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TfL Cycle Facility Trials: Alternative Separation Methods for Cycle Lanes

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Contents

Executive summary

Introduction

Transport for London (TfL) commissioned the Transport Research Laboratory (TRL) to conduct a series of trials to examine the impact of different methods of cycle lane separation on the behaviour and safety of road users (inc. cyclists, car drivers, motorcyclists, HGV drivers and pedestrians). The methods of separation investigated were:

1. a kerb with 365 mm hard margin (full continuous segregation with physical barrier);

2. bolt-on delineators: the Zicla Zebra 9™ (a type of intermittent separation with low-profile barriers positioned in 2.5 m intervals);

3. 1-m high marker posts: Jislon™ 'wands' (intermittent separation with high-profile barriers positioned in 2.0 m intervals)

In addition, a painted solid white line (mandatory cycle lane line, continuous separation with no physical barrier) was used to provide an experimental baseline, enabling researchers to control for differences between different groups of participants on different trial days.

Objectives

Cyclist and driver trials aimed to determine the extent to which the method of cycle lane separation influenced:

- the behaviour (in particular speed and position in the lane); and
- perceptions of road users, with a focus on usability (i.e. understanding of the cycle lane markings and ease of navigating the route) and perceptions of safety.

Pedestrian trials aimed to determine the extent to which the method of cycle lane separation influenced the perceptions of pedestrians when crossing the road.

Method

Each separation method was trialled on a separate day, so each trial day represents a different sample of participants. Each group of participants experienced the white line separation on one section of the TRL test track and only one out of the three physical separations on a different part of the track. For each day, therefore, comparisons were made between the white line separation and the method of physical separation. To directly compare the three types of physical separation tested on different days (i.e. the treatment conditions), difference scores were calculated relative to the ratings of the white line separation (i.e. the control condition):

Difference score = Treatment score – Control score

Thus, a positive difference indicates that the physical separation (the treatment) received higher scores than the white line separation (the control). The conclusions

summarised below and throughout this report are related to difference scores for each of the three physical separation methods.

Key findings

Key statistically significant findings[1] have been reported so as to provide direct conclusions relating to each road user group.

In general, cyclist, driver and pedestrian ratings of perceived usability and safety were high for all separations (wands, Zebras, kerb and white line) indicating that all four methods were viewed as fairly safe and fairly easy to use. Nonetheless, statistically significant differences were found between the methods, indicating small but distinct variations in the perceptions and behaviour of the different road users. Such variations may have design implications when implementing integrated and segregated cycle lanes.

Low profile intermittent separation: Zicla Zebras

- Of the three physical separations investigated, intermittent separation provided by the Zebras was found to offer the smallest improvements to the perceived usability and safety of cyclists and car drivers.
- For motorcyclists and HGV drivers, the Zebras (unlike other forms of physical segregation) were perceived to be less safe and harder to navigate past than a painted white line. For example, ratings of safety for the Zebras were 4-5% lower for motorcyclists and 15% lower for HGV drivers compared to ratings for the white line. This observation is consistent with qualitative comments reported by motorcyclists indicating they considered themselves at greater risk of collision with the Zebra separation.

Full continuous separation: Kerb with 365-mm hard-margin

- The use of a solid kerb was preferred over a painted white line by cyclists and car drivers, but not by motorcyclists or pedestrians. For example, riding past the kerb separation was rated about 8% more difficult and 5-8% less safe than riding past the white line separation by motorcyclists.
- Evidence from motorcyclists' chosen riding path supports the conclusion that they were more aware of a risk of injury from collision with the kerb, thereby increasing the cognitive load of the riding task and reducing their perceptions of safety. When calculated against a standardised baseline, the lateral position of motorcyclists indicated that they travelled, on average, around 230 mm further from the edge of the kerb than from the edge of Zebras and around 110 mm further than from the edge of the wand separation.
- Due to perceived increased difficulty of crossing the road and reduced safety when crossing a road with a kerb separated cycle lane, the kerb was also rated as least favourable for pedestrians compared to the white line separation.
- Difference scores related to the perceived safety of cyclists were larger for the kerb (mean, M = 0.75) than the Zebras (M = 0.25), indicating that perceived safety was greater with the kerb.

[1] 'Statistically significant' indicates any pattern or relationship in the data that has a probability of occurring by chance of less than 5% (i.e. $p < 0.05$).

- Consistent with this finding, cyclists travelled an average of approximately 100 mm closer to the kerb than to the Zebras; this supports evidence from questionnaire ratings showing an increased perception of safety when protected by a kerb.

High profile intermittent separation: Jislon wands

- The Jislon wands were the only physical separation method which offered improved perceptions of safety and usability over white line separation for all road users (except pedestrians where no significant differences were identified).
- Difference scores related to cyclists' perceived safety of wand separation (M = 0.54) were significantly larger than those for intermittent Zebra separation (M = 0.25), but were not significantly different than those for kerb separation (M = 0.75). This indicates that perceived safety was greater with the wands.
- Cyclists travelled closer to the wand separation than to the other separation methods. Calculation of lateral position against a standardised baseline indicated cyclists passed on average up to 280 mm further away from the Zebras and around 100 mm further away from the kerb separation.
- The lateral position of vehicles showed that car drivers, motorcyclists and HGV drivers allowed a clearance from the wand separation around 230 mm, 120 mm and 170 mm greater, respectively, than from the Zebras. Motorcyclists also travelled around 110 mm closer to the wands than the kerb.

Conclusions

Comparison of the alternative methods of cycle lane separation revealed statistically significant differences in the speed and road position of cyclists and drivers, and in their perceptions of usability and safety. However, the extent of those differences was not so large as to raise fundamental objections to the use of any one method. Cyclists rode in fairly central positions in the lane with all separation methods, and at similar speeds. Importantly though, the width of the separation methods differs substantially, ranging from 100 mm wide for the wands to 365 mm for the kerb. The latter would normally be 500 mm wide so as to provide a physical 'buffer' between cyclists and vehicles with large wing-mirrors (such as HGVs and buses). There are clearly great savings in the road space required to install the intermittent methods. However, implications of reducing the width of this buffer must be considered, especially given the observation that cyclists rode closer to the wands (suggesting they made greater use of the available width).

Of the separations investigated, continuous kerb separation and intermittent wand separation may offer the greatest benefits to cyclists. Whilst intermittent Zebra separation offers some benefits for the safety and usability of cyclists compared to a painted white line, the extent of those benefits is smaller than with other physical separations.

The wands were the only physical separation method which showed increases in the perceived safety and usability of motorcyclists and HGV drivers compared to the white line separation. Zebra and kerb separation was found to decrease the ease of navigating the route and reduce feelings of safety for motorcyclists. Given the limitations of any off-street trial, it cannot be assumed that the same findings would be replicated in a real street environment, so further study through *on*-street trials is needed before definitive design recommendations can be made.

1 Introduction

Traditional methods for segregating cyclists from traffic have tended to involve either taking cyclists off the carriageway completely, sharing space with pedestrians (which can lead to loss of priority as well as other difficulties), or significant infrastructure construction for methods such as kerb segregation within the carriageway. This requires a lot of road space, which can limit the choice of locations where it can be installed, as well as having significant implications for drainage, maintenance, road sweeping and gritting etc. For these reasons there has been recent interest in so-called 'light' methods for separating cyclists from the traffic, which utilise a variety of different forms of intermittent features (such as blocks, planters, or bolt-on delineators), vertical barriers, or 'wands' (such as bollards or marker posts), or enhancement of conventional lane markings (such as rumble strips and reflective studs). 'Light' methods require less space, and are therefore able to be more widely used, without interfering with drainage and also, by virtue of not creating a continuous barrier, enable cyclists to leave the separated cycle lane should they need to do so (for example, when turning right at junctions). However, consideration must be given to how cyclists and other road users will respond to such facilities, for example, how do light methods affect perceptions of comfort and safety, and what impacts do they have on the chosen position of road users in the lane?

As part of a wider programme of off-street trials of innovative cycling infrastructure, the Transport Research Laboratory (TRL) was commissioned by Transport for London (TfL) to examine the impact of different methods of cycle lane separation (see Table 1) on the behaviour and safety of a) cyclists, b) other road users (i.e. car drivers, motorcyclists and HGV drivers), and c) pedestrians. Following an initial review of literature on separation methods, which was mostly international guidance, it was decided to carry out off-street trials of two examples of intermittent separation, one high-profile and one low. The objective was to compare these with full segregation (via a solid kerb) and a white-line only mandatory cycle lane, representing 'traditional' approaches to separation. While variants on these basic approaches also exist, such as using reflective studs and textured markings, it would be expected that user responses would lie within the range of the methods tested.

The key research questions examined in these trials were:

- *What impact did the method of cycle lane separation have on usability?*
- *What impact did the method of cycle lane separation have on safety?*

It was also of interest to understand the influence of the presence of other road users (i.e. the vehicle interaction) on cyclist behaviour and safety, specifically:

- *What impact did the vehicle interaction have on cyclist usability?*
- *What impact did the vehicle interaction have on cyclist safety?*

Each of the alternative methods of cycle lane separation were presented to participant cyclists, car drivers, motorcyclists and HGV drivers who were asked to travel along a set route on the TRL test track. The route was split into two sections of road; one with a mandatory cycle lane marked with a painted white line (i.e. the control condition) and one with a cycle lane separated by one of the three physical methods (i.e. a kerb, wands, or Zebras). Each participant took part in one trial day only, so they all experienced the white line separation and only one of the three physical separations. Whilst the method of physical separation was varied between the trial days, the white

line separation remained unchanged across all trial days, thereby enabling a consistent reference on which to base all comparisons between the three physical methods. This was crucial to the design of the trial, necessary to control for confounding factors relating to variability between the different groups of participants who took part on different trials days. Hence, when comparisons are made between the three methods of physical separation, this is done by comparing results from three different sets of participants, each using the same section of track; while comparisons between white line separation and each physical separation involves comparing results from the same group of participants, but on different sections of track.

Table 1 Methods of separation tested in trials.

