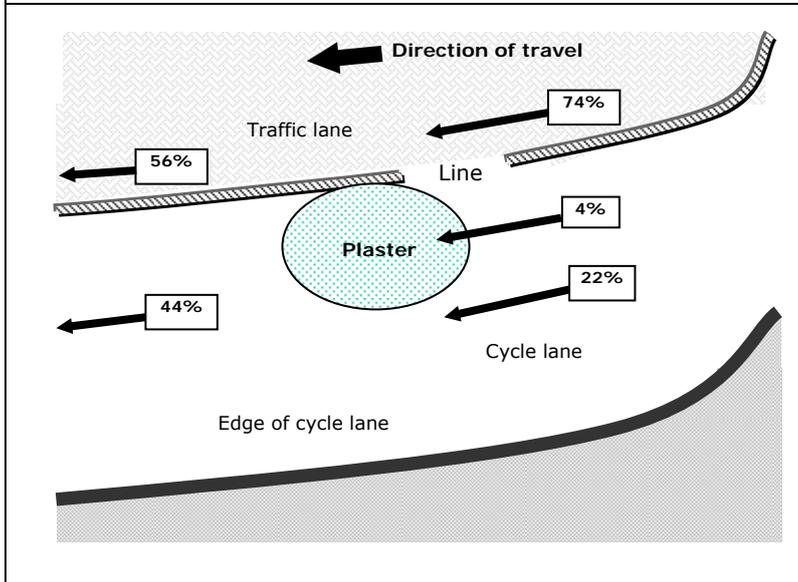
<p>Object 5: Parked Truck</p> <p>Description: A truck parked in the cycle lane.</p> <p>Analysis: Approximately 20 m before the truck, 34% of cyclists were cycling in conflict and 66% were in the cycle lane. All cyclists moved further into conflict at the truck with 3% of cyclists looking back for traffic.</p>	<p>Object 5: Parked Truck</p> <p>Description: A truck parked in the cycle lane.</p> <p>Analysis: Approximately 20 m before the truck, 34% of cyclists were cycling in conflict and 66% were in the cycle lane. All cyclists moved further into conflict at the truck with 3% of cyclists looking back for traffic.</p>
<p>Object 6 Traffic turning bay</p> <p>Description: 100kph highway where the road shoulder merges into a vehicle turning bay.</p> <p>Analysis: All cyclists entered into the vehicle turning bay and so into conflict with traffic. Cyclists either chose to go into conflict with traffic early (zone 3, 17%), late (zone 1, 60%) or somewhere in between (zone 2, 33%).</p>	<p>Object 6 Traffic turning bay</p> <p>Description: 100kph highway where the road shoulder merges into a vehicle turning bay.</p> <p>Analysis: All cyclists entered into the vehicle turning bay and so into conflict with traffic. Cyclists either chose to go into conflict with traffic early (zone 3, 17%), late (zone 1, 60%) or somewhere in between (zone 2, 33%).</p>
<p>Object 7 bridge</p> <p>Description: A cycle lane that is reduced in width due to a small bridge over a stream. Some debris was present in the cycle lane at the bridge.</p> <p>Analysis: All cyclists moved into increased conflict with traffic at the bridge (including the 14% of cyclists already in conflict), with only 16% of cyclists looking back. Forty five percent of cyclists moved out of conflict with traffic immediately after the bridge.</p>	<p>Object 7 bridge</p> <p>Description: A cycle lane that is reduced in width due to a small bridge over a stream. Some debris was present in the cycle lane at the bridge.</p> <p>Analysis: All cyclists moved into increased conflict with traffic at the bridge (including the 14% of cyclists already in conflict), with only 16% of cyclists looking back. Forty five percent of cyclists moved out of conflict with traffic immediately after the bridge.</p>



Object 8 drainage grates

Description: Two drainage grates were positioned in the cycle lane at a left turn corner.

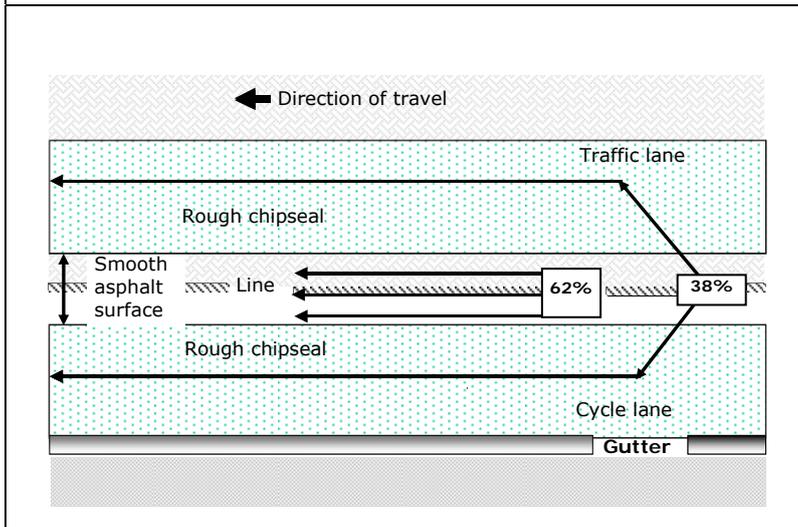
Analysis: Only 18% of cyclists were able to maintain their position in the cycle lane at this corner without going into conflict with traffic.



Object 9 plaster

Description: A thin layer of plaster that most likely fell off a truck. This object was reached immediately after a left turn corner.

Analysis: Only 4% of cyclists hit the plaster. Seventy four percent of cyclists were in conflict with traffic when adjacent to the plaster. Fifty six percent of cyclists remained in conflict with traffic after the plaster.



Object 10 rough surfaces

Description: A road composed of a smooth strip of asphalt surrounded by rough chipseal. The smooth strip of asphalt was directly beside the line marking separating the cycle and traffic lanes.

Analysis: A majority of cyclists (62%) cycled on the smooth asphalt rather than on the rough chipseal.

<p>Diagram illustrating the gravel obstacle. The road layout includes a Traffic lane, a Line, a Cycle lane, and a Gutter. A Gravel patch is located in the Cycle lane. The Direction of travel is indicated by arrows pointing left. Data points: 55% of cyclists remained in conflict while passing the gravel; 21% hit the gravel; 24% (29% of those who hit the gravel) avoided it by moving into conflict with traffic.</p>	<p>Object 11 gravel</p> <p>Description: A piece of road where loose gravel (or metal) filled the entire cycle lane for a short distance.</p> <p>Analysis: Twenty one percent of cyclists hit the gravel. Twenty four percent of cyclists avoided the gravel by moving into conflict, and of these only 29% looked back for traffic. Fifty five percent of cyclists remained in conflict while passing the gravel.</p>
<p>Diagram illustrating the underpass obstacle. The road layout includes a Traffic lane, a Line, and a Cycle lane. A Bridge support is located in the Cycle lane. The Direction of travel is indicated by arrows pointing left. Data points: 100% (4.5%) of cyclists entered into conflict with traffic at this corner; 73% of cyclists looked back for traffic; 27% of cyclists immediately after the corner moved back out of conflict and into the cycle lane.</p>	<p>Object 12 underpass</p> <p>Description: A tight left turn corner on a road that underpasses a bridge.</p> <p>Analysis: All cyclists enter into conflict with traffic at this corner, with 45% of cyclists looking back for traffic. Immediately after the corner 73% of cyclists move back out of conflict and into the cycle lane.</p>

4.4 Discussion

A baseline site was used in this study to indicate how cyclists would ride given a smooth cycle lane free of obstruction. Given that being in conflict with traffic is risky for cyclists, it would be expected that most cyclists would use a cycle lane without obstruction, and the finding was that 90% of cyclists rode in the cycle lane and 10% rode in conflict with traffic.

Riding in conflict

That some cyclists prefer to ride in conflict is an unusual finding, but may be the result of strategies adopted as a result the characteristics of cycle lanes generally. Cycle lanes are not continuous and often have obstacles in them, and as a result cyclists cannot ride in the cycle lane all the time. They have to pull out of the cycle lane into traffic at some

point, and may find that during this manoeuvre traffic does not let them in. Because of this some cyclists have reported that they prefer to occupy the road space at all times.

Effects of smooth and rough surfaces

A piece of road with smooth and rough strips was included as an object in the present study for the purpose of seeing whether cyclists prefer to ride on smooth surfaces. The results showed that 62% of participants rode on the smooth surface. The smooth surface chosen was to the right of the cycle lane, on the cycle lane line, and in the left part of the traffic lane. It was anticipated that cyclists would ride in the centre and left of the cycle lane in the baseline case, making it easy to see the effect of the smooth surface on riding position. Unexpectedly 65% of cyclists rode to the right of the cycle lane, on the cycle lane line, and in the left part of the traffic lane in baseline. Because of this it is not possible to say how rough and smooth surfaces affect cyclist behaviour. What is required is a section of road with a smooth strip on the left of the cycle lane to see if this shifts riding position.

