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The effects of line markings for wet/night visibility on cycle safety

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1. ABSTRACT

This study investigates the influence of 15 line marking types on cycle instability. Six paid participants completed more than one thousand runs over test lines using the same instrumented racing cycle. Recordings of lateral acceleration and handle bar angle were combined to form a single measure of instability relative to recordings of normal riding over smooth asphalt. New techniques to control for learning effects were used within an experimental procedure that controlled for the angle and speed of the cyclist. Findings compare the influence of line markings such as audio tactile lines, new structured markings, thermoplastic markings and traditional waterborne markings. Oversized thermoplastic lines (7mm thick) and audio tactile lines showed significant effects on the stability of cycles whereas traditional chlorinated rubber lines and waterborne line showed no significant impact on cycling. This research enables a relative assessment of the effect of line marking types on cycle stability.

2. INTRODUCTION

On most New Zealand roads a separate provision for cyclists is usually neither practical nor affordable, and as a consequence cyclists share road space, particularly the road shoulder. Cyclists are sometimes forced to share space with motorists because of parked cars, bridges, intersections; potholes; rough ground; gravel; and poor design or maintenance of the road shoulder. However, even the provision of an adequate road shoulder presents a conflict of needs for cyclists and motorists. For optimum safety cyclists require a well-defined, uninterrupted path of travel away from motorists (Khan & Bacchaus, 1995). Motorists also require a well-defined path, particularly in, wet, night conditions. The feature that defines the space for cyclists and motorists is the edge delineation or line marking. New markings designed for improved motorists' safety, such as audio tactile markings, and structured markings, may present a hazard to vulnerable road users such as cyclists. This induces a reluctance to apply new material in areas where they may provide benefits and the need to determine an objective way to evaluate the effect line markings types on cycle stability.

Road markings 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., Audio tactile line 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 cyclist but tend not to be durable, discolour with wear and present inferior retroreflectivity for motorists. Thermoplastic lines are durable, present superior retroreflectivity, but perhaps present a hazard to cyclists, most particularly when structured into a audio tactile marking designed to warn motorists crossing the edge line.

The present study examines a wide range of marking types for their effect on cycle stability. These include Rainline (designed for wet conditions), Audio tactile line and a new structured marking, used currently in Switzerland in snow conditions. Other road markings investigated include thermoplastic paint lines of heights raging from 2 mm to 7 mm, with visibead or drop on beads, and calcite. Waterborne paint and chlorinated rubber are not regarded as presenting any real impact on cycle stability but these markings are included to provide a comparison for the other line types.

Cyclists face a number of other objects in the cycle path that may affect cycle stability. Munster, Koorey, and Walton (2001) surveyed 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%) while a grouping of surface irregularities (e.g., potholes, uneven surface) were frequently cited (39%). There has been some examination of line markings in particular. Munster, Dravitzki, and Mitchell (1999) investigated the effects of thermoplastic lines on cycle stability with tests conducted by riding over thermoplastic lines at an approach angle of between 0 and 10%. The physical effects of the line on cycle stability were subjectively assessed by the cyclists and appraised by an observer. No detectable effects on cycle stability was found with thermoplastic lines markings below 2.1 mm. Effects were found for road markings around 4mm, and consistently observed for road markings above 7 mm in height.

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: torque on the handlebars, angle of the handlebars, vertical acceleration, and lateral acceleration. In the present study the angle of the handlebars and the lateral acceleration are measured because either or both of these will be affected if stability is compromised (Jones, 1970).

Using human participants introduces confounding factors that need to be controlled for into an experimental study. Participants might anticipate the effect of a line or learn how to ride over the test lines with repeated experience. If this were the case then the true effects on cycle stability would not be detected because they would be reduced and eliminated with learning. The results from such a study would underestimate the effect of an object on cycle stability and not generalise to a population of riders encountering the object for the first time. Participants riding behaviour also needs to be analogous to the riding behaviour of cyclists under road conditions for the results to generalise to roads conditions. In normal road conditions cyclists do a number of tasks such as avoid obstacles, look back for traffic, and brake.

In the present study the tasks that cyclists are asked to perform before encountering the object will be 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 are told whether they pass or fail 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 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 use in actual road conditions. These 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. Audio tactile line, 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.

3. METHOD

3.1 PARTICIPANTS

Six participants were involved in the research. Each of the participants rode over all 15 lines, 12 times and completed a number of trials over blank asphalt to establish a baseline of riding behaviour. Due to the time this entailed these participants were paid for their time.