Type of separation	Method used		Notation used in this report	Type of trial variable
Continuous separation with no physical barrier	Solid painted white line		'white line'	Control
Continuous segregation with a physical barrier	Kerb with 365 mm[2] hard margin		'kerb'	Experimental/ Treatment
Intermittent separation with low profile barriers	Zicla Zebra 9™ bolt-on delineators (a.k.a. 'armadillos')		'Zebra'	Experimental/ Treatment
Intermittent separation with high profile barriers	1-m high marker posts: Jislon™ wands		'wand'	Experimental/ Treatment

The main objective of the trials was to determine the extent to which the method of cycle lane separation influenced the behaviour (in particular speed and position in the lane) and perceptions of road users, with a focus on usability (i.e. understanding of the cycle lanes and ease of navigating the route) and feelings of safety. Data for the three

[2] Standard specification for solid kerb segregation indicates a hard-margin of 500 mm, however this width could not be achieved for the trials due to space constraints on the test track.

physical separation methods (i.e. the treatment conditions) are presented relative to data obtained for the white line separation (i.e. the control condition). The influence of specific interactions between vehicles and cyclists at the entrance, the middle and the exit of the cycle lanes was also examined.

Data were provided by questionnaires administered on-track during the trial and off-track after the trial, and by traffic counters located on the trial route. The Appendices describe the data handling and statistical analysis used for this study. Statistical analysis of the questionnaire and traffic counter data has enabled identification of findings that are 'statistically significant' (i.e. any pattern or relationship in the data that has a small probability of occurring by chance). It is commonly accepted that if a finding has occurred with a confidence level of 95% or more, then it did not occur by chance (i.e., $p < 0.05$), and it is statistically significant. Sometimes the probability of a chance finding will be less than 5% and this is expressed accordingly (e.g. $p < 0.001$ means probability was less than 0.1%). Full results from the statistical analysis are available in the Appendices.

Analysis of qualitative reports given by participants (e.g. for some questions in the off-track questionnaire participants were asked to give free text answers), focused on identification of common themes in responses based on the subject of discussion, the type of separation method or the type of road user.

The purpose of this report is to present the **key statistically significant findings** and **common qualitative themes** from the trials so as to provide direct answers to the four research questions. **Non-statistically significant results have not been discussed.** Section 2 deals with results related to cyclists, section 3 presents the results related to other road users and section 4 presents the findings from the pedestrian trial. The results are summarised and implications are discussed in section 5. Information regarding the participant sample, the research methodology, example questionnaires used for data collection, photographs of the trial sites and full details of statistical analysis used for this study and the associated statistical output can be found in the separate Appendices document.

2 Cyclists

2.1 Introduction

This section presents the findings from the cyclist behaviour trials, which investigated the influence of the method of cycle lane separation on the user behaviour and safety of 241 participant cyclists. The influence of specific interactions with cars whilst using the cycle lanes was also examined.

Usability (i.e. understanding of the cycle lanes and ease of navigating the route) and perceptions of safety were assessed via several means. During the trial, an on-track questionnaire was used to obtain ratings related to the comprehension of cycle lane markings, the ease of using the cycle lane, and perceptions of safety. These topics were also further assessed using an off-track questionnaire after each trial session. Traffic survey tubes were used to record the speed and lateral position of cyclists using the cycle lanes under different traffic conditions. This section collates data from all three of these sources in order to establish key findings for the cyclist user group. Comparisons have been drawn between the physical and non-physical separation methods (i.e. white line vs. wands/Zebras/kerb) and between each of the three physical separation methods (i.e. wands vs. Zebras vs. kerb).

2.2 What impact did the method of cycle lane separation have on cyclist usability?

2.2.1 Ratings of understanding the cycle lane markings

2.2.1.1 Physical separation vs. no physical separation

In this section, and elsewhere in the report, the term 'cycle lane markings' is used to refer to the structure and composition of the cycle lane separation (e.g. the presence of a solid kerb) and is not strictly limited to painted markings or signage.

Whilst the cyclists were on-track, they were asked to rate **the ease of understanding the cycle lane markings after their first encounter** with the white line separation and the physical separation. Cyclists' responses revealed no significant differences between the white line separation and any of the physical separation methods (i.e. wands, Zebras, or kerb), suggesting their **'first impressions' of the markings were comparable between physical and non-physical separation**.

An off-track questionnaire was used to probe further into cyclists' views on various aspects of the cycle lane markings, including how clearly the markings identified the cycle lane and conveyed understanding of how to proceed, and how easy or difficult it was to understand where the cycle lane began and finished. Some significant differences in perception of the markings were identified from the off-track questionnaire. In general, mean ratings were quite high (> 3, where 5 is the top of the scale indicating 'very clear', or 'very easy' to understand), indicating cyclists found it fairly easy to understand the markings. However, compared to non-physical separation (i.e. the white line), statistical analysis revealed that:

- Markings on the cycle lane separated by a kerb resulted in clearer identification of the cycle lane and more clearly showed how to proceed onto and through the cycle lane.
- Cyclists found it significantly easier to understand where the cycle lane began and finished with the wand separation than with the white line.
- It was easier to understand where the cycle lane finished with the Zebras than with the white line.

Overall, responses to the off-track questionnaire show that the markings on the cycle lanes separated by physical methods (i.e. wands, Ziclas and a kerb) were clearer and easier to understand than those on the cycle lane separated by a painted white line. It is particularly clear that cyclists found it easier to understand where the cycle lane finished for all physical methods of separation compared to the cycle lane separated by only a white line, with the greatest improvements in understanding found for the wand and kerb separation methods. These results suggest that the use of physical separation methods may help to clearly differentiate the cycle lane from the main carriageway.

2.2.1.2 Effect of the type of physical separation

Each separation method was trialled on a separate day, meaning each trial day represents a different sample of participants. Each group of participants therefore experienced the white line section and only one out of the three physical separation methods. To directly compare ratings of the cycle lane markings across each of the types of physical separations (i.e. across different days) scores were calculated relative to ratings of the markings on the white line separation (a.k.a. 'difference scores', see Equation 1).

Equation 1:	*Difference score = Treatment score - Control score*

…where the Treatment Scores were ratings for the physical separation methods (i.e. wands, Zebras, kerb) and the Control Scores were ratings for the non-physical separation (i.e. the white line).

Ratings from the on-track questionnaire obtained cyclists' 'first impressions' and analysis showed no statistically significant differences in the difference scores between the cycle lane separated by wands, Zebras, or a kerb.

The off-track questionnaire allowed participants to make a more reflective assessment of the cycle lane markings. Mean difference scores for the off-track questionnaire ratings of the cycle lane markings are shown in Figure **1**. As the difference scores are all positive it is clear that cyclists rated all three physical methods higher than the white line, scoring on average 0.04 to 0.45 higher than the white line. Statistical analysis revealed the following statistically significant findings:

- Ratings of ease of identification of the cycle lane markings were higher for the **kerb separation** (mean difference score, M = 0.23) than the Zebra separation (M = 0.07) and the wand separation (M = 0.04)
- Markings at the entrance and the exit were easier to understand on the cycle lane separated by wands (M = 0.36 and 0.45, respectively) than equivalent markings with Zebra separation (M = 0.10 and 0.17, respectively).

- Markings at the entrance were rated higher for the wands (*M* = 0.36) than the kerb (*M* = 0.05).

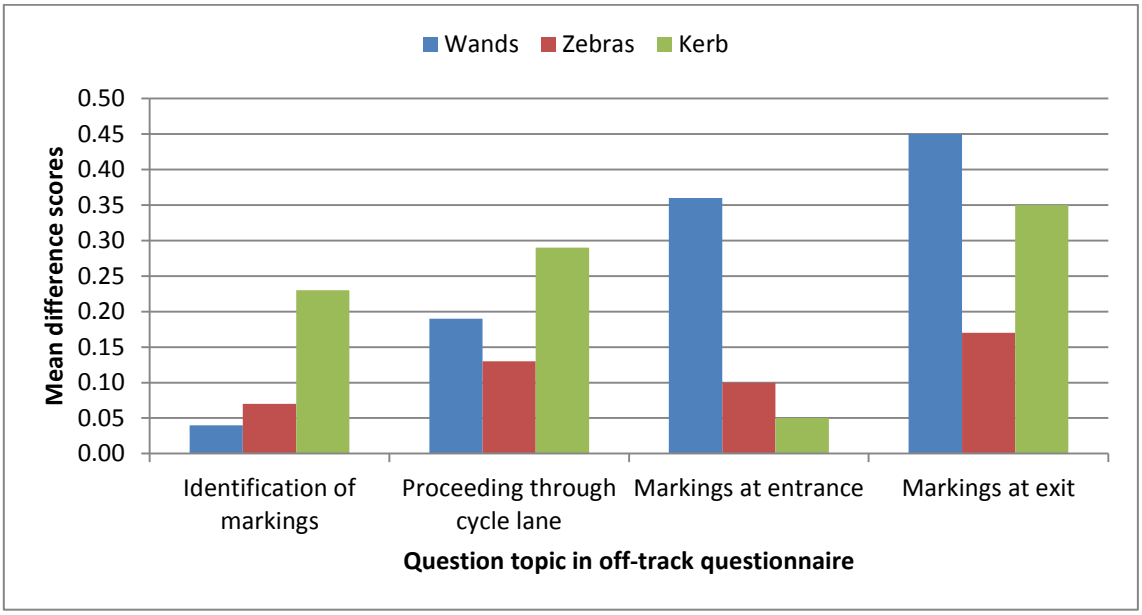

Figure 1 Mean difference scores for off-track questionnaire ratings of cycle lane markings for each method of separation (positive difference indicates physical method rated higher than white line).

On-track questionnaire ratings obtained cyclists' 'first impressions' whilst off-track questionnaire ratings allowed a more reflective assessment. Significant differences were only found for off-track questionnaire ratings, indicating that the method of physical separation influenced the perception of the cycle lane markings, but that there may be little impact on behaviour when actually using the cycle lanes, at least for the first time.

Overall though, results indicate that:

- The continuous barrier of the kerb separation enabled easier identification of the cycle lane than either the Zebras or wands, but:

2.2.2 Ratings of ease of using the cycle lane

2.2.2.1 Physical separation vs. no physical separation

During the trial cyclists were asked to rate the ease of using the cycle lane with the white line separation and the physical separation.