Avoidance of obstacles

A range of objects were used in this study to see which would be avoided and how they would be avoided. The results showed various degrees of avoidance around objects. Avoidance was defined here as visible deviation of the cyclist from their path before or after the object. Avoidance defined this way can only be seen under circumstances where there is a clear straight cycle path, and cyclists do not move gradually before the object. Because of this our measure of avoidance was very conservative and could only be established for some of the objects. Avoidance is also a function of the position of the object relative to the path that cyclists take. If an object is not in the path of cyclists they will not have to take any action to avoid it. One such object was the steel utility access cover.

All the cyclists avoided objects such as the parked truck and the narrow bridge because the objects blocked the entire cycle path, and hitting the objects would have resulted in an accident. Although hitting the pedestrian crossing island would have resulted in an accident, it was avoided by 56% of cyclists because it only blocked part of the cyclist's path. Important factors determining avoidance appear to be the amount of the cycle lane blocked by the object and the physical effects of hitting the object.

The raised utility access cover and the loose gravel blocked most of the cyclist's normal path, and were avoided by 56% and 24% of the cyclists respectively. Study 1 quantitatively described the effect on cycle stability of a raised utility access cover and loose gravel, and found that cycle stability was affected more by a utility access cover than by loose gravel. The results of the present study provide some indication as to how cycle stability measured quantitatively relates to avoidance behaviour.

In the case of the raised utility access cover and pedestrian crossing, cyclists had the choice of avoiding the object while staying to the left of the cycle lane line, or avoiding the object by going into the traffic lane and so moving into conflict with traffic. The percentage of cyclists who avoided an object by riding into conflict was 24% for the raised

utility access cover and 52% for the pedestrian crossing. In the case of the raised utility access cover there was a 60 cm gap in the cycle lane to the left of the cover. In the case of the pedestrian crossing there were two gaps within the cycle lane, one to the left of the crossing of 85 cm width, and one to the right of the crossing of 45 cm width. The left gap was very rarely taken, and this may have been because it is not an obvious route to cyclists, because of cyclist preference to avoid gutter regions, or some other factor. If we exclude going left around the pedestrian crossing as an option, then we are left with a 45 cm gap to the right of the crossing compared to the 65 cm gap to the left of the raised utility access cover. That fewer cyclists move into conflict with a greater gap suggests that the size of the gap left within the cycle lane influences the percentage of cyclists who move into conflict.

Because the grate and plaster were on curves, it was not possible to determine whether cyclists were actively avoiding these objects. The percentage in conflict can be compared to baseline levels to give an indication of whether or not the objects were avoided. The percentage in conflict at the grate was 82%, at the plaster 74%, and in the baseline 10%. It seems reasonable to assume that cyclists were avoiding the grate and the plaster, and that the percentage avoiding moving into conflict was 72% for the grate and 64% for the plaster. The gap to the right of the grates was 29 cm and so the finding that 72% were avoiding conflict would support a negative relationship between gap size and the percentage of cyclists who avoid moving into conflict. There was also a gap to the left of the plaster of 112 cm which, given that 64% of cyclists avoided conflict, would not support a negative relationship between gap size and the percentage of cyclists who avoid moving into conflict. This result may be explained looking at the results from two other objects.

Objects causing change in behaviour

The three objects where cyclist behaviour changed after the object were examined: the corner, the narrow bridge, and the underpass. As a result of these obstacles cyclists were forced to move into conflict. Of interest was whether they pulled out of conflict when they could, or whether they maintained their path in conflict. In the case of the underpass 73% pulled out of conflict when they could, while in the case of the corner and the narrow bridge only 31% and 45% respectively pulled out of conflict when they could. Cyclists could see objects up ahead in the case of the corner (the parked truck was just beyond the corner), and the narrow bridge (the drainage grates were beyond the narrow bridge), while there were no visible obstructions after the underpass. This might account for the difference. Cyclists may maintain their place in conflict if they perceive obstructions in the cycle lane ahead that might force them into conflict.

The plaster object was clearly visible after the drainage grates so cyclists forced out by these grates may have chosen to stay in conflict around the plaster rather than pull out of conflict. This may account for the higher percentage of cyclists who chose to be in conflict even though there was a wide gap in the left of the cycle lane. The percent of cyclists in conflict around the plaster should not serve as counter evidence for the possible negative relationship between gap size and the percent of cyclists in conflict.

The narrow bridge, the traffic turning bay, and the parked truck forced all the cyclists into conflict. Of interest is how cyclists behaved when moving into conflict. When forced into conflict cyclists appeared to maintain their speed. Before entering into conflict the percentage of cyclists who looked for traffic was 3% for the parked truck, 16% for the narrow bridge, and 20% for the traffic turning bay. Overall these percentages are quite low given that a car could have occupied the space that the cyclist was moving into. It might be argued that cyclists could hear approaching cars, cars might be travelling slowly, and that cars were infrequent. Variation in these factors may account for some of the difference in looking for traffic between objects, but cannot account for the overall low result. In the case of the traffic turning bay wind made it hard to hear traffic, it was a 100 km/h zone, and the traffic was heavy. The percentage of cyclists who looked for traffic when moving into conflict as a result of other objects was also low. It appears that cyclists generally do not look for traffic when entering a situation where traffic may pose a risk to them. This seems counter intuitive and we will explore some possible reasons for this finding in the following paragraph.

Looking for traffic

In Study 1, participants were instructed to look back and tell the time from a clock when they were cycling toward an object. This was to duplicate the task of looking for traffic when confronting an object. The results of that study revealed that looking back creates cycle instability, making traversing the object more difficult. Following from this it is reasonable to suggest that cyclists do not look for traffic in the natural environment because this would make traversing the object more difficult. Another possibility is that there may be little that cyclists can do even if they looked and saw traffic. When running out of cycle lane, as in the case of the traffic turning bay, the cyclist's only realistic option is to stop before they run out of roadway. If they were to stop, they would have to start off again at a lower speed making it more difficult to compete with the oncoming vehicle traffic. Cyclists may rely on their hearing for the cue to avoid traffic, but this explanation also implicates the issue of instability, it being preferable to cyclists to avoid 'looking back'. The conclusion to draw is that cyclists are not inclined to look back at oncoming competing traffic.

Whatever the reasons for the low percentage of cyclists who look for traffic, it appears that cyclists do not manage their safety but rather rely on motorists to avoid them. Further research is required to see whether motorists perceive that they should watch out and give way to cyclists. Anecdotal evidence, however, suggests that motorists do not see that they should give way to cyclists. If it were the case that each group relies on the other group to give way, then cyclists and motorists would be in conflict.

Summary

This study 3 was conducted on roads under normal conditions where a variety of other factors existed that might have affected avoidance. For instance the location of the obstacles in the cycle lane, the width of the cycle lane, the width of the obstacle, the presence of vehicle traffic, and the space and position of cyclists on the road before the obstacle were not constant across obstacles. These factors mean that the results should not be interpreted as definitive evidence of how likely an obstacle is to be avoided relative

to another obstacle, or how likely a particular obstacle is to be avoided by entering into conflict with traffic. Rather the results should be interpreted as an indication of what may occur in the natural environment, and what might be the cause.

4.5 Recommendations

- Guidelines are needed for road asset managers on how to interpret the natural cycling path and allocate space within the roadway. These guidelines should assist road managers to identify obstacles that cyclists will avoid, and develop maintenance plans to either remove these obstacles or create alternative road space for cyclists.

The use of extensive flush medians to aid traffic manoeuvres needs to be balanced against an obstruction-free natural cycle pathway that is free of unexpected cycle/vehicle conflicts.

- Education is needed so that motorists have an appreciation of cyclist behaviour, and can scan the road ahead from a cyclist's perspective to identify cycle obstacles that will force the cyclist into their path. This is particularly important near intersections, or at pedestrian crossing facilities, where road managers often constrict the space available to cyclists.
- Further research is needed to identify a minimum cycle space around obstacles, and whether an edge line can effectively partition cycle and vehicle paths.

5. Study 4: Parents' perceptions of cycle safety for high-school children

5.1 Introduction

Previous stages of this report have examined the actual stability effects and avoidance behaviour of cyclists when encountering common roadside features. It was found that avoidance of features for safety reasons often occurred a considerable period before the feature was encountered, suggesting high awareness of the perceived hazard. The purpose of the present study is to examine whether people avoid cycling as a consequence of perceived cycle hazards. If this is the case then changing road features or hazards may increase the number of journeys completed by cycling.

This study is focused on urban children who are driven to their local school by car. The traffic congestion and health detriments created by the use of motorised transport have led to some studies on the choice of travel mode to school. Bradshaw (1995) surveyed a sample of British children aged 9-13 years and their parents, and found that only 6% of these children had ever cycled to school. The most common reason that parents gave for accompanying children to school was the personal safety of the child/children. Road safety was also given as a reason to accompany children to school. Bradshaw noted too that convenience and the length of journey influenced mode choice in favour of motor vehicles.