3.2 MATERIALS

3.2.1 The cycle

Apart from the 15 lines and their attendant characteristics (as outlined in Table 1) the most important equipment used in this study is the instrumented racing cycle. A racing cycle is considered the most vulnerable of cycle types presently using the road network. The instrumented cycle had general purpose racing tyres of dimension 700 x 22/23C[1] and these were inflated to approximately 70 psi. Attached to the frame and steering pinion was a potentiometer to measure the angle of steering every 1/10 of a second. An accelerometer was mounted under the seat to measure lateral acceleration, again every 1/10 of a second. The cycle also carried a speedometer to assist the cyclist, though cycle speed was measured externally using two laser trip beams. A logger on the cycle recorded the main measures and these were synchronised to the hitting of the line by a single trip beam placed over the line

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

markings linked to a telemetric device. In this way measures of handle bar activity and lateral acceleration were recorded and matched to the position of the cycle.

A laser mounted to the frame provided a reference for the cyclists to determine direction, and direction was manipulated experimentally using a target board. To assist in ensuring the laser was visible in bright daylight conditions the target board was covered with reflective material, the same as that used for road signage. Cyclists could also choose to wear glasses that enhance the visibility of laser.

3.2.2 The course

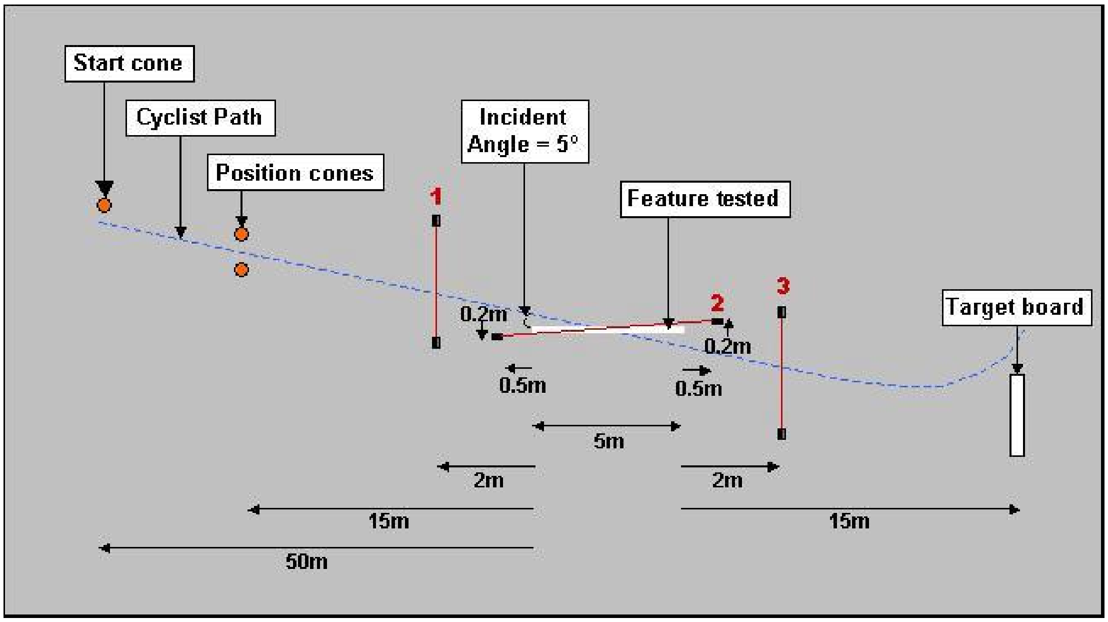

Figure 1. General layout of cycle course with measurements.

*Lines 1, 2 and 3 indicate the approximate positions of the laser trip beams.

Table 1. The road marking line types used in the experiment including a features of each and BPN to measure skid resistance: height in millimetres (mm), bead type, presence of calcite, and type of line.

Line	BPN	Height	Bead	Calcite	Line
	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	Audio tactile line
24	41	0.2	None	No	Waterborne Paint

3.3 PROCEDURE

Munster et al. (1999) noted that the angle of approach of 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 to lines at a 5° angle using cones and by aiming a cycle-mounted visible laser at a target board.

All lines were cycled over when wet. Water was applied to the line and to 2 m of the cycle path in front of the line, prior to each participant starting to ride the course.