Analysis of these ratings revealed that physically separated cycle lanes were, in general, easier to use than the cycle lane separated by a white line.

Specifically, the wand separation and the kerb separation were rated as significantly easier to use than the cycle lane separated by a white line, but no significant differences were found between the Zebras and the white line.

From the off-track questionnaire, the wand separation was also rated as easier to use (with one car present) than the cycle lane separated by a white line. Likewise, the kerb

separation was rated as easier to use (with one car present and in scenarios with busy town centre traffic) than the white line separation.

Overall, the cycling task was easier when the cycle lane was separated by either 1m high wands or a solid kerb with a 365 mm hard margin than when separated by a painted white line. No differences in the ease of use were found between the Zebras and the white line separation. The improvement in usability associated with kerb separation was particularly evident when respondents were asked to imagine using the cycle lane in busy town centre traffic.

2.2.2.2 Effect of the type of physical separation

As with the analysis of cycle lane markings, direct comparison between ratings of the ease of using the cycle lanes for each of the physical separation methods was performed by calculating scores relative to the ratings of the white line separation (see Equation 1, above). This was necessary because each separation method was trialled on a separate day with different groups of participants.

Statistical analysis revealed no significant differences in on-track questionnaire ratings of ease of using the cycle lane between any of the physical separation methods. Mean difference scores for the off-track questionnaire ratings are shown in Figure 2. As the difference scores are all positive it is clear that cyclists considered all three physical methods to be easier to use than the white line, scoring on average 0.01 to 0.51 higher than the white line. Statistical analysis revealed significantly higher difference scores for ratings of ease of using the cycle lane (in conditions of busy traffic) for the kerb separation (M = 0.51) than both the wand separation (M = 0.1) and the Zebra separation (M = 0.07).

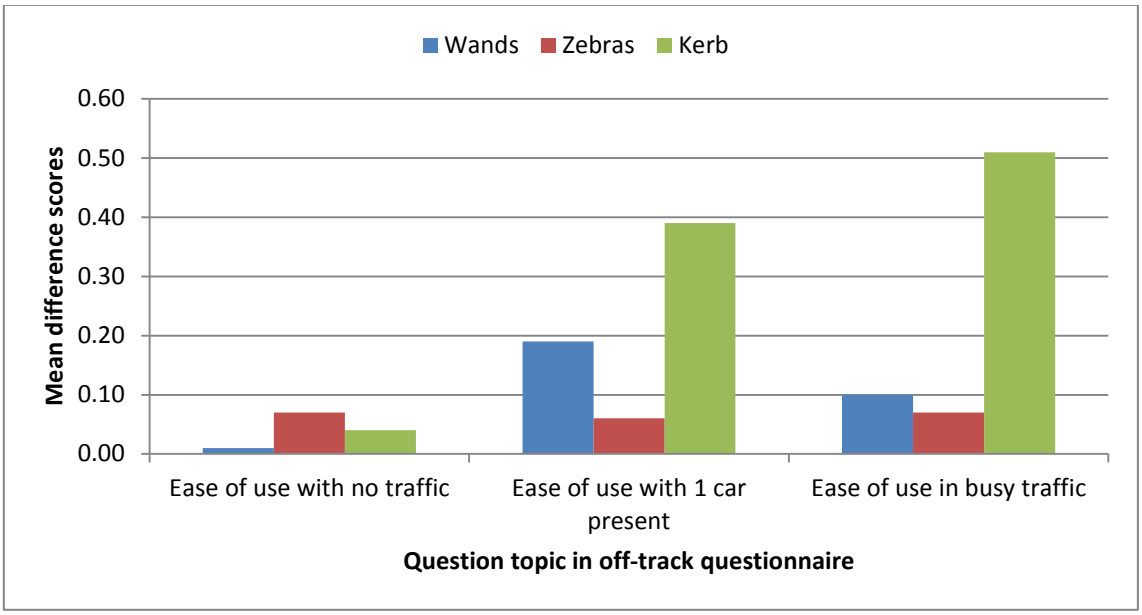

Figure 2 Mean difference scores for off-track questionnaire ratings of ease of using the cycle lane for each method of separation (positive difference indicates physical method rated higher than white line).

Overall then, there is some evidence to suggest that cycling in conditions of busy traffic was considered an easier task when using a cycle lane continuously separated by a solid kerb than by other intermittent separation methods (as indicated by responses to the off-track questionnaire) when respondents were asked to imagine using the lane in busy traffic.

2.2.2.3 Cyclist speed

The speed of cyclists (m/s) when using each of the physical separation methods (wands, Zebras, kerb) was compared using the white line separation as a baseline measure, as shown in Equation 2:

Equation 2:	*Speed difference = Treatment speed - Mean control speed*

…where the treatment speeds were individual speeds (m/s) measured on the physically separated cycle lanes (i.e. wands, Zebras, kerb) and the mean control speeds were the mean speeds (m/s) measured on the non-physically separated cycle lane (i.e. the white line). Negative speed differences indicate that the speed of cyclists using the physically separated cycle lanes was lower than when using the cycle lane separated by a white line; almost all speed differences were negative as the white line cycle lane was positioned on the same downhill slope and the physically separated lanes on the same uphill slope. However, it is the relative differences between the three methods which are important, as the slopes were the same for all trial days.

Figure 3 shows the mean differences in cyclist speed for the entrance, the middle and the exit of each cycle lane (the mean speed difference measured at the middle of the kerb separation is not shown due to missing traffic counter data). The differences in speed are greatest at the exit of the cycle lanes; likely because this location was at the bottom of a slope on the control lane and at the top of a slope on the treatment lane.

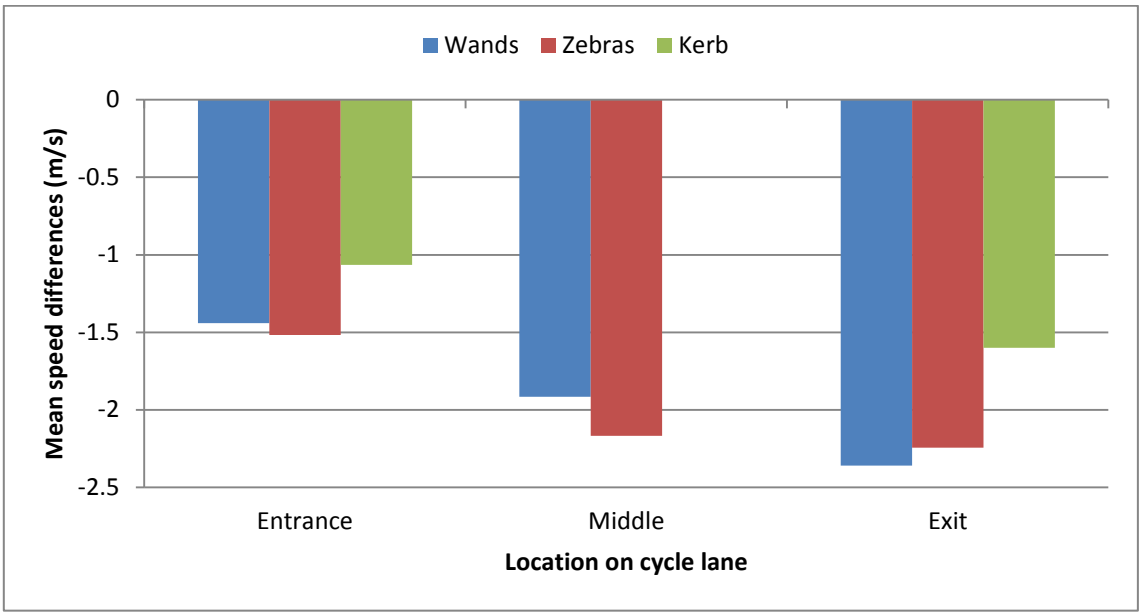

Figure 3 Mean speed differences for each physical method of separation (Positive differences indicate speed was greater with physical separations than the white line, negative differences indicate the opposite).

Statistical analysis revealed small but statistically significant effects of the type of physical separation on cyclist speed at all three locations on the cycle lane.

The differences in the speed of cyclists shown in Figure 3 may be equated to absolute speeds by normalising the means relative to a baseline. Table 2 shows these speed measurements under the assumption that this baseline is equal to 7 (i.e. a speed of 7 m/s when using the white line separation). A value of 7 was selected for the baseline on the grounds that it is comparable to the mean speed of cyclists using the white line cycle lane.

Relative to this baseline, cyclists were, on average:

- 1.0-1.4 mph faster (depending on the measurement location, i.e. entrance, middle, exit) when using the kerb separation than when using the Zebra separation, and;
- 0.9-1.7 mph faster (depending on the measurement location, i.e. entrance, middle, exit) when using the kerb separation than when using the wand separation.

As shown in Table 2, cyclists were slowest when using the Zebra separation, although this was only slightly slower than when using the wands.

Table 2 Mean absolute speed (ms^{-1} / mph) of cyclists in each cycle lane, normalised to a mean speed of 7 ms^{-1} on the white line cycle lane.

Measurement location	Normalised absolute speed (ms^{-1} / mph) [White line (i.e. 7 ms^{-1}) + mean difference]			
	White line	Wands	Zebras	Kerb
Entrance	7 / 15.66	5.56 / 12.44	5.48 / 12.26	5.94 / 13.29
Middle	7 / 15.66	5.08 / 11.36	4.83 / 10.80	-
Exit	7 / 15.66	4.64 / 10.38	4.76 / 10.65	5.40 / 12.08

Small but statistically significant differences in cyclist speed were observed, with cyclists travelling faster when using the kerb separation than when using the other physical separation methods, when normalised to the speed measured on the white line separation. This may be explained by the increased ease of using the cycle lane separated by a kerb, as indicated by the questionnaire ratings of usability (see section 2.2.2). Evidence from research in driving suggests that people self-pace their behaviour in order to maintain a tolerable level of task difficulty. For example, drivers are known to reduce their speed to compensate for increases in perceived task difficulty (Fuller, 2000; 2008; 2011, as cited by Kinnear and Helman, 2013). The evidence from greater usability ratings supports the conclusion that greater confidence when using the kerb separation may have encouraged cyclists to travel through the lane at a faster speed compared to the other methods.