Dellinger & Stanton (2002) surveyed households containing children aged 5-18 years, and to look at barriers to children walking and cycling to school. Only 6% of respondents reported that children in the household had cycled to school in the week before the survey. Distance and dangerous motor vehicle traffic were the most common barriers reported to walking and cycling to school. Weather, crime, and school policy were also mentioned as barriers. Where no barriers were reported, children were six times more likely to walk or cycle to school. These overseas studies suggest that the percentage of children who cycle to school is very low, and that road safety and road features may play a role in this.

To investigate the role of safety concerns in deterring potential cyclists, the measurement of children's attitudes towards cycling risks may not be ideal. It is often reported that children engage in risky behaviour. Indeed most literature on risk in youth revolves around helping adults prevent risky driving, sexual-, and drug-related behaviour (for example Coggan et al. 1997). It falls to parents to make safety-related decisions around children, and one of those decisions may be whether a child cycles to school.

Because of the context of risk taking behaviour in children, parental attitudes regarding the road safety of their children are measured in the present study. Levels of parental concern about the safety impact of road features on cycling will not reveal whether safety actually influences whether children cycle or not. What is required is for levels of safety concern to be correlated to whether children actually cycle to school.

The present study surveys parents who drive their children to school, and parents whose children cycle to school, to compare differences in children's behaviour. It is hypothesised that:

1. parents whose children cycle to school will have more positive attitudes towards cycling than parents who drive their children to school;
2. parents who drive their children to school perceive cycling as less safe than parents whose children cycle to school; and
3. parents who drive their children to school will be more concerned about the safety impact of road features than those whose children cycle to school.

5.2 Method

5.2.1 Participants

Two adult samples were obtained. The first sample consisted of parents who had children who cycled to high school at least once per week ($n = 37$). Sample 2 consists of parents of children of high-school age who did not cycle to high school ($n = 52$). Parents of children of high-school age were used to minimise any role of the children's age in safety assessments. Of the 204 questionnaires sent out, 89 were returned, giving an overall response rate of 44%.

In the overall sample ($N = 89$), 43 were females and 45 males, and the average age was 46.5 years ($SD = 6.7$ years). There were no differences in age ($t(85) = -.622, p > .05$), gender ($\chi^2(1, N = 88) = 3.657, p > .05$) or income ($t(79) = -.678, p > .05$) between the sample of parents whose children cycled to high school and the sample of parents who dropped their children off at high school by motor vehicle. Likewise, distance from high school did not differ between the cycling ($M = 3.83$ km) and motor vehicle ($M = 4.09$ km) sample groups ($t(86) = -.582, p > .05$).

Parents of children who cycled to high school reported that their children on average cycle to high school 3.59 days ($SD = 1.67$ days) in a typical week (remembering that students only attend high school 5 days of the week). From the sample of parents who drove their children to school, 22% ($n = 11$) had children who still cycled for reasons other than trips to high school.

5.2.2 Materials

The questionnaire was made up of 66 items. Likert scales were used for 44 items that examined perceived hazards to cyclists of high-school age, whether cycling has become safer, whether the parents or their child/children like cycling, and whether more funding should be placed to increase cycle safety. Three items examined the safety of the cycle routes of children, three items examined the cycling habits of parents when they were at high school, and the same three items were repeated regarding their child/children's cycling habits. Seven items examined the perceived probability that a high school student will succumb to common dangers, such as accidental drowning, injury through sport, or riding in a motor vehicle. These seven items form a scale of parental concern similar to that used by Becker et al. (1996) (for which they cite Schneider et al. 1993), but adapted

for greater focus on transport rather than health. Four items asked about demographics, two items asked about survey difficulty and survey completion time.

5.2.3 Procedure

Two methods were used to gain a sample of parents whose children cycled to high school ($n = 29$). First, high schools within the Hutt Valley area in New Zealand were contacted to participate in the study. Fifty-two survey packs were delivered to participating high schools, where children who cycled to school were given the survey packs at assembly and took them home for their parents to fill in. Second, advertisements were placed in local papers in the Hutt Valley area, asking for parents of children of high-school age that cycled to school. Nine parents responded to the advertisement. The sample of parents who drove their children to high school ($n = 60$) was gained from the number plates of vehicles dropping children off at participating high schools in the Hutt Valley area. Only addresses of parents within approximately 5 km of the high schools were mailed surveys, to reduce the likelihood that distance was a factor in why the children did not cycle to school. One hundred and forty three survey packs were mailed to parents who drove their children to high school by motor vehicle.

The survey packs included a personally signed cover letter explaining the project, a questionnaire regarding perceptions of cycle safety, and a self-addressed return envelope in which to return the questionnaire. Participants received either entry to a prize draw to win cycle shop gift tokens, or scratch-and-win lottery tickets for their participation.

An item was placed in the questionnaire to examine how often their child/children cycled to high school in an average week. One of the cycling parents in the sample did not actually have a child who cycled to high school at least one day of the week, and nine of the driving parents sample had children who cycled to high school at least one day of the week. This altered the cycling parents sample size to 37, and the driving parents sample size to 52.

5.3 Results

5.3.1 Likelihood of harm for high school children

When placed into a scale, the 7 items relating to likelihood of harm had high inter-item correlations, with a Cronbach's Alpha of .80, showing the scale had high internal reliability. Parents of children who dropped their children to high school by car rated likelihood of harm to children of high-school age more highly than parents of children that cycled to high school ($t(85) = -2.627, p < .05$). More specifically, independent samples t -tests found that parents of children who drove their children to high school by car were more likely to rate a child of high-school age as: being injured while riding a bicycle ($t(86) = -2.410, p < .05$); being injured by a motor vehicle when walking ($t(84) = -2.674, p < .01$); and being diagnosed with a serious illness ($t(86) = -2.838, p < .01$). Parents who drove their children to high school did not perceive riding in a motor vehicle as more likely to cause injury than did parents who let their child/children cycle to high school ($t(86) = -.967, p > .05$).

Paired samples t-tests were used to analyse the relative risk of each transport mode within the cycling and driving groups (Figure 5.1). Parents of cyclists perceived walking to be the safest mode ($p < .05$), and found no difference in likelihood of injury between cycling and riding in a motor vehicle ($p > .05$). Parents who drove their children to high school by car also found walking to be the safest mode ($p < .05$), but rated the likelihood of injury when cycling as the least safe mode ($p < .05$).

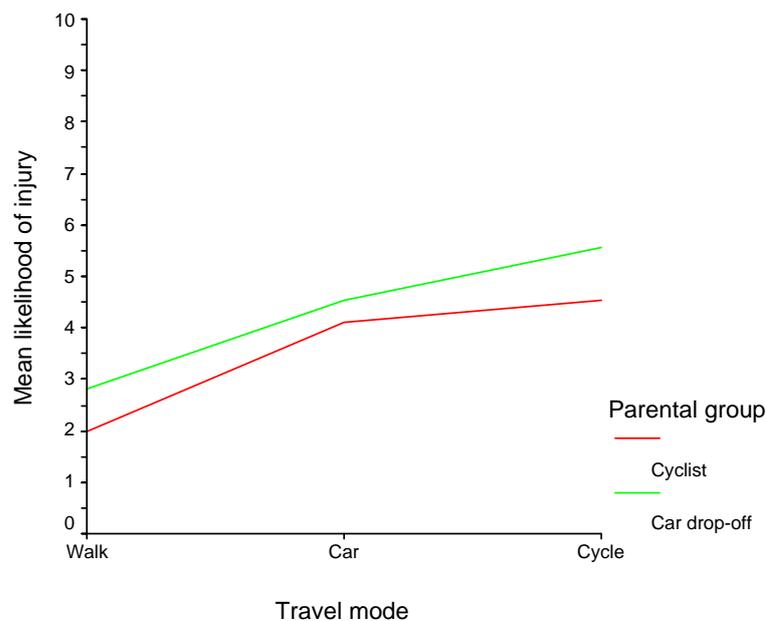


Figure 5.1 Mean perceived likelihood of injury for children of high-school age when travelling by different modes for the parents of children who cycled to school and the parents of children who were dropped off at school by car.

5.3.2 Cycle route

Parents who let their children cycle to school rated their child/children's cycle route ($t(87) = -2.637, p < .01$), and the cycle routes of other children at the same high school ($t(82) = -2.742, p < .01$), as safer than parents who drove their children to school by car. A correlation to assess the level of association suggests that around 7% of the choice to drive rather than cycle is explained by a perception of the safety of the cycle route ($r(87) = .272, p < .01$). There was no significant difference between the groups for the cycle route of the average student at any New Zealand school ($p > .05$), with both groups rating the average New Zealand school cycle route as slightly dangerous (Figure 5.2).