Three tasks were designed to prevent a learning effect and to distract the cyclists from giving full attention to crossing the line. These tasks were intended to simulate real cycling actions, such as those required to check traffic when merging and braking to avoid obstacles. The tasks also helped to with the intended experimental control over the angle hitting the line.

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

(1) Target: cyclists were instructed to keep the frame-mounted laser pointer on the target board. At the end of the run a judge determined whether the participant "passed" or "failed" the task and this was told to the participant. A "pass" was scored if the laser was visibly on the target board when the cycle was just prior to the line marking (i.e., laser beam 2).

(2) Lookback: cyclists were instructed to look back and report the time indicated by a large clock held by the experimenter. On each run the experimenter changed the hands of the dial. Participants were told if they "passed" or "failed" the task. A pass was scored if the time given by the participant matched that on the clock card.

(3) Brake: After breaking the first laser beam participants were told "Brake". They were instructed that 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 the instruction "brake" was given. A pass was scored if the cycle braked on or before the line marking (i.e. laser beam 2).

A complete run required the cyclist to ride from the start position at speed aiming the laser pointer at the target board (in case of a request to 'target'), cross through the laser trip beams (to record speed and the time that the line was hit), traverse the line, perform the task requested, and return to the start position. After each run the riders were asked for a subjective evaluation of the influence of the line marking on ride stability. "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?" The entire procedure constituted a completed trial.

Each participant had 12 trials of the line marking, three trials with each task and three with no task. There were 20 randomised orders that the tasks were presented. An order of task presentation for each of the 12 trials over a line was randomly selected from this list prior to participant beginning to cycle. The main dependent variables derived from the physical recordings of the instrumented bike were trimmed to 1.5 seconds prior to the line synchronisation record and 1.5 seconds post this 'time stamp' to obtain before and after records for each run. These data were then averaged for the three runs of each task.

4. RESULTS

3.1 BASELINE

A section of asphalt without a marked line was used as a baseline condition. Repeated measures Analysis of Variance (ANOVA) contrasts showed that before and after measures for average handle bar position ($F(1, 24) = 49.618$, $p < .05$), average acceleration of cycle ($F(1, 24) = 8.150$, $p < .05$), range of handlebar position ($F(1, 24) = 42.486$, $p < .05$) and after range of acceleration of cycle ($F(1, 24) = 7.304$, $p > .05$) were significantly different. This was expected as before hitting the second laser beam participants were targeting the laser on the target board and after they were altering their path to avoid the target board and proceed back for the next trial. In effect the cycle path curved to the left after the second laser beam rather than remaining straight. This means that the effects of line type cannot be determined solely from differences between before and after measures. Instead the difference between before and after measures for a line need to be assessed relative to the difference between before and after for the baseline condition.

3.2 EFFECTS OF OBJECT TYPE ON A COMBINED MEASURE OF CYCLE STABILITY

Previous analysis determined that the average handle bar position, the average acceleration, the range of handle bar position, and the range of acceleration are distinct factors.[2] Any measure of overall cycle stability should take into account all

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[2] This work is available from authors upon request.

these distinct factors (see Jones, 1970). These measures though need to be combined in a fashion that permits objects to be ranked in terms of their effect on cycle stability. There is no previous work that enables ready derivation of one measure from the measures collected. However with some assumptions a measure can be calculated.

When cycling on a level piece of even asphalt a cycle can be assumed to be in a normal and stable state. Under this condition there will be average handle bar position, an average lateral acceleration, a normal range of handle bar position, and a normal range of lateral acceleration. The relative contribution of these four measures to the stable state can be ascertained by forcing the derivation of one factor (cycle stability) using a principal components factor analysis and looking at the factor coefficients of the measures. Assuming that the measures contribute the same to cycle performance in an unstable state as they do in a stable state the factor coefficients can 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 data from before the lines are shown in Table 2. The before line data was regressed against the after line data for each measure to obtain residuals free of variance due to differences before the line. 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. 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 position before the objects.

Component	**Coefficient**
Average handle bar position	-.458
Average acceleration of cycle	.386
Range of acceleration of cycle	.427
Range of handle bar position	.348

Table 3 shows the results of univariate ANOVA's comparing the combined measure for each object and the baseline condition. It can be seen that 11 of the 15 line markings resulted in a significantly higher mean of the combined measure than baseline. The means are ordered by the difference between the baseline and line marking means from negative to positive. A negative number indicates that a line marking has an adverse effect on stability. It can be seen that although the 7 mm in height line markings create some of the greatest instability in comparison to other line markings, 3 mm and 3.5 mm height lines also appear to create considerable instability. Instability does not appear to be a simple function of height.