2.3 What impact did the method of cycle lane separation have on cyclist safety?

2.3.1 Ratings of perceived safety

2.3.1.1 Physical separation vs. no physical separation

Perceptions of safety were principally examined using the on-track questionnaire which asked participants to provide a rating on a 1 to 10 scale, where 1 = very unsafe and 10 = very safe.

Figure 4 shows the mean on-track safety ratings for the white line separation and each of the physical methods of separation.

In general, while mean safety scores were high (> 8.8) for all methods, cyclists felt safer when using physical separation rather than non-physical separation. Statistically significant differences in on-track questionnaire ratings showed that cyclists felt safer when using the cycle lane separated by wands, Zebras and a kerb than with the white line. The greatest improvements in safety were found with the kerb separation (which showed about an 8% increase in mean ratings relative to the white line separation).

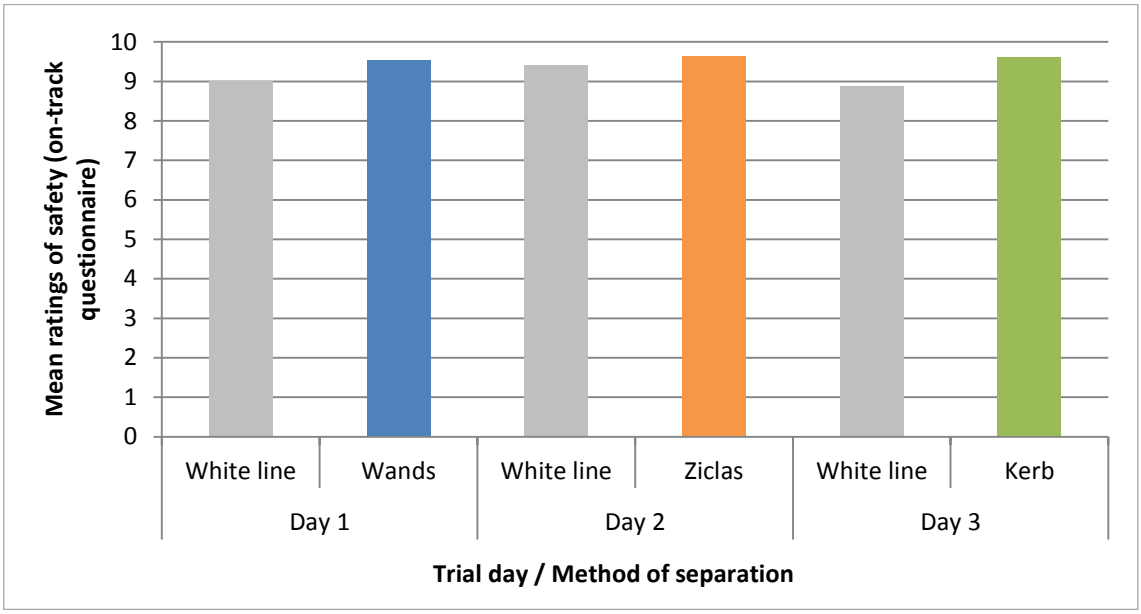

Figure 4 Mean on-track questionnaire ratings of safety for each method of separation (where 1 = very unsafe and 10 = very safe).

Perceptions of safety were also examined using the off-track questionnaire. **The wand separation and the kerb separation were consistently rated as more safe than the white line separation when**:

- One car was present in the road, and;
- Imagining using the lane in busy town centre traffic.

Likewise, the Zebra separation was rated as safer than the white line when using the lane with one car present in the road.

Physical separation between the cycle lane and the main carriageway improves cyclists' perceptions of safety compared to non-physical separation.

2.3.1.2 Effect of type of physical separation

As each separation method was trialled on a separate day, it is important to remember that each trial day represents a different sample of participants. Each group of participants therefore experienced the white line section and only one out of the three physical separation methods. For each day, therefore, Figure 4 (above) provides a comparison between the perceived safety scores for white lines and the method of physical separation, but comparisons should not be made between days (i.e. between physical separation methods), since it cannot be assumed that different groups of participants would have rated each separation method in a similar fashion.

Overall, it is clear that participants felt very safe on all days and with all separation methods, with the lowest mean score of 8.85 from the on-track questionnaire data (i.e. nearly at the top of the scale, where 10 indicates they felt very safe). To directly compare ratings of safety across each of the types of physical separation methods, scores were calculated relative to the ratings of the white line separation (see Equation 1).

The mean difference scores for the wands, Zebras and kerb are shown in Figure 5.

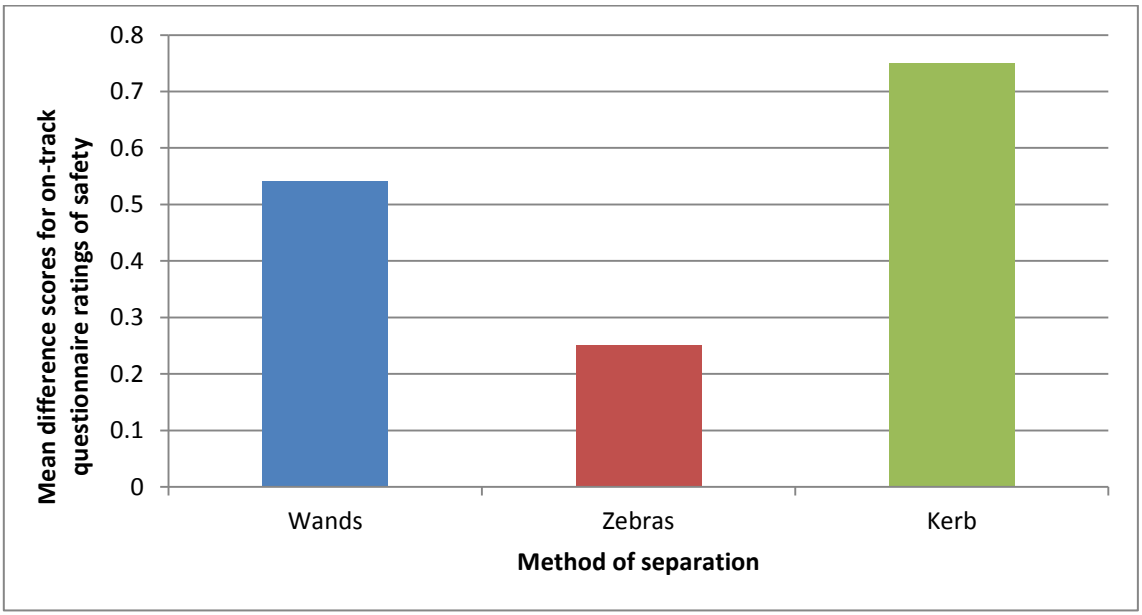

Figure 5 Mean difference scores for on-track questionnaire ratings of safety for each method of separation (positive differences indicate physical method rated safer than white line, negative differences indicate the opposite).

As the difference scores are all positive it is clear that the participants considered all three physical separations to be safer than the white line, scoring, on average, between 0.25 and 0.75 points higher on the 10-point scale than the white line.

Statistical analysis of these 'difference scores' enabled assessment of which of the physical methods were perceived to be safest overall, on the basis of the difference from the control (i.e. the white line).

Statistically significant effects of the type of physical cycle lane separation on perceived safety were identified. Specifically, analysis of the on-track safety ratings revealed:

- Both the wand separation (*M* = 0.54) and kerb separation (*M* = 0.75) were perceived to be safer than the Zebra separation (*M* = 0.25).
- No significant differences were found between the wand and kerb separation methods.

This is illustrated in Figure 5 which shows that the difference scores for the wand and the kerb were similar.

Using the same method of calculating difference scores, a significant effect of the method of physical separation on safety ratings was also found with the off-track questionnaire responses:

- The wand separation (*M* = 0.45) was rated as safer than the Zebra separation (*M* = 0.10) in conditions of busy traffic.
- The kerb separation (*M* = 0.54) was rated as safer than the Zebras (*M* = 0.19) when considering scenarios with one car present
- The kerb separation (*M* = 0.70) was rated as safer than the Zebras (*M* = 0.10) and in scenarios with busy traffic.

Overall it can be concluded that:

- Cyclists felt very safe with all methods of separation, and;
- All the physical separation methods showed perceived safety benefits over white line. however;
- Cyclists considered the 1-m high wands and the 365 mm hard-margin kerb to offer a better safety barrier between the cycle lane and the main carriageway than the bolt-on Zebras.

2.3.2 Lateral position of cyclists within the cycle lane

The lateral position of cyclists within the cycle lanes (i.e. the distance between the left-hand edge of the cycle lane separation and the bicycle wheel, in metres) was measured using traffic counters. As stated in section 1, comparisons between the three methods of physical separation have been made by comparing results from three different sets of participants, each using the same section of track; while comparisons between white line separation and each physical separation involves comparing results from the same group of participants using different sections of track. Here, the lateral position of cyclists in each physically separated cycle lane has been compared across the different groups of participants by normalising to a common reference (i.e. the white line cycle lane).

Specifically, lateral position was calculated by subtracting the mean position measurement (in each trial session) on the white line cycle lane from individual position measurements on the physically separated cycle lanes (see Equation 3).

Equation 3:	*Position difference = Treatment position - Mean control position*

…where the treatment positions were individual measurements of lateral position (m) on the physically separated cycle lanes (i.e. wands, Zebras, kerb) and the mean control positions were the mean lateral position (m) on the non-physically separated cycle lane

(i.e. the white line) measured during the same trial session. A positive difference in lateral position indicates the cyclist was further away from the separation method when using the physical separation than when using the white line separation, and a negative difference indicates the opposite.

Statistical analysis revealed a significant overall effect of separation method on cyclist lateral position at all measurement locations. At all locations along the cycle lane, cyclists travelled closer to the wand separation than the Zebras or a solid kerb (except at the entrance to the cycle lane where cyclists were closer to the kerb than the wands). Cyclists also travelled closer to the kerb than the Zebras at the entrance and exit of the cycle lane.