Within subjects, repeated measures using t-tests reveal that the parents of the school cyclist group rated the cycle route of the average New Zealand school cyclist as more dangerous than either their child/children's cycle route or the average child at their school's cycle route ($p < .05$). No differences were found between routes for the car drop-off group.

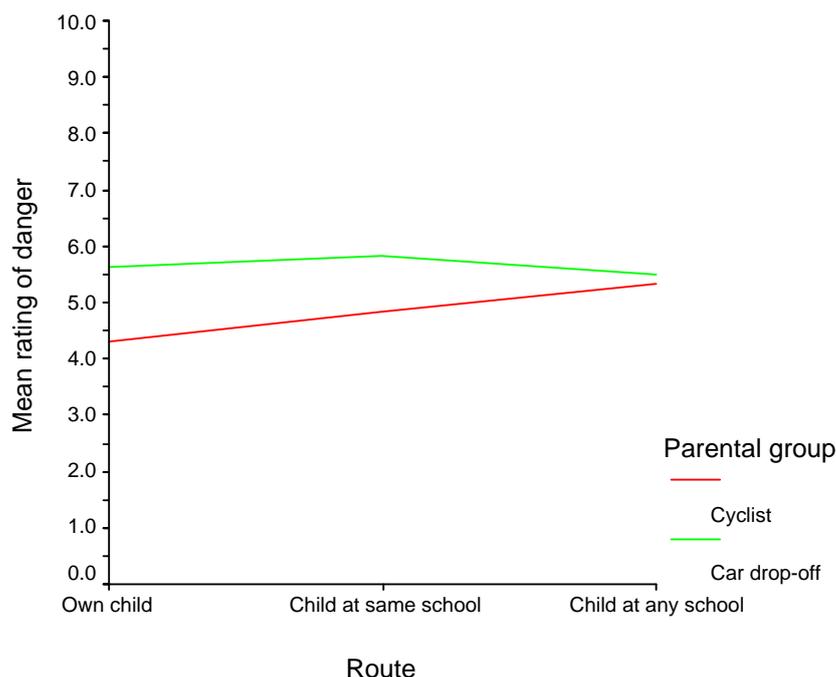


Figure 5.2 Mean rating of danger of the cycle route to school for their child/children, children at the same school, and children at any high school in New Zealand, for parents whose children cycled to high school and parents who dropped their children at high school by car.

The Likert scale items were separated into seven topic areas: road features, temporal factors, convenience and discomfort, other road users, cycle safety factors, cyclist encouragement and cycle facilities, and relative perceived risk. The Likert scales range from 1 = Strongly agree to 5 = Strongly disagree. The statistical differences between the means of the parents whose children cycle and the parents who drive their children to school were examined. In addition, the overall percentage of parents who either strongly agree or agree to each statement is given below (Tables 5.1 to 5.7).

5.3.3 Road features (11 items)

Parents of cyclists were more likely to consider that narrow road shoulders force cyclists into the driver lane than parents who drove their children to school ($Q12, t(87) = -2.173, p < .05$). Both parental groups strongly believe that narrow road shoulders and narrow roads are safety issues for cyclists (Table 5.1). Likewise, there is a high level of agreement by parents that 100 km/h speed zone areas, trucks passing cyclists, parked cars, and wet road markings all present hazards for cyclists (Table 5.1). There is reasonable agreement (55%) that poor design forces cyclists into dangerous situations. About a third of parents agree that the road shoulder is too rough and has too much loose gravel for safe cycling.

Table 5.1 Road feature statements, means, and standard deviations (SD) for parents of cyclists and parents who drove their children to school. The probability values indicate significant differences between the groups, and the overall percentage agreement to each statement.

Road feature statement	Cyclist group		Driving group		p	%Agree
	Mean	SD	Mean	SD		
Q29 Roads that are narrow make cyclists vulnerable to accidents	1.81	0.70	1.81	0.56	0.982	95.5
Q12 Narrow road shoulders force cyclists into the driver lane	1.84	0.69	2.13	0.60	0.033*	87.6
Q15 Even when cycling in a cycle lane, being passed by big trucks is hazardous for cyclists	1.97	0.83	1.96	0.82	0.949	84.3
Q14 Roads with 100km/h speed limits are dangerous for cyclists	2.11	1.09	1.87	0.79	0.252	81.8
Q8 Parked cars present a significant hazard to cyclists	2.19	1.13	2.19	0.89	0.988	76.4
Q2 Road markings can be difficult for cyclists to negotiate when wet	1.97	0.93	2.12	0.91	0.467	76.1
Q6 Cyclists are forced into dangerous situations by the poor design of roads	2.42	1.06	2.75	0.99	0.135	55.1
Q21 The road shoulder is too rough to cycle on	2.92	1.01	3.04	0.91	0.568	37.1
Q11 There is too much loose gravel to cycle safely on the road shoulder	3.08	0.95	3.02	0.88	0.756	29.5
Q26 Roads are designed for motorists, not cyclists	1.86	1.11	2.15	0.79	0.191	28.4
Q38 Cyclists can negotiate roundabouts very easily	3.68	1.03	3.77	0.70	0.634	11.2

* $p < .05$. ** $p < .01$. *** $p < .001$

5.3.4 Temporal factors (8 items)

Parents of cyclists were more likely to enjoy cycling now (Q10, $t(86) = -3.475$, $p < .01$), have liked cycling when at high school (Q20, $t(85.724) = -3.345$, $p < .01$), and think it was safe to cycle when they were at high school (Q41, $t(82.566) = -2.874$, $p < .01$) compared to parents who drove their children to school. There was a high level of agreement within both parental groups that the actual and perceived dangers of cycling have increased in recent times (Table 5.2).

Table 5.2 Temporal factor statements, means, and standard deviations (SD) for parents of cyclists and parents who drove their children to school. The probability values indicate significant differences between the groups, and the overall percentage agreement to each statement.

Temporal factor statement	Cyclist group		Driving group		p	%Agree
	Mean	SD	Mean	SD		
Q22 Cycling is more dangerous today than when I was at high school	1.89	0.58	2.10	0.89	0.189	83.0
Q31 People are more concerned about cycle safety than they used to be	2.46	0.77	2.23	0.76	0.167	71.9
Q41 It was safe to cycle when I was at high school	2.05	0.82	2.59	0.92	0.005**	68.2
Q20 I really liked to cycle when I was at high school	1.97	0.83	2.71	1.22	0.001**	67.0
Q13 It is safe for high school students to cycle these days	2.61	0.95	2.83	0.92	0.279	53.9
Q10 I really like to cycle now	2.22	1.13	3.10	1.20	0.001**	50.0
Q24 Cycling has become safer over the last 10 years	3.31	0.97	3.41	0.85	0.606	20.5
Q5 Cyclists are less vulnerable to accidents nowadays	3.86	1.03	3.83	0.94	0.858	10.1

* p <.05. ** p <.01. *** p <.001

5.3.5 Convenience and discomfort (6 items)

Parents who drove their children to school were more likely to agree that students would be too tired to concentrate in class if they cycled to school (Q4, $t(70.77) = 2.831$, $p <.01$), that the only way they would be sure that their children would get to school on time would be if they took them (Q27, $t(82.58) = 4.031$, $p <.001$), that the wind in Wellington makes it difficult to cycle to school (Q28, $t(86) = 2.305$, $p <.05$), and that they live too far away for their children to cycle to school (Q30, $t(87) = 3.085$, $p <.01$). Despite these differences, neither parent group believed that distance from school, tiredness in class or tardiness were good reasons not to cycle (Table 5.3).

Table 5.3 Convenience and discomfort statements, means, and standard deviations (SD) for parents of cyclists and parents who drove their children to school. The probability values indicate significant differences between the groups, and the overall percentage agreement to each statement.

Convenience and discomfort statement	Cyclist group		Driving group		p	% Agree
	Mean	SD	Mean	SD		
Q7 It's hard for students to carry books and other equipment to school on a bicycle	3.03	1.19	2.65	1.02	0.121	55.7
Q23 Bicycles are likely to get stolen or damaged if taken to school	2.93	1.07	2.67	0.90	0.233	46.1
Q28 The wind we get in Wellington makes it difficult to cycle to school	3.50	1.04	2.96	1.11	0.022*	33.0
Q27 The only way I would be sure my child would get to school on time would be if I took them myself	4.03	0.96	3.15	1.07	0.000***	24.7
Q30 We live too far away for my child to cycle to school	4.27	0.77	3.65	1.03	0.002**	13.5
Q4 Students would be too tired to concentrate in class if they cycled to school	4.49	0.69	4.10	0.60	0.007**	2.2

* p <.05. ** p <.01. *** p <.001.