Table 3. ANOVA comparisons for the combined measure, each line compared to baseline. Shown is the difference when each mean is subtracted from baseline, the standard error, and significance. Lines are ordered by mean difference from negative to positive.

LN	Type	Height	Beads	Calcite	BPN	MD	SE
11	Thermoplastic	7	None	No	67	-.179***	0.035
2	Thermoplastic	3.5	Visibeads	Yes	58	-.120***	0.028
16	Thermoplastic	7	Dropon	Yes	57	-.118**	0.039
22	Audio tactile line		None	No	59	-.104**	0.034
12	Thermoplastic	3	Dropon	Yes	54	-.103**	0.034
17	Thermoplastic	4.5	Dropon	Yes	58	-.0997*	0.041
14	Waterborne Paint	0.5	Dropon	No	50	-.0992***	0.024
13	Thermoplastic	3.5	None	No	70	-.07616*	0.033
19	Structured Marking	3	Dropon	No	68	-.06596**	0.019
9	Waterborne Paint	0.5	Visibeads	No	52	-.06178*	0.026
21	Rainline		None	No	91	-.06178*	0.024
8	Thermoplastic	2	None	No	63	-0.02649	0.027
24	Waterborne Paint	0.2	None	No	41	-0.012	0.017
4	Waterborne Paint	0.5	Visibeads	Yes	59	0.03215	0.016
10	Chlorinated Rubber	0.2	None	No	46	0.03874	0.021

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

Baseline asphalt is one comparison that can be used to assess the relative effect of a line marking. However lines can also be compared to each other. Table 4 shows ANOVA comparisons for the combined measure with each line marking compared to the audio tactile line and is ordered by the difference between the audio tactile line and line marking means from negative to positive. A negative number indicates that a line marking causes more instability than the audio tactile line. It can be seen that the baseline, waterborne paint lines 24 and 4, and the chlorinated rubber line 10 all cause significantly less instability than the audio tactile line.

Table 5 shows the results of ANOVAs for the participant rating of each object compared with baseline, 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 the participants rating of stability. Across all objects participants 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 (Rs (20) = .880, P < .05).

Table 4. ANOVA comparisons for the combined measure, each line 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. Lines are ordered by mean difference from negative to positive.

LN	**Type**	**Height**	**Beads**	**Calcite**	**BPN**	**MD**	**SE**
11	Thermoplastic	7	None	No	67	-0.07517	0.046
2	Thermoplastic	3.5	Visibeads	Yes	58	-0.01647	0.042
16	Thermoplastic	7	Dropon	Yes	57	-0.0143854	0.05
12	Thermoplastic	3	Dropon	Yes	54	0.00026526	0.046
17	Thermoplastic	4.5	Dropon	Yes	58	0.0038893	0.051
14	Waterborne Paint	0.5	Dropon	No	50	0.004425	0.039
13	Thermoplastic	3.5	None	No	70	0.0274672	0.045
19	Structured Marking	3	Dropon	No	68	0.037668	0.036
21	Rainline		None	No	91	0.0418387	0.039
9	Waterborne Paint	0.5	Visibeads	No	52	0.04184	0.04
8	Thermoplastic	2	None	No	63	0.07712	0.043
24	Waterborne Paint	0.2	None	No	41	.091529*	0.035
3	Baseline Asphalt				72	.104**	0.034
4	Waterborne Paint	0.5	Visibeads	Yes	59	.136***	0.035
10	Chlorinated Rubber	0.2	None	No	46	.14237***	0.037

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

Table 5. ANOVAs for the mean participant rating of each line marking compared with baseline. Shown is the difference when each mean is subtracted from baseline, the standard error, and significance.