The differences in lateral position (calculated via Equation 3) may be reverted to absolute positions of cyclists in the lane by normalising the means relative to a single baseline measurement. Table 3 shows these position measurements under the assumption that this baseline is equal to 1 (i.e. a distance of 1 metre from the edge of the white line separation method). A value of 1 was selected for the baseline on the grounds that it is a reasonable approximation of the overall mean position of cyclists using the white line cycle lane, across all trial sessions.

Table 3 Mean absolute lateral position (m) of cyclists in each cycle lane (distance from cycle lane separation), normalised to a mean position of 1 metre on the white line cycle lane.

Measurement location	Normalised absolute position (m) [White line (i.e. 1m) + mean difference]			
	White line	Wands	Zebras	Kerb
Entrance	1	0.91	1.02	0.83
Middle	1	0.87	0.90	1.00
Exit	1	0.65	0.93	0.84

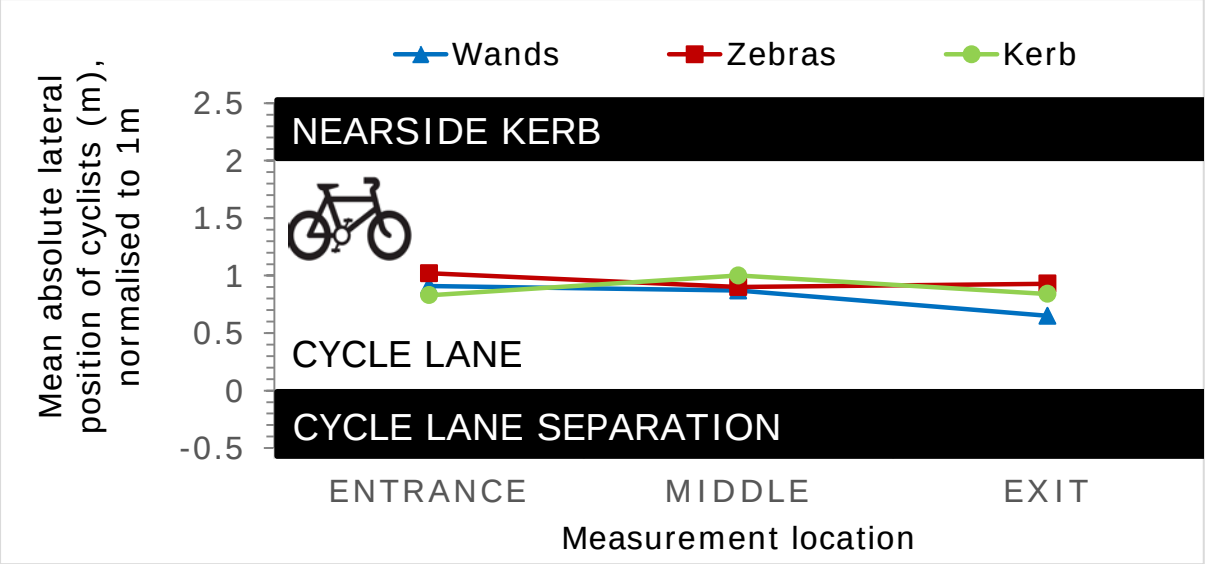

Figure 6 Mean absolute position (m) of cyclists in each physically separated cycle lane (distance from separation), normalised to a mean position of 1 metre on the white line cycle lane.

Figure 6 shows that cyclists generally travelled in fairly central positions, but that they tended to ride furthest from the Zebras and closest to the wands. This observation is consistent with evidence from the reduction in perceived safety observed with the Zebra separation compared to the wand separation (as shown by the questionnaire ratings discussed in section 2.3.1). Inexperienced or less confident cyclists frequently believe that the safest place to cycle is close to the left-hand edge of the road, as they may perceive this to minimise risk of conflict with passing vehicles. As such, cycle training programmes, for example *Bikeability*[3], specifically advise cyclists to ride further out in the lane to give themselves more space to avoid potholes, etc., and to discourage following drivers from overtaking where there is insufficient space. Hence, cyclists' willingness to ride further away from the left-hand road edge with the wand separation is consistent with greater perceived safety and confidence to occupy the road space.

The observation that cyclists ride further out in lanes separated with wands means that they are using a greater proportion of the road space that has been re-allocated to them with this method of separation, further implying that the wands may be helpful in creating separated lanes where space is more constrained. This finding can be expressed by the 'separation efficiency ratios' shown in Table 4, which is simply the ratio of the position of the cyclist in the lane to the total road space required to create the lane, i.e. the lane width added to the width of the separation. The higher ratio achieved by the wands is because they require less space in the road compared to other methods and cyclists use more of that space. Furthermore, standard specifications for kerb separation state a hard-margin of 0.5 metres, an additional 0.135 m compared to the configuration tested in these trials, so the space saving on live roads would be even greater.

Table 4 Road space required with each physical separation method and amount of space used by cyclists.

Physical separation method	Width of separation (m)	Total space required by separation (with 2 m cycle lane)	Average distance between cyclists and road edge (m)	Separation efficiency ratio (Position of cyclist / Total space required by separation)
Wands	0.100	2.100	1.190	**0.57**
Zebras	0.164	2.164	1.050	0.49
Kerb	0.365	2.365	1.110	0.47

[3] See Bikeability Delivery Guide, DfT

Lateral position data show that cyclists made better use of the cycle lane width with the wand separation. This supports the finding that cyclists felt safest when using the cycle lane separated by wands, followed by the cycle lane separated by a solid kerb, and least safe when using the cycle lane separated by Zebras.

The wands require less space for installation on the road compared to other methods and evidence suggests that they encourage cyclists to ride further out in the lanes, meaning they make greater use of the space that has been re-allocated to them.

2.4 What impact did vehicle interaction have on cyclist usability?

2.4.1 Effect of vehicle interaction on ratings of ease of using the cycle lane

On each trial day, cyclists were exposed to four vehicle interaction conditions on each cycle lane (i.e. the white line condition and one of the three physical separations). The four types of interaction were: no vehicle interaction, car passing cyclist at entrance to cycle lane, in middle of cycle lane and at exit of cycle lane.

When cycling along the lane separated by Zebras, cyclists' ratings of ease of using the cycle lane were marginally higher with no vehicle interaction compared to when a vehicle passed them at the exit. However, no other specific patterns in the on-track questionnaire responses were found. This suggests that the cyclists' on-track ratings of usability were not greatly affected by the presence of a vehicle, regardless of the type of cycle lane separation.

Ratings of usability were also obtained for three different traffic conditions using the off-track questionnaire: no cars, one car and busy town centre traffic. The latter of these options required cyclists to imagine using the cycle lane in a hypothetical scenario, since busy town centre traffic was not trialled on the track.

Figure 7 shows the mean off-track usability ratings for the white line separation and each of the methods of physical separation. It should be noted that the mean ratings across different days should not be directly compared because different groups of participants were tested on each of the 3 days. When comparing the ratings *within* each trial day, it is clear from that the ease of use was dependent on the level of traffic present when using the cycle lane, for all methods of separation. Specifically, ratings of ease of using the cycle lane decreased with increasing number of vehicles.

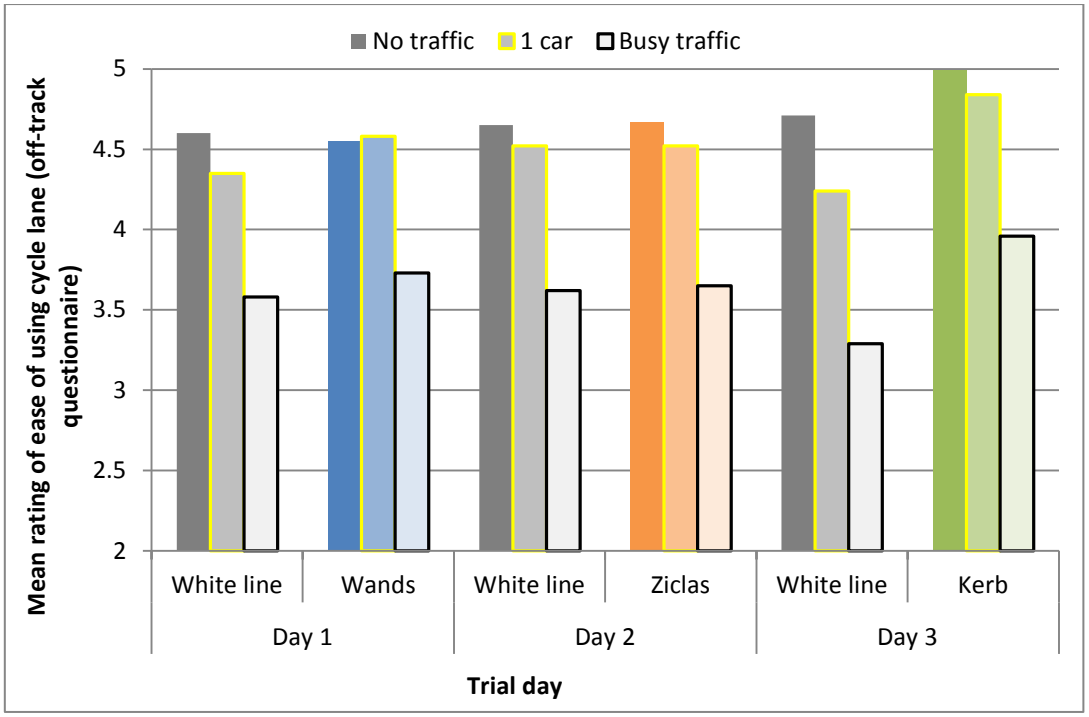

Figure 7 Mean off-track questionnaire ratings for ease of using the cycle lane.

Significant differences in off-track questionnaire ratings indicated an effect of traffic condition on the ease of using the separated cycle lane, regardless of the method of separation employed. Generally, ratings were lowest when cyclists were asked to imagine using the lanes in considered scenarios of increasing traffic volume from no cars, to one car, to busy traffic.

2.5 What impact did the vehicle interaction have on cyclist safety?

2.5.1 Effect of vehicle interaction on ratings of perceived safety

The type of vehicle interaction was also found to have a significant effect on the perceived safety of cyclists, regardless of the method of cycle lane separation. As expected, cyclists generally rated their journey as more safe when there was no vehicle interaction than when a car passed them at some point along the cycle lane.