5.3.6 Other road users (5 items)

There is very strong agreement that when several cyclists ride abreast of each other they are at greater risk, and that traffic density does affect cyclist safety (Table 5.4). The perception among parents is that car drivers do not have high consideration for, or awareness of, cyclists. No significant differences between the groups were found for these items.

Table 5.4 Other road user statements, means, and standard deviations (SD) for parents of cyclists and parents who drove their children to school. The probability values indicate significant differences between the groups, and the overall percentage agreement to each statement.
 p < .05. ** p < .01. *** p < .001

Other road user statement	Cyclist group		Driving group		p	%Agree
	Mean	SD	Mean	SD		
Q1 Cyclists are at greater risk of accident when there are a lot of them riding abreast of each other	1.46	0.56	1.52	0.80	0.697	94.4
Q32 The amount of traffic on the roads makes it dangerous to cycle	2.68	1.06	2.37	0.99	0.165	66.3
Q34 Car drivers have very little consideration for cyclists	2.69	1.06	2.50	1.02	0.390	59.1
Q3 Car drivers are usually very aware of cyclists	3.41	1.09	3.27	1.07	0.559	31.5
Q35 People rarely open car doors in the path of cyclists	3.73	0.84	3.37	1.05	0.072	19.1

5.3.7 Cyclist safety factors (5 items)

Parents of cyclists were more likely to consider that high school students understand road rules enough to cycle safely (Q33, $t(87) = -3.371$, $p < .01$), and less likely to agree that it takes years of experience to cycle safely (Q9, $t(86) = 2.199$, $p < .05$), or that teenagers make too many risky decisions to be safe cyclists (Q39, $t(69.317) = 3.471$, $p < .01$). Parents of cyclists believe that high-school cyclists understand the road rules, have the experience, and do not make too many risky decisions to be safe cyclists (Table 5.5). Contrary to these findings, 97% of parents believe that cycling is safer for adults than for teenagers.

Table 5.5 Cyclist safety statements, means, and standard deviations (SD) for parents of cyclists and parents who drove their children to school. The probability values indicate significant differences between the groups, and the overall percentage agreement to each statement.
 p < .05. ** p < .01. *** p < .001

Cycle safety statement	Cyclist group		Driving group		p	%Agree
	Mean	SD	Mean	SD		
Q33 High school students understand the road rules enough to be able to cycle safely	2.14	0.71	2.75	1.01	0.001**	66.3
Q9 It takes years of experience to be able to cycle safely on the road	3.21	1.00	2.71	1.07	0.031*	45.5
Q39 Teenagers make too many risky decisions to be safe cyclists	3.43	1.04	2.70	0.88	0.001**	38.2
Q45 Cyclists often fail to look for motor vehicles when entering the traffic lane	3.22	1.13	3.00	0.91	0.340	34.8
Q36 Cycling is safer for teenagers than for adults	3.97	0.65	3.79	0.54	0.159	3.4

5.3.8 Cyclist encouragement and cycle facilities (5 items)

Overall, there is a high level of agreement that high school students should be encouraged to cycle more, and that more money should be put in to meeting the needs of cyclists (Table 5.6). Parents who drove their children to school were less likely to consider that high school children should be encouraged to cycle more (Q40, $t(85.224) = -4.682$, $p < .05$), or that more money should be spent on providing for the needs of cyclists (Q44, $t(87) = -4.078$, $p < .05$), and were more likely to agree that whether their children cycled depended upon whether their friends cycled (Q37, $t(81.090) = 2.695$, $p < .05$). There is a reasonable agreement that schools should do more to encourage students to cycle, and low agreement that schools provide adequate facilities for student cyclists (Table 5.6).

Table 5.6 Cyclist encouragement and cycle facility statements, means, and standard deviations (SD) for parents of cyclists and parents who drove their children to school. The probability values indicate significant differences between the groups, and the overall percentage agreement to each statement.

Cyclist encouragement and cycle facility statement	Cyclist group		Driving group		p	%Agree
	Mean	SD	Mean	SD		
Q40 High-school students should be encouraged to cycle more	1.92	0.68	2.67	0.83	0.000***	66.3
Q44 More money needs to be spent on providing for the needs of cyclists even if this means less money is spent on motorists	1.81	0.88	2.58	0.87	0.000***	65.2
Q42 Schools don't do enough to encourage students to cycle to school	2.32	0.94	2.63	0.60	0.083	46.1
Q25 Schools provide enough facilities for students cycling to school	2.95	1.00	2.98	0.78	0.860	33.7
Q37 Whether my child cycles or not depends on whether their friends cycle	3.76	1.04	3.13	1.12	0.009**	32.6

* $p < .05$. ** $p < .01$. *** $p < .001$

5.3.9 Relative perceived risk (2 items)

Parents who drove their children to school were more likely to consider that walking was a safer activity than cycling (Q19, $t(49.862) = 2.854$, $p < .05$). There was a high level of agreement that walking was safer than cycling (Table 5.7).

Table 5.7 Perceived risk statements, means, and standard deviations (SD) for parents of cyclists and parents who drove their children to school. The probability values indicate significant differences between the groups, and the overall percentage agreement to each statement.

Perceived risk statement	Cyclist group		Driving group		p	%Agree
	Mean	SD	Mean	SD		
Q19 For students, walking is safer than cycling	2.49	1.04	1.94	0.57	0.006**	80.7
Q43 Students are at more risk of being a victim of crime when walking than they are when cycling	2.59	1.04	2.73	0.87	0.524	48.9

* $p < .05$. ** $p < .01$. *** $p < .001$

5.3.10 Cycling history

Parents of students who cycle to high school were more likely to cycle when they were at high school than parents who drive their children to school ($t(87) = 2.448, p < .05$).

5.4 Discussion

Parent Attitudes

Parents whose children cycle to school have more positive attitudes towards cycling, and perceive cycling as less hazardous than parents who drive their children to school. There is no evidence to support the hypothesis that parents who drive their children to school are more concerned about the safety impact of road features than those parents whose children cycle to school. The findings show that both parental groups perceive that road features, such as wet road markings, narrow roads, and narrow road shoulders, are hazardous to cyclists.

The parental perception that certain road features are hazardous to cyclists has low impact on whether their children cycle to high school. If road features did play a large role in why parents do not let their children cycle to school, then the parents who currently drive their children to school would have rated road features as more dangerous compared with the ratings of parents of cyclists. Improvement in road features may reduce parental anxiety regarding the hazard of cycling to high school, but there is no evidence to suggest that this will induce a shift in behaviour to increase cycling to high school.

Parents whose children cycle to school, as well as having more positive attitudes towards cycling, have more of a history of cycling than parents who drive their children to school. Children of high-school age were more likely to cycle to school if their parents enjoyed cycling, and if their parents also cycled to high school when they were teenagers. Improving the attitudes of parents towards cycling and providing parents with cycle experience is likely to encourage their children to cycle.

Parents who drive their children to high school by car perceive that children of high-school age are exposed to greater risk than do parents of cyclists. In particular, parents who drive their children to school perceive higher risk in the vulnerable transport modes of walking and cycling. Parents who drive their children to high school view riding in a motor vehicle as less likely to cause an injury than riding a bicycle. These findings support previous research which found that the perceived danger of cycling influences cycling behaviour (Bradshaw 1995; Dellinger & Stanton 2002).

Both groups of parents strongly believe, however, that cycling is safer for adults than for teenagers, that cycling has become more dangerous in recent years, and that motorists do not adequately attend to cyclists and their needs. These findings provide further evidence of self-enhancement bias, where the perceived ability of their teenage cyclist is enhanced to balance the perceived dangers of their teenager cycling to school.

Cycle route

The cycle route to school is also a cause for concern among parents who drop their children to school by car. The cycle routes to their child/children's school, and the cycle routes of children at other New Zealand schools are consistently rated as slightly dangerous by parents who drive their children to school.

Parents of cyclists also rate the cycle routes of children at other schools as slightly dangerous. However, they rate the cycle routes to their child/children's school as more safe. This is evidence of self-enhancement bias in the parents of cyclists. Parents of cyclists do not want to believe they are actively placing their child/children in danger by allowing them to cycle to school, yet believe that the cycle routes are unsafe. Enhancing the perceived safety of the cycle routes to their particular school reduces this dissonance.

It is unlikely that this perception of enhanced safety within the cycle routes of children who cycle to school is based on an actual difference in the safety of the routes. Parents of cyclists did not rate the cycle routes of other children at the same school as more dangerous, therefore all cycle routes to their particular school are perceived as safer than those to the typical New Zealand school. Parents of children who drive their children to exactly the same schools do not rate the cycle routes to their school as safer than the typical New Zealand school. This suggests a bias in perception that is not based on actual differences in the safety of the cycle route. Parents of cyclists responded that teenagers have the knowledge, experience and decision-making ability to cycle safely.