LN	Type	Height	Beads	Calcite	BPN	**MD**	**SE**
16	Thermoplastic	7	Dropon	Yes	57	-1.444**	0.467
22	Audio tactile line		None	No	59	-1.347***	0.348
17	Thermoplastic	4.5	Dropon	Yes	58	-1.306**	0.443
2	Thermoplastic	3.5	Visibeads	Yes	58	-1.292**	0.415
13	Thermoplastic	3.5	None	No	70	-1.097**	0.383
11	Thermoplastic	7	None	No	67	-1.083**	0.344
12	Thermoplastic	3	Dropon	Yes	54	-1.042*	0.408
21	Rainline		None	No	91	-.917**	0.311
24	Waterborne Paint	0.2	None	No	41	-.705*	0.347
8	Thermoplastic	2	None	No	63	-.658*	0.314
14	Waterborne Paint	0.5	Dropon	No	50	-0.556	0.316
10	Chlorinated Rubber	0.2	None	No	46	-0.5	0.264
19	Structured Marking	3	Dropon	No	68	-0.486	0.259
9	Waterborne Paint	0.5	Visibeads	No	52	-0.278	0.185
4	Waterborne Paint	0.5	Visibeads	Yes	59	-0.111	0.139

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

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 ($t = 1.183$, $p > .05$), the presence or absence of beads ($t = -1.444$, $p > .05$), and the presence or absence of calcite ($t = 1.635$, $p > .05$) did not account for a significant amount of the variance of the combined measure. Height accounted for accounted a significant amount of the variance ($t = 5.085$, $p < .05$).

A similar regression was performed for the thermoplastic road markings only (11, 13, 2, 16, 12, 17, and 8). For these lines the presence or absence of beads correlated precisely with the presence or absence of calcite. Whether beads were present or not was excluded from the regression The BPN ($t = .199$, $p > .05$) and the presence or absence of calcite ($t = -.316$, $p > .05$) did not account for a significant amount of the variance of the combined measure. Height accounted for a significant amount of the variance ($t = 2.366$, $p < .05$). Height appears to be the only measured physical characteristic that plays any role in cycle stability.

5. DISCUSSION

Many guidelines are available for dedicated cycle paths (e.g., Austroads, Part 14) but what is needed in NZ are guidelines to establish limits for the road design that are at least tolerable for safe cycling but are balanced with motorists' needs and affordability.

Height is used in the current NZ standards for road markings. The sample of fifteen different road markings that was investigated in the present study had a variety of heights. It can be seen that the 7 mm height lines are amongst those road markings that cause the most instability but there are 3 and 3.5 mm road markings that also cause a significant level of instability. The data suggests that the current 4 mm standard does not appear to fully account for the effect road markings have on cycle stability. When examining the characteristics of the lines that contribute to instability it is found that bead type, skid resistance and the presence of calcite are not significant compared to the height of the line.

Four types of road markings 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 .2 mm and .5 mm in height (one with visibeads and calcite and one without beads and calcite), and a .2 mm chlorinated rubber line. Because these lines create no more instability than asphalt they do not represent a hazard to cyclists, when assessed under these testing conditions.

The measure of cycle stability used here enables relative comparison. It does not allow for absolute statements about the safety of a particular line marking except for those that do not differ significantly from baseline. To be able to make safety related conclusions in an absolute sense would require a relationship between the combined measure and the probability of accident. Such a relationship would have to be established with real riders because cycling is a dynamic interaction between cyclists, cycle, and environment. The risk to participants precluded this in the present study.

Participants were told to perform one of three tasks, or told nothing, on each trial. One of the reasons for this was to prevent the learning of how to ride across lines from influencing the results. If learning had influenced the results in a substantial way here then differences in stability across objects would have been masked. Clear differences across objects were found here. Thus it is unlikely that learning effects influenced the results.

Further opportunity for research involves the examination of a wider range of roadside obstacles, such as catseyes, gravel, rough surfaces, potholes, puddles and utility covers. Also, here is a need to understand cyclists' management of the hazards that are identified objectively through these sorts of testing procedures. It is still unclear how cyclists recognised and respond to common features of the roadside that have a detectable significant affect on stability.

6. CONCLUSIONS

The method developed produced clear findings on the relative effects of different line markings. An assessment of the line markings effects on cyclists suggests the current four-mm standard for thermoplastic lines is probably a little too liberal because clear effects are observed for 3.5 mm thermoplastic lines. The audio tactile line has a detectable effect on cycle stability, it is amongst the poorest performers and is recognised by the cyclists as inducing a significant effect. Alternate lines, such as the new structured marking from Switzerland and the more traditional Rainline performed well, even though they produce noticeable effects they are preferred by cyclists and score better than alternatives such as thermoplastic lines and non-structure markings.

Because the road features that cause cycle instability are numerous and vary along a number of dimensions further work is required. The method could also be used to explore how other cycle and cyclists' factors affect stability. More research using this method will enable precise specifications to be developed for the design and maintenance of cycle-safe environments.

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