Mean safety ratings when a vehicle passed the cyclist in the middle of the cycle lane were typically marginally higher than when a vehicle passed the cyclist at either the entrance or the exit of the cycle lane. Differences were small but significant, suggesting that cyclists felt slightly more vulnerable to traffic both before joining the cycle lane and when re-joining the main carriageway. The magnitude of those differences was smaller for the physical separation methods than the non-physical separation, suggesting that the reduction in perceived safety associated with a vehicle interaction was mediated by the presence of physical separation.

These findings are supported by responses to the off-track questionnaire, which obtained further ratings of safety for each cycle lane under three different traffic conditions: no cars, one car and busy town centre traffic. Figure 6 shows the mean off-track safety ratings for the white line separation and each of the physical methods of separation.

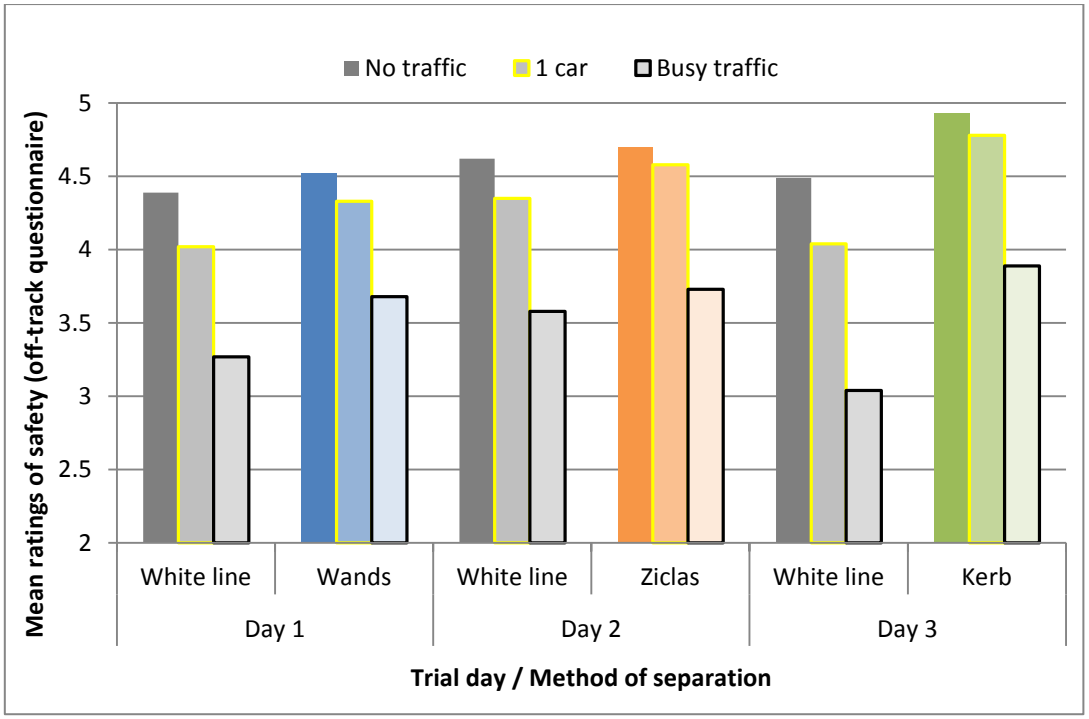

Figure 8 Mean off-track questionnaire ratings of safety for each method of separation under different traffic conditions.

As with the analysis presented in section 2.4.1, comparison of mean ratings across different days is not appropriate since different groups of participants were tested on each of the 3 days. Comparison of the ratings of perceived safety within each trial day shows a clear dependence on the level of traffic present when using the cycle lane, with all methods of separation. Cyclists' perceptions of safety generally decreased with increasing number of vehicles.

Findings from both the on-track and off-track questionnaire give some indication of how cyclists may feel when using separated cycle lanes under 'real-world' traffic conditions. Cyclists' overall feelings of safety improve when using physically separated lanes.

2.5.2 Effect of vehicle interaction on lateral position of cyclists within cycle lane

There were few differences in the lateral position of cyclists when a vehicle passed them at the entrance, middle or exit of the cycle lane compared to when there was no vehicle. The only significant result found suggested that, relative to when using the white line separation, when in the middle of the wand separated cycle lane cyclists travelled closer to the wands with no vehicle interaction than with a vehicle interaction.

2.6 Further comments

Qualitative comments about each of the methods of cycle lane separation obtained from the off-track questionnaire are listed in the Appendices document. From these comments it was possible to identify a number of common themes:

- Physical separation from the main traffic improves the feeling of safety.

- The markings and signage at the end of the cycle lane were considered to be insufficient by more than 40 participants. There was concern expressed by many participants regarding safety and usability at the exit of all cycle lanes, partly due to confusion about right-of-way and ambiguity with cyclists and cars merging into one lane.
- Using the cycle lane separated by wands in conditions with several cyclists may be more challenging and less safe, for example, with two-way cycle traffic.
- Some concern was expressed by cyclists over how pedestrians would interact with the wand separation when attempting to cross over the road.
- More traffic, including HGVs, would be necessary to enable participants to make a realistic judgement.
- Some concern was expressed over conspicuity of Zebras, particularly at night.

2.7 Summary and conclusion

Comparison of the four methods of cycle lane separation (white line, wands, Zebras and kerb) revealed statistically significant differences in the speed and position of cyclists, and in their perceptions of usability and safety. It is important to note however, that the differences were not so substantial to warrant concern for cyclists if any one of the methods were implemented on road. Cyclists rode in fairly central positions in the lane with all separation methods, and at similar speeds, and in general, ratings of usability and safety were fairly high for all separations, indicating that all four methods were viewed as fairly safe and fairly easy to use. Nevertheless, statistically significant differences were found between the methods, indicating small but distinct variations in cyclists' perceptions and behaviour in response to each separation. In particular, all physical methods showed benefits for cyclists over the use of a painted white line. These benefits are summarised below.

Cyclists found it easier to understand the cycle lane markings when a physical method of separation was employed. Continuous solid kerb separation was favoured over those used with intermittent separations.

Compared to when using the cycle lane separated by a white line, it was easier to use the cycle lane physically separated from the main carriageway by either a kerb or Jislon wands, but not by Zicla Zebras. The continuously separated kerb method was given higher ratings of usability than the other intermittent separation methods, particularly when participants were asked to imagine travelling in high volume traffic. This finding is supported by measurements of cyclist speed within the cycle lanes which showed a smaller reduction in speed relative to the white line separation for the kerb over the other physical methods. Increased confidence when using the kerb separation, i.e. as shown by the higher ratings of usability, may have encouraged cyclists to travel at higher speeds.

Perceptions of safety were higher when the cycle lane was separated by physical methods than when it was separated by only a painted white line. The intermittent wand separation and the continuous kerb separation were given higher ratings of safety than the intermittent Zebra separation. As with the usability ratings, this was particularly evident for scenarios when high volume traffic is present. Relative to the white line separation, cyclists generally travelled closer to the main carriageway when using wand

separation than when using both the Zebra and kerb separation, supporting the increased safety perceived when using the wand separation.

It is noteworthy that the width of the separation methods differs substantially, ranging from only 100 mm wide for the wands to 365 mm for the kerb. Given that the latter would normally be built to a 500 mm width, there are clearly great savings in the road space required to install the intermittent methods. The observation that cyclists were willing to ride slightly further out in the lane separated by wands suggests that they made better use of the available width.

Qualitative data obtained during the trial highlighted a number of concerns expressed by participants. The most commonly reported issue was related to the markings and signage at the end of the cycle lane, which were felt to be insufficient by many respondents. There was concern expressed regarding safety and usability at the exit of all cycle lanes, partly due to confusion about right-of-way and ambiguity with cyclists and cars merging into one lane.

There were also some comments suggesting that using the cycle lane separated by wands with several other cyclists present may be more challenging. Finally, a few respondents raised concern over the conspicuity of the Zebras, particularly at night. This may be improved through increased use of white paint or reflective material.

Findings from the cyclist behaviour trial indicate that:

- the solid kerb separation was viewed as the easiest to use, whilst;
- both the wand separation and the kerb separation offered the greatest perceived safety benefit to cyclists.

The finding of increased perceived safety is consistent with the observation that cyclists allowed a wider clearance from the edge of road when using the wand separation, i.e. cyclists feel comfortable using more of the available lane space when separated from traffic by wands.

3 Other road users

3.1 Introduction

This section presents the findings from the driver behaviour trials, which investigated the influence of the method of cycle lane separation on the user behaviour and safety of 237 participant car drivers and 173 participant motorcyclists in an independent samples design[4], and 13 participant HGV drivers in a repeated measures design[5] (see full methodology in Appendices for further information).

Usability and safety were assessed via the means used in the cyclist behaviour trial (see section 2.1). This section presents key findings for the driver user group. Comparisons have been drawn between the physical and non-physical separation methods (i.e. white line vs. wands/Zebras/kerb) and between each of the three physical separation methods (i.e. wands vs. Zebras vs. kerb).

3.2 What impact did the method of cycle lane separation have on driver usability?

3.2.1 Ratings of understanding the cycle lane markings

3.2.1.1 Physical separation vs. no physical separation

In this section, and elsewhere in the report, the term 'cycle lane markings' is used to refer to the structure and composition of the cycle lane separation (e.g. the presence of a solid kerb) and is not strictly limited to painted markings or signage. Perceptions of the cycle lane markings were assessed via the on-track and off-track questionnaires. Key findings from these measures are shown below for each road user.

Car drivers

While drivers were on track they were asked to rate the ease of understanding the cycle lane markings after their first encounter with each cycle lane. Car drivers' ratings were statistically significantly higher for the Zebra separation than the white line separation, but no other significant differences between the white line and other physical separation methods were found.

Ratings from the off-track questionnaire revealed further significant findings. Car drivers' ratings were higher for the wand separation than the white line separation concerning clarity when identifying the cycle lane, clarity in understanding how to proceed past the cycle lane, ease of understanding where the cycle lane began and ease of understanding where the cycle lane finished.