One of the primary factors identified in the literature as a barrier to cycling is travel distance (Bradshaw 1995; Dellinger & Stanton 2002). This study attempted to control for the influence of travel distance on cyclist behaviour by limiting the distance of journeys to within 5 km of the school. Travel distance, wind effects on cyclists, tiredness in class after cycling, and tardiness due to cycling, were all acknowledged as barriers to cycling more readily among parents who drove their children to school. However, parents of both groups generally disagree that these were genuine reasons not to cycle.

Both groups of parents, but in particular the parents of cyclists, believe that greater promotion of cycling should occur within high schools, and that more money should be spent meeting cyclist needs. Likewise, the importance of cycling promotion at high-school level is obvious, as early cycle experience will affect cycle use later.

5.5 Conclusions

Parents believe there is a high risk of danger when students cycle to high school. Parents of cyclists compensate for this risk with an enhanced perception of their child/children's ability to manage that risk, by enhancing the perceived safety of their child/children's cycle trip to school, and by enhancing the perceived ability of their child/children to ride safely.

Other parents simply negate these 'perceived' risks by driving their children to school. Improving the attitudes of parents towards cycling by reducing anxiety regarding cycle safety, or improving their perceived enjoyment of cycling, is likely to encourage cycling behaviour in their children. Merely removing hazardous road features is unlikely to achieve a significant improvement in parental attitudes towards cycling.

5.6 Recommendations

- Address the cohort effect concerning cycling experience and its likely influence on reducing cycling in school-aged children. This can be done by promoting cycling in schools, recognising that there will be a long-term benefit that is currently not recognised in the evaluation of such programmes.
- Address the heightened perception of the relative riskiness of cycling with information that targets parental concerns for safety of the roading context, and balances these concerns with information concerning the benefits of cycling.
- Any effort to improve the roading environment to reduce parental perception of cycling danger should address cycle/traffic conflict as this appears, more than road features in themselves, to be the basis of the heightened concern for the safety of cycling.

6. References

- Austrroads. 1995. *Guide to Traffic Engineering Practice: Part 13 Pedestrians*. Austrroads Inc., Sydney, NSW.
- Austrroads. 1999. *Guide to Traffic Engineering Practice: Part 14 Bicycles*. Austrroads Inc. and Standards Australia, Sydney, NSW. 124pp.
- Austrroads. 2000. *Pedestrian and Cyclist Safety – Recent Developments*. Austrroads Inc., Sydney, NSW.
- Bachman, D. 2001. Rumble strips. Finding a design for bicycles and motor vehicles. *Transportation Research News 215*: 28-29.
- Baker, C.J. 1991. The problems of road vehicles in cross winds. *Highways and Transportation (May 1991)*: 6-9.
- Becker, H., Hendrickson, S.L., Shaver, L. 1996. Nonurban parental beliefs about childhood injury and bicycle safety. *American Journal of Health Behaviour 22(3)*: 218-227.
- Bayer, B., Nels, H. 1987. Über den Einfluss von Profilierten Fahrbahnmarkierungen auf die Fahrstabilität von Motorrädern. *Verkehrsunfall und Fahrzeugtechnik 25(11)*: 292-296.
- Bradshaw, R. 1995. Why do parents drive their children to school? *Traffic Engineering and Control 36(1)*: 16-19.
- British Standard BS EN 1436: 1997. *Road marking materials – Road marking performance for road users*. European Committee for Standardisation.
- Bucko, T., Khorashadi, A. 2001. Evaluation of milled-in rumble strips, rolled-in rumble strips and audible edge strips. California Department of Transportation, California.
- Cairney, P. 2003. User acceptability as the basis for performance-based specifications for a major cycling facility. *Road and Transport Research*.
- Coggan, C.A., Disley, B., Patterson, P., Norton, R. 1997. Risk-taking behaviours in a sample of New Zealand adolescents. *Australian and New Zealand Journal of Public Health 21(5)*: 455-461.
- Cynecki, M.J. 1980. Development of a Conflicts Analysis Technique for Pedestrian Crossings. *Transportation Research Record 743*.
- Dellinger, A.M., Stanton, C.E. 2002. Barriers to children walking and biking to school. *Morbidity and Mortality Weekly Report 51(32)*: 701-704.
- Institute of Highways and Transportation (IHT). 1996. *Cycle-friendly Infrastructure, Guidelines*.
- Jones, D.E.H. 1970. The stability of the bicycle. *Physics Today (April 1970)*: 34-40.

- Jones, E.E., Sigall, H. 1971. The bogus pipeline: A new paradigm for measuring effect and attitude. *Psychological Bulletin* 76: 349-364.
- Loder and Bayly Consulting Group. 1989. Width of Kerbside Lanes for Cyclists. *Bicycle Coordination Unit of the Roads Corporation 1508/A/P*.
- Martinez, J.E. 1977. Effects of pavement grooving on friction, braking, and vehicle control. *Transportation Research Record* 633: 8-12.
- Munster, D., Koorey, G., Walton, D. 2001. Role of road features in cycle-only crashes in New Zealand. *Transfund New Zealand Research Report No. 211*.
- Munster, D., Dravitzki, V.K., Mitchell, T.J. 1999. Performance of thermoplastic markings and cyclist's safety. Stage 2 Line thickness and skid resistance studies. *Opus International Consultants, Central Laboratories Report 99-527550.02*, for Transit New Zealand.
- Munster, D., Dravitzki, V.K. 2000a. Performance of thermoplastic markings and cyclist's safety. Stage 1 Review of current practice. *Opus International Consultants Central Laboratories Report No. 00-527550*, for Transit New Zealand.
- Munster, D., Dravitzki, V.K., Mitchell, J. 2000b. Performance of thermoplastic markings and cyclist's safety. Stage 3 Further line thickness studies. *Opus International Consultants Central Laboratories Report: 00-527559.00*, for Transit New Zealand.
- Outcalt, W. 2001. Bicycle friendly rumble strips. *Colorado Department of Transportation, Denver Colorado Report No. CDOT-DTD-R-2001-4*. Federal Highway Administration, Springfield, Va.
- Plant, J. 1995. Raised-rib road-markings: research into the safety implications. *Traffic Engineering and Control (May 1995): 277-281*.
- Schneider, M.L., Ituarte, P., Stokols, D. 1993. Evaluation of a community bicycle helmet promotion campaign: what works and why. *American Journal of Health Promotion* 7: 281-287.
- Strayer, D.L., Johnston, W.A. 2001. Driven to distraction: Dual-task studies of simulated driving and conversing on a cellular telephone. *Psychological Science* 12(6): 462-466.
- Transit New Zealand. 2003a. Draft: *Cycling Design Guide*.
- Transit New Zealand 2003b. *Specification for Reflectorised Pavement Marking TNZ P/22. SP/SP22-030320*.
- Weerdesteyn, V., Schillings, A.M., van Galen, G.P., Duysens, J. 2003. Distraction affects the performance of obstacle avoidance during walking. *Journal of Motor Behaviour* 35(1): 53-63.

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Appendix 1: Study 1

Consent and Survey Forms for Cyclists

I enter into this research trial as a volunteer (print name)

cyclist on the following understandings, that;

1. The research trial is aimed at simulating cyclists travelling over a range of road surface irregularities on a road surface under both dry and wet conditions
2. The trial is to be carried out on our two off road test sites – both consist of a yard sealed with road like material, which contain the surface irregularities (our test surfaces). These surfaces include potholes, drain covers and line markings
3. The test surfaces may create a level of hazard for cyclists under certain circumstances and I may be at risk of falling off the cycle during the trial
4. My task will be to ride across the test surfaces as instructed. If at any stage I consider I am at risk of a fall I will discontinue with that series
5. I am however fully fit to perform the activity of cycling under these conditions and have no known impairment that will effect my ability to control the cycle
6. I will wear all safety equipment provided at all times and follow instructions provided by Opus staff
7. Opus International Consultants Ltd need not accept any liability for personal injury or damage to personal equipment should an accident occur
8. I have the right to withdraw from the trial at any stage and for any reason

.....
(Volunteer Cyclist)

.....
(Opus Staff Member)

...../...../.....

...../...../.....

Appendix 2: Survey forms

Part I Pre-cycle Survey

Subject Number

IMPORTANT POINTS

1. *There are no right or wrong answers*
2. *We value your opinion*
3. *If a question doesn't make sense then let us know, but try to answer by choosing the most appropriate response*
4. *We will not ask you to identify yourself for the survey, so your answers are entirely confidential*
5. *You may withdraw your participation at any point*
6. *You are entitled to a brief summary of the findings: you can obtain this by contacting us using the details above*
7. *The survey will be given to you in two parts. Part I now and Part II when you have finished cycling*
8. *There is a comments section at the end of Part II of the survey*

1. How many days do you cycle on sealed roads in a typical week?

- 0 1 2 3 4 5 6 7

2. Approximately how many kilometres do you cycle on sealed roads in an average week?

- | | |
|----------------------------------|--------------------------------------|
| <input type="checkbox"/> Under 1 | <input type="checkbox"/> 121-150 |
| <input type="checkbox"/> 1-30 | <input type="checkbox"/> 151-190 |
| <input type="checkbox"/> 31-60 | <input type="checkbox"/> 191-220 |
| <input type="checkbox"/> 61-90 | <input type="checkbox"/> 221 or more |
| <input type="checkbox"/> 91-120 | |

3. Approximately what is your average speed when cycling on sealed roads?

- | | |
|-------------------------------------|--|
| <input type="checkbox"/> 1-5 km/h | <input type="checkbox"/> 26-30 km/h |
| <input type="checkbox"/> 6-10 km/h | <input type="checkbox"/> 31-35 km/h |
| <input type="checkbox"/> 11-15 km/h | <input type="checkbox"/> 36-40 km/h |
| <input type="checkbox"/> 16-20 km/h | <input type="checkbox"/> 41 km/h or more |
| <input type="checkbox"/> 21-25 km/h | |

4. Do you, or would you, recognize thermoplastic paint markings when cycling?

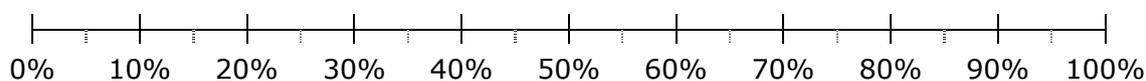
- Yes No

5. How many times have you fallen off whilst cycling on sealed roads?

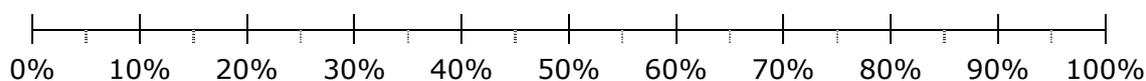
- | | |
|--------------------------------|-------------------------------------|
| <input type="checkbox"/> None | <input type="checkbox"/> 21-25 |
| <input type="checkbox"/> 1-5 | <input type="checkbox"/> 26-30 |
| <input type="checkbox"/> 6-10 | <input type="checkbox"/> 31-35 |
| <input type="checkbox"/> 11-15 | <input type="checkbox"/> 36 or more |
| <input type="checkbox"/> 16-20 | |

6. What percentage of the times you fell off was caused by line markings?

(Place an X on the line)



7. What percentage of the times you fell off was caused by other road characteristics? *(Place an X on the line)*



8. Please indicate your gender

- Male Female

9. Please indicate your age

- Under 16
 56-65

 16-25
 66-75

 26-35
 76-85

 36-45
 86 or more

 46-55

10. Please indicate your height

- Under 140 cm
- 181-190 cm

- 141-150 cm
- 191-200 cm

- 151-160 cm
- 210-220 cm

- 161-170 cm
- 221 cm or more

- 171-180 cm

11. Please indicate your weight

- Under 40 kg
- 81-90 kg

- 41-50 kg
- 91-100 kg

- 51-60 kg
- 101-110 kg

- 61-70 kg
- 111 kg or more

- 71-80 kg

Please tick the box that most appropriately represents your agreement or disagreement with the following statements	Strongly Agree	Agree	Not sure	Disagree	Strongly Disagree
12. Line marks are a safety hazard for cyclists.	<input type="checkbox"/>				
13. Line marks are beneficial to all road users.	<input type="checkbox"/>				
14. The current way of marking lines is acceptable.	<input type="checkbox"/>				
15. More resources should be spent on improving road marking for cyclists	<input type="checkbox"/>				
16. Any safety risk to cyclists from road markings is small in comparison to other road hazards.	<input type="checkbox"/>				

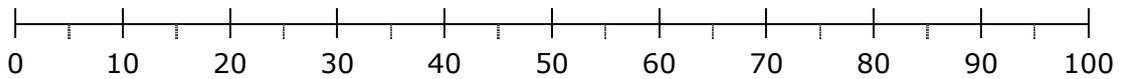
Part II: Post-cycle survey

Subject number

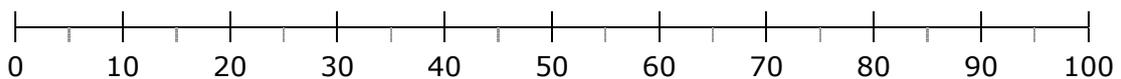
During the cycling part of this study you were asked:

"On a scale of 0-10 (with 0 being not noticeable and 10 being caused dangerous instability) how much effect did the line have on your ride stability?"

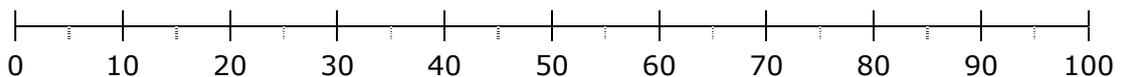
17. If you rated a line as a "8", how many times out of 100 would you fall off? (Place an X on the line)



18. If you rated a line as a "2", how many times out of 100 would you fall off? (Place an X on the line)

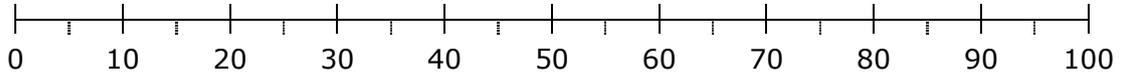


19. If you rated a line as a "5", how many times out of 100 would you fall off? (Place an X on the line)



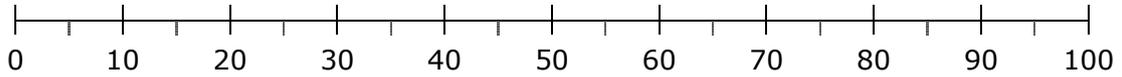
20. If you rated a line as a "10", how many times out of 100 would you fall off?

(Place an X on the line)



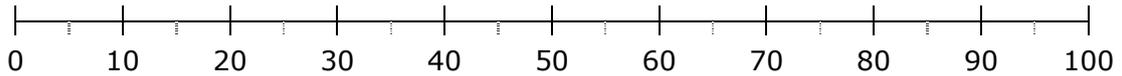
21. If you rated a line as a "1", how many times out of 100 would you fall off? (Place

an X on the line)



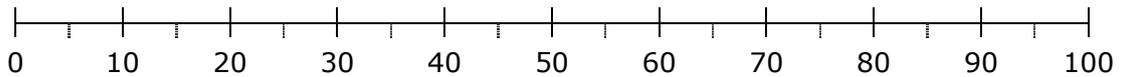
22. If you rated a line as a "7", how many times out of 100 would you fall off? (Place

an X on the line)

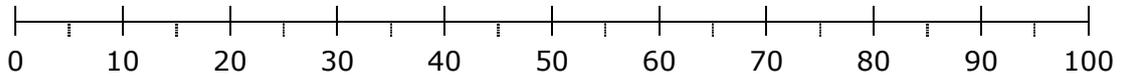


23. If you rated a line as a "0", how many times out of 100 would you fall off? (Place

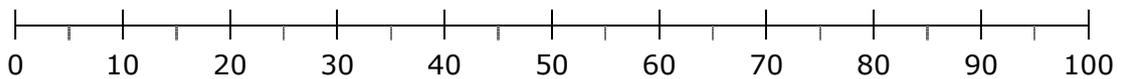
an X on the line)



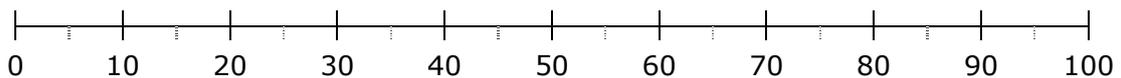
24. If you rated a line as a "6", how many times out of 100 would you fall off? (Place an X on the line)



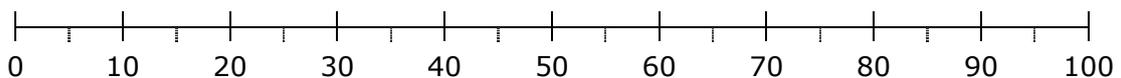
25. If you rated a line as a "3", how many times out of 100 would you fall off? (Place an X on the line)



26. If you rated a line as a "4", how many times out of 100 would you fall off? (Place an X on the line)



27. If you rated a line as a "9", how many times out of 100 would you fall off? (Place an X on the line)



Please tick the box that most appropriately represents your agreement or disagreement with the following statements	Strongly Agree	Agree	Not sure	Disagree	Strongly Disagree
28. Line marks are a safety hazard for cyclists.	<input type="checkbox"/>				
29. Line marks are beneficial to all road users.	<input type="checkbox"/>				
30. The current way of marking lines is acceptable.	<input type="checkbox"/>				
31. More resources should be spent on improving road marking for cyclists	<input type="checkbox"/>				
32. Any safety risk to cyclists from road markings is small in comparison to other hazards.	<input type="checkbox"/>				