- Ratings of ease of understanding where the cycle lane finished were higher for the Zebra separation than the white line separation, but no other significant differences were found.

[4] Independent samples design: where participants are exposed to only one experimental variable (i.e. car drivers and motorcyclists experienced only 1 type of physical separation).

[5] Repeated measures design: where participants are exposed to all experimental variables (i.e. HGV drivers experienced all 3 types of physical separation).

- The cycle lane markings on the kerb separation were rated as more clear in terms of understanding how to proceed past the cycle lane than the white line separation.
- It was easier to understand where the cycle lane finished with the kerb than the white line.

Motorcyclists

For motorcyclists, off-track questionnaire ratings were higher for the wand separation than the white line separation relating to clarity when identifying the cycle lane, ease of understanding where the cycle lane began and ease of understanding where the cycle lane finished. There were no significant differences in ratings of the cycle lane markings between the white line separation and the Zebra separation, suggesting the two methods of cycle lane separation were comparable for the motorcyclist user group. Compared to the kerb separation, the white line separation was given significantly higher ratings for clarity of identifying the cycle lane, and for ease of understanding where the cycle lane began.

HGV drivers

Neither the on-track questionnaire nor off-track questionnaire ratings from the HGV drivers revealed significant differences between the white line separation and the physical separation methods for any of the measures of cycle lane markings.

The results suggest that car drivers favoured the cycle lane markings on the physically separated cycle lanes over those used on the white line cycle lane. For motorcyclists, the wand separation was a useful measure for distinguishing the cycle lane, but the Ziclas and the kerb were not as effective. Contrary to the car driver user group, motorcyclists preferred the markings on the white line separation over the kerb cycle lane. No significant findings were discovered for HGV drivers.

3.2.1.2 Effect of the type of physical separation

As each separation method was trialled on a separate day, each trial day represents a different sample of participants[6]. Car drivers, motorcyclists and HGV drivers were therefore trialled on separate days, and on each day, each group of participants experienced the white line section and only one out of the three physical separation methods. For each day, therefore, a comparison is made between ratings of the white lines and the method of physical separation (as discussed above in section 3.2.1.1). To compare ratings across days, and therefore between physical separation methods, it was necessary to calculate difference scores for the ratings of the cycle lane markings on physical separations relative to those for the white line (see Equation 1).

Analysis of these difference scores revealed no significant effects of the method of physical separation on ratings of cycle lane markings (from the on-track questionnaire) for car drivers, motorcyclists or HGV drivers.

[6] HGV drivers were tested in a repeated measures design, meaning that the same participants returned on all three trial days, and thus experienced all three physical separation methods. Nevertheless, it was necessary to analyse findings using difference scores, as with the car driver and motorcyclist trials, in order to account for variability between trial days.

For car drivers, there were also no significant effects for the off-track questionnaire ratings. However, some statistically significant effects were found for the motorcyclist and HGV driver groups.

Figure 9 shows the mean difference scores for the off-track questionnaire ratings of the cycle lane markings given by motorcyclists.

Motorcyclists' difference scores were higher for the wands than the Zebras and the kerb for measures related to:

- Clarity of identifying cycle lane (Wands *M* = 0.22, Zebras *M* = -0.09, Kerb *M* = -0.29)
- Ease of understanding where the cycle lane began (Wands *M* = 0.17, Zebras *M* = -0.04, Kerb *M* = -0.32)
- Ease of understanding where the cycle lane finished (Wands *M* = 0.45, Zebras *M* = -0.01, Kerb *M* = -0.13)

HGV drivers' difference scores were higher for the wands than the Zebras for measures related to:

- Clarity of identifying the cycle lane (Wands *M* = 0.00, Zebras *M* = -0.38).

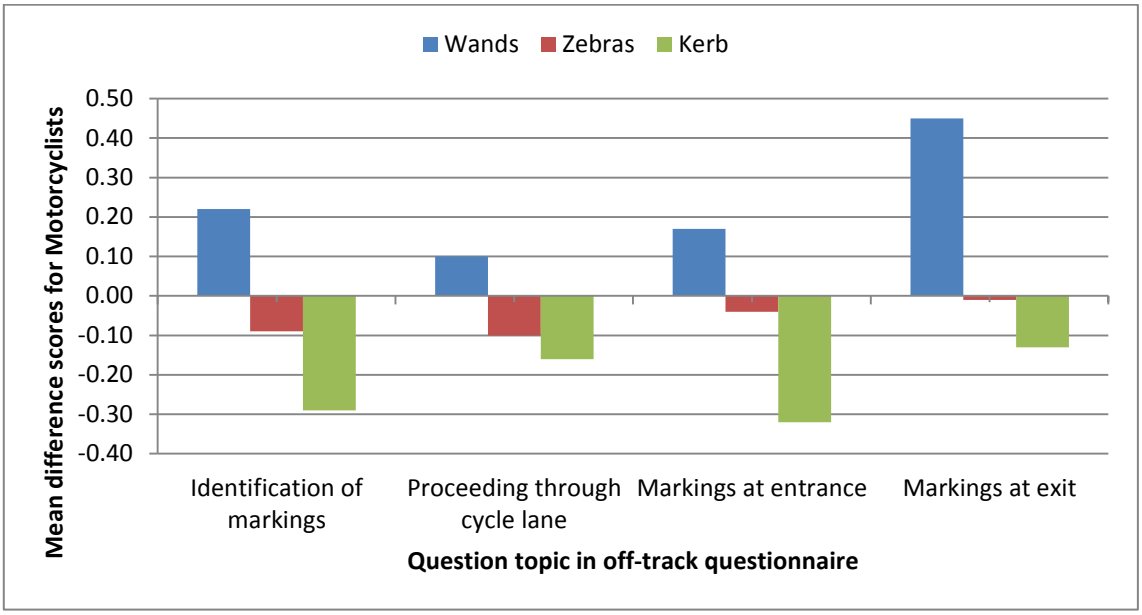

Figure 9 Mean difference scores for motorcyclists' off-track questionnaire ratings of cycle lane markings for each method of separation (positive difference indicates physical method rated higher than white line, negative difference indicates the opposite).

Whilst car drivers preferred markings on physically separated cycle lanes over the white line separation, the method of physical separation made little difference to ratings. Both the motorcyclist and HGV driver user group showed some preference for the cycle lane markings on the cycle lane separated by wands than the cycle lane separated by other physical methods.

3.2.2 Ratings of ease of navigating the trial route

3.2.2.1 Physical separation vs. no physical separation

Perceptions of the ease of navigating the trial route were assessed via the on-track questionnaire administered during the trial and off-track questionnaire administered after the trial. Key findings from these measures are shown below for each road user.

Car drivers

Responses to the on-track questionnaire revealed that **car driver ratings of the ease of navigating past the cycle lane were higher for the wand, Zebra and kerb separation than the white line separation**.

The ease of navigating the route was also assessed using the off-track questionnaire. Car driver ratings indicated that when one cyclist was using the cycle lane, it was easier to navigate the route with physical separation than with the white line separation. Likewise, when asked to imagine travelling in busy traffic scenarios, car drivers indicated that navigating past all three physical separation methods would be an easier task than the white line separation.

Motorcyclists

Motorcyclist on-track ratings were higher for the wand separation than the white line separation, but no other significant differences between the physical and non-physical separation methods were found.

From the off-track questionnaire it was determined that, compared to the Zebra separation, motorcyclists considered navigating past the white line cycle lane as an easier task in conditions of busy traffic. Similarly, it was easier to navigate past the white line separation with one cyclist present in the lane and with no cyclists in the lane than when using the route with kerb separation.

HGV drivers

No significant differences were found between HGV driver on-track questionnaire ratings of usability. Off-track questionnaire ratings for ease of navigating the route in busy traffic conditions were higher for the wand separation than the white line separation, suggesting the wands offered some benefit to the driving task.

Compared to the white line separation, motorcyclists found it easier to navigate the route when the cycle lane was separated by wands but harder to navigate past with either Ziclas or the kerb. For car drivers, navigating the route was easier with all kinds of physical separation compared to when the cycle lane was separated only by a painted white line.

Collision with a physically separated cycle lane has greater consequences for a motorcyclist than a car driver. Possibly, awareness of the risk of collision with physically separated cycle lanes increased the task load for motorcyclists making it harder to navigate the route than when the cycle lane was separated only by a painted white line.

3.2.2.2 *Effect of the type of physical separation*

As with the analysis of cycle lane markings, direct comparison across the trial days, i.e. between the three physical separations, was performed by calculating difference scores for the ratings of ease of navigating past the cycle lanes with physical separations relative to those for the white line (see Equation 1).

Statistical analysis of the difference scores for car driver and HGV driver ratings of ease of navigating the route (from the on-track questionnaire) were **not** dependent on the method of physical separation.

However, analysis of the difference scores for motorcyclist ratings of ease of navigating the route (from the on-track questionnaire) were dependent on the method of physical separation.

Difference scores for motorcyclists were significantly higher for wand separation (*M* = 0.34) than both the kerb (*M* = -0.02) and Zebra (*M* = 0.10) separations, suggesting the wands were rated highest.

Analysis of the off-track ratings of usability showed similar results. Figure 10 shows the mean difference scores for the motorcyclists' off-track questionnaire ratings of usability.

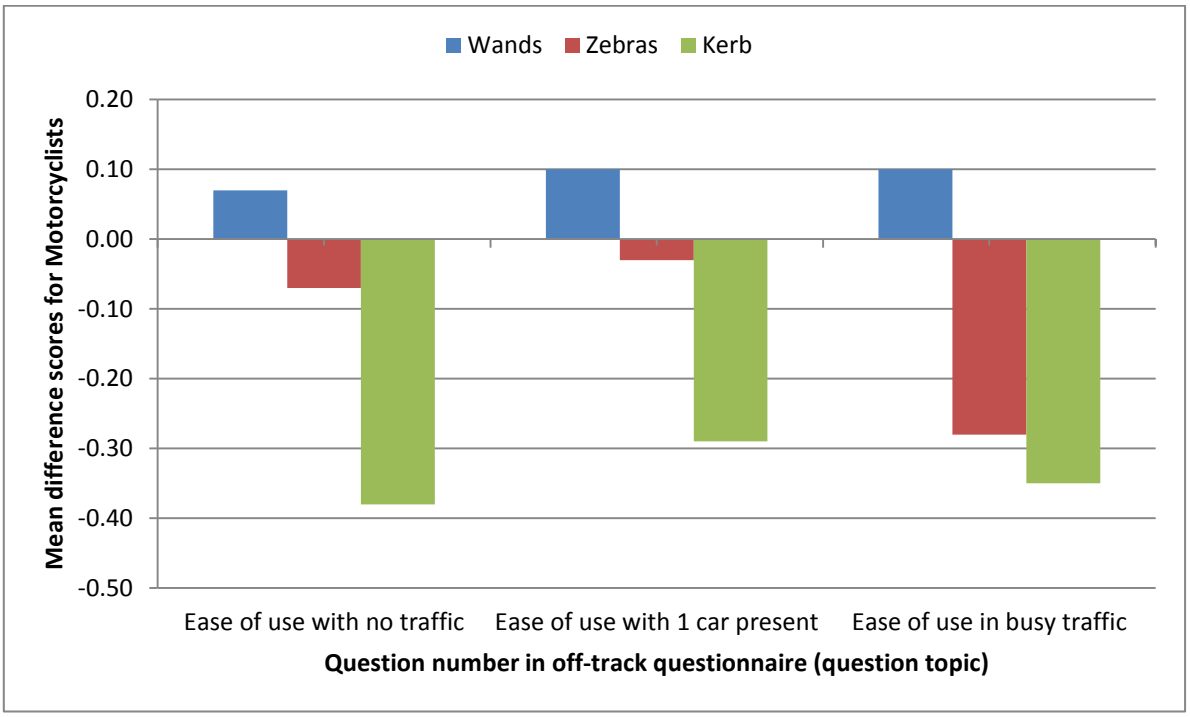

Figure 10 Mean difference scores for off-track questionnaire motorcyclist ratings of ease of navigating past the cycle lane for each method of separation (positive difference indicates physical method rated higher than white line, negative difference indicates the opposite).

It is clear from this figure that motorcyclists generally rated the wands higher than the white line, but the Zebras and kerb as lower than the white line. Statistical analysis revealed that motorcyclists' difference scores were:

- Higher for wand separation (*M* = 0.10) than the Zebra (*M* =-0.28) and kerb (*M* = -0.35) separation for busy traffic scenarios, and
- Higher for wand separation (*M* = 0.07) than the kerb separation (*M* =-0.38) for conditions with no traffic.

There was some evidence that the HGV drivers preferred the wand separation over the Zebra separation, for conditions with 1 cyclist present in the lane and when imagining using the route in busy traffic conditions. Unfortunately, because of a reduced sample, analysis was not performed for the kerb separation method.

Responses to both the on- and off-track questionnaires indicate that:

- Motorcyclists found it easier to navigate past the cycle lane separated by wands than when the cycle lane was separated by either Ziclas or a kerb (which were rated as harder to navigate past than a painted white line).
- No differences were found for the car driver group, suggesting that the method of physical separation did not impact on their ratings of usability.

3.2.2.3 Driver speed

The speed of drivers (m/s) when navigating past each of the physical separation methods (wands, Zebras, kerb) was compared using the white line separation as a baseline measure, as shown in Equation 4.

Equation 4:	*Speed difference = Treatment speed - Mean control speed*

…where the treatment speeds were individual speeds (m/s) measured on main carriageway adjacent to the physically separated cycle lanes (i.e. wands, Zebras, kerb) and the mean control speeds were the mean speeds (m/s) measured on carriageway adjacent to the non-physically separated cycle lane (i.e. the white line). Positive differences indicate the speed travelled past the physical separation was greater than that with the white line, negative differences indicate the opposite. Most speed differences were negative indicating that drivers tended to travel slower past the physical separations than the white line separation, possibly because the latter was located on a downhill slope.

Mean speed difference scores for each driver group when navigating past the wand, Zebra and kerb separations are shown in Figure 11. Statistical analysis revealed significant effects of the type of physical separation on driver speed.

The differences in the speed of drivers shown in Figure 11 may be equated to absolute speeds by normalising the means relative to a baseline. Table 5 shows these speed measurements under the assumption that this baseline is equal to 11 (i.e. a mean speed of 11 m/s when driving past the white line separation).

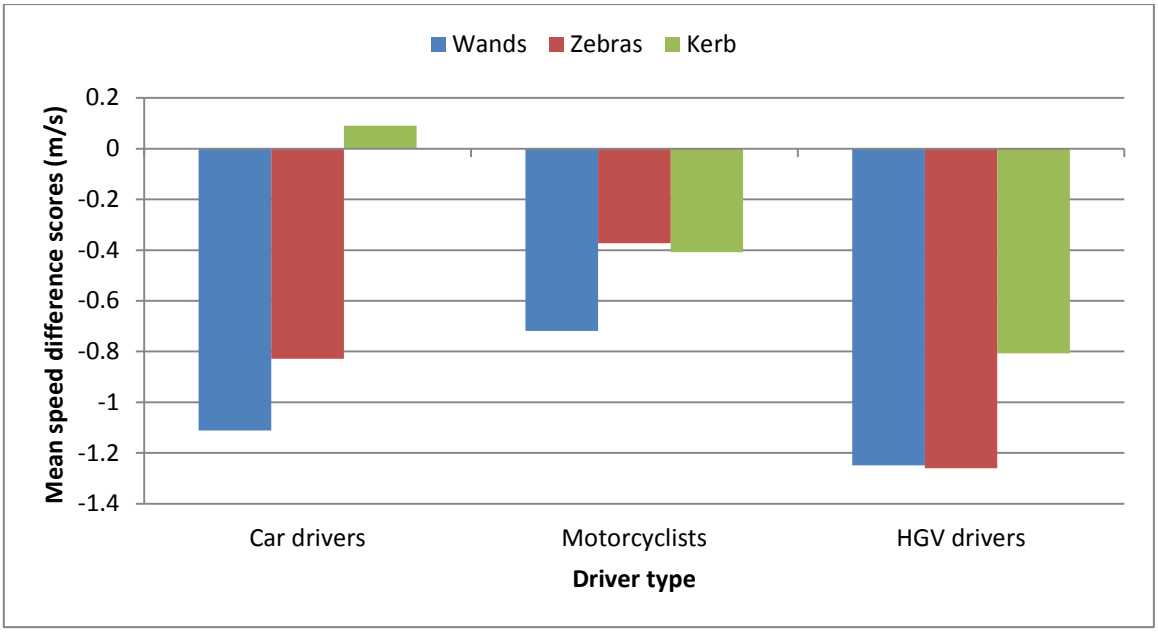

Figure 11 Mean speed differences for road users when navigating past the wand, Zebra and kerb separations. (Positive differences indicate the speed travelled past the physical separation was greater than that with the white line, negative differences indicate the opposite).

Table 5 Mean absolute speed (ms^{-1} / mph) of drivers in road, normalised to a mean speed of 11 ms^{-1} for the white line separation.

Participant type	Normalised absolute speed (ms^{-1} / mph) [White line (i.e. 11 ms^{-1}) + mean difference]			
	White line	Wands	Zebras	Kerb
Car drivers	11 / 24.61	9.89 / 22.12	10.17 / 22.75	11.09 / 24.81
Motorcyclists	11 / 24.61	10.28 / 23.00	10.63 / 23.78	10.59 / 23.69
HGV drivers	11 / 24.61	9.75 / 21.81	9.74 / 21.79	10.19 / 22.79

A value of 11 was selected for the baseline on the grounds that it is a reasonable estimate of the mean speed of vehicles driving past the white line cycle lane. Relative to this baseline, car drivers travelled, on average, around 2 mph faster past the kerb separation than the Zebra separation, and around 0.6 mph faster past the Zebras than the wands. Motorcyclists travelled around 1 mph faster past the kerb than the wands, and 0.7 mph faster past the Zebras than the wands. There were no significant differences in HGV driver speed identified in the analysis.

Car drivers and motorcyclists tended to travel slowest past the wand separation compared to the other physical methods, as shown by the normalised mean absolute speeds in Table 5. The speed of drivers when navigating past the physically separated cycle lanes may be related to the complexity of the driving task, however no significant differences in usability ratings were found for the car driver group (see section 3.2.2.2) suggesting the differences in speed do not reflect any substantial differences in task load.

Motorcyclists indicated that it was easier to navigate past the wand separation than the Zicla or kerb separation (see section 3.2.2.2), however they travelled past the wand separation slower than when travelling past the Zebras and the kerb, respectively. It may be that the riding task was easier as a result of a reduction in speed when passing the wand separation, but firm conclusions about cause and effect cannot be established from this trial.

3.3 What impact did the method of cycle lane separation have on driver perceptions of safety?

3.3.1 Ratings of perceived safety

3.3.1.1 Physical separation vs. no physical separation

Perceptions of safety were principally examined using the on-track questionnaire which asked participants to provide a rating on a 1 to 10 scale (where 1 = very unsafe and 10 = very safe). Mean safety ratings (from the on-track questionnaire) for the white line separation and each of the physical methods of separation are shown in Figure 12 (car drivers) and Figure 13 (motorcyclists).

Key findings from these measures, and from the off-track questionnaire ratings, are shown below for each road user.

Car drivers

It is clear from Figure 12 that mean safety ratings (from the on-track questionnaire) were fairly high (> 9.16, i.e. near the top of the 10-point scale) for all methods of separation, but there was a tendency for car drivers to give higher ratings of perceived safety with the physical separations than the white line. Specifically, car driver on-track safety ratings were 4%, 3% and 2% higher for wand, Zebra and kerb separation, respectively, compared to the white line separation.

Likewise from the off-track questionnaire, car driver ratings of safety were:

- 6% higher for the wand separation than the white line separation where 1 cyclist was present in the lane.
- 17% higher for the wand separation than the white line separation when drivers were asked to imagine travelling in busy town centre traffic.
- 8% higher for the Zebra separation than the white line separation for scenarios where 1 cyclist was present in the lane.
- 9% higher for the Zebra separation than the white line separation when drivers were asked to imagine travelling