Appendix 3: Study 1 Random task order sheet

1	2	3	4	5
1 Nothing	1 Lookback	1 Target	1 Brake	1 Brake
2 Lookback	2 Brake	2 Nothing	2 Nothing	2 Nothing
3 Target	3 Lookback	3 Target	3 Lookback	3 Target
4 Nothing	4 Nothing	4 Lookback	4 Brake	4 Target
5 Lookback	5 Target	5 Lookback	5 Nothing	5 Nothing
6 Brake	6 Brake	6 Brake	6 Lookback	6 Brake
7 Target	7 Target	7 Nothing	7 Nothing	7 Target
8 Brake	8 Nothing	8 Lookback	8 Target	8 Lookback
9 Nothing	9 Nothing	9 Nothing	9 Lookback	9 Lookback
10 Lookback	10 Lookback	10 Brake	10 Target	10 Nothing
11 Brake	11 Brake	11 Target	11 Target	11 Brake
12 Target	12 Target	12 Brake	12 Brake	12 Lookback

6	7	8	9	10
1 Lookback	1 Brake	1 Nothing	1 Lookback	1 Nothing
2 Nothing	2 Lookback	2 Target	2 Nothing	2 Nothing
3 Brake	3 Target	3 Target	3 Brake	3 Target
4 Nothing	4 Target	4 Lookback	4 Lookback	4 Target
5 Target	5 Brake	5 Target	5 Target	5 Brake
6 Brake	6 Target	6 Brake	6 Target	6 Target
7 Brake	7 Lookback	7 Lookback	7 Nothing	7 Lookback
8 Target	8 Brake	8 Brake	8 Target	8 Lookback
9 Lookback	9 Lookback	9 Lookback	9 Brake	9 Brake
10 Lookback	10 Nothing	10 Brake	10 Nothing	10 Lookback
11 Target	11 Nothing	11 Nothing	11 Brake	11 Brake
12 Nothing	12 Nothing	12 Nothing	12 Lookback	12 Nothing

11	12	13	14	15
1 Brake	1 Target	1 Brake	1 Lookback	1 Target
2 Target	2 Lookback	2 Nothing	2 Brake	2 Target
3 Nothing	3 Target	3 Brake	3 Brake	3 Nothing
4 Brake	4 Nothing	4 Brake	4 Lookback	4 Nothing
5 Lookback	5 Lookback	5 Target	5 Lookback	5 Lookback
6 Lookback	6 Lookback	6 Lookback	6 Target	6 Nothing
7 Target	7 Nothing	7 Target	7 Nothing	7 Lookback
8 Nothing	8 Brake	8 Nothing	8 Target	8 Brake
9 Lookback	9 Nothing	9 Target	9 Target	9 Brake
10 Brake	10 Brake	10 Lookback	10 Brake	10 Brake
11 Target	11 Brake	11 Nothing	11 Nothing	11 Lookback
12 Nothing	12 Target	12 Lookback	12 Nothing	12 Target

16	17	18	19	20
1 Target	1 Brake	1 Target	1 Lookback	1 Target
2 Brake	2 Lookback	2 Brake	2 Lookback	2 Lookback
3 Nothing	3 Brake	3 Nothing	3 Target	3 Brake
4 Lookback	4 Target	4 Brake	4 Brake	4 Lookback
5 Lookback	5 Lookback	5 Nothing	5 Nothing	5 Nothing
6 Target	6 Nothing	6 Lookback	6 Lookback	6 Target
7 Nothing	7 Brake	7 Lookback	7 Target	7 Nothing
8 Target	8 Target	8 Target	8 Nothing	8 Brake
9 Lookback	9 Nothing	9 Brake	9 Brake	9 Nothing
10 Brake	10 Lookback	10 Nothing	10 Brake	10 Brake
11 Brake	11 Target	11 Lookback	11 Target	11 Lookback
12 Nothing	12 Nothing	12 Target	12 Nothing	12 Target

Appendix 4: Study 2 Schedule of truck speeds and separation distances of anemometers

Truck Speed (km/h)	Separation Distance (m)				
	0.5	1.0	1.5	2.0	3.0
30	✓	✓	•	•	•
50	✓	✓	✓	✓	✓
70	✓	✓	✓	✓	✓
80*	•	✓	✓	✓	•

* Originally planned to be 90 km/h, but could not find a suitable site with an open road speed limit.

Appendix 5: Study 3 Information, consent form, and survey forms for cyclists

Information Sheet

Thank you for coming to participate in this criterion. This criterion is aimed at simulating cyclists travelling on a variety of road conditions. For this reason you will be cycling as you would normally cycle on the road without any extra traffic control. Please exercise the care you would normally exercise under these road conditions.

Cyclists will start on the basis of their number, with the lowest number starting first. We will be releasing you separated at timed intervals however this is not meant to be a race and no end time will be recorded. The attached map shows the route that the criterion covers. The route has been broken down into two sections, Stage 1 and Stage 2. In Stage 1 you will be started at *point 1* and proceed to *point 3* via *point 2*. There will then be a break whilst we organise ourselves for Stage 2. Drinks will be provided. You will then be started at *point 3* and proceed to *point 5* via *point 4*. A prize draw will be held at the completion of Stage 2.

Please ride at least 10 metres apart from another other rider unless this is unavoidable (e.g. at an intersection).

Before we start you need to complete the form below, the Consent form, and the Survey.

Procedure Information

Name: _____

Please reply yes or no to the following statements

1. **I know the route that I am required to cycle in the study.**
Yes No

2. **There is nothing about riding in the study that I believe would place me at more risk than my usual riding.**
Yes No

3. **I participate in this study of my own accord and without coercion.**
Yes No

4. **I ordinarily cycle over similar road types.**
Yes No

5. **I understand that I need to obey all road rules as no extra traffic control measures are put on this route.**
Yes No

6. **I understand that the cycle activity is not a race**
Yes No

Consent Form

I enter into this study as a volunteer
(print name)

cyclist on the understanding, that;

1. The study is aimed at simulating cyclists travelling under a variety of road conditions.
2. The study is to be run on roads under normal conditions, without any additional traffic control (e.g. blocking motor vehicle traffic).
3. I will obey all road rules.
4. There is a level of hazard for cyclists under normal road conditions and because of this study I will be exposed to this normal risk.
5. My task will be to ride from the start to the finish point. If at any stage I consider I am at risk I will discontinue.
6. I am fully fit to perform the activity of cycling under these conditions and have no known impairment that will effect my ability to cycle or will be affected by my cycling.
7. I will be riding a cycle in good mechanical order for normal use.
8. I will wear a helmet when riding my cycle.
9. I have the right to withdraw from the study at any stage and for any reason.

.....
(Volunteer Cyclist)

.....
(Opus Staff Member)

...../...../.....

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Part I: Pre-cycle Survey

IMPORTANT POINTS

1. *There are no right or wrong answers*
2. *We value your opinion*
3. *If a question doesn't make sense then let us know, but try to answer by choosing the most appropriate response*
4. *We will not ask you to identify yourself for the survey, so your answers are entirely confidential*
5. *You may withdraw your participation at any point*
6. *You are entitled to a brief summary of the findings: you can obtain this by contacting us using the details above*
7. *There is a comments section at the end of the survey*

1. How many days do you cycle on sealed roads in a typical week?

- 0 1 2 3 4 5 6 7

2. Approximately how many kilometres do you cycle on sealed roads in an average week?

- | | |
|----------------------------------|--------------------------------------|
| <input type="checkbox"/> Under 1 | <input type="checkbox"/> 121-150 |
| <input type="checkbox"/> 1-30 | <input type="checkbox"/> 151-190 |
| <input type="checkbox"/> 31-60 | <input type="checkbox"/> 191-220 |
| <input type="checkbox"/> 61-90 | <input type="checkbox"/> 221 or more |
| <input type="checkbox"/> 91-120 | |

3. Approximately what is your average speed when cycling on sealed roads?

- | | |
|-------------------------------------|--|
| <input type="checkbox"/> 1-5 km/h | <input type="checkbox"/> 26-30 km/h |
| <input type="checkbox"/> 6-10 km/h | <input type="checkbox"/> 31-35 km/h |
| <input type="checkbox"/> 11-15 km/h | <input type="checkbox"/> 36-40 km/h |
| <input type="checkbox"/> 16-20 km/h | <input type="checkbox"/> 41 km/h or more |
| <input type="checkbox"/> 21-25 km/h | |

4. What is your best time for a 40km trial on a flat course? (if you have not done a time trial then estimate your best time for 40km and add the word "estimate").

Time:

Part II: Post-cycle Survey

Participant No _____

IMPORTANT POINTS

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1. Was your cycling behaviour during the study today typical of your normal cycling?

Yes No

If yes go to Question 4

2. How did your cycling behaviour differ from your usual cycling?

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3. Why did your cycling behaviour differ from your usual cycling?

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4. What aspects of your cycling behaviour do you believe we were interested in observing?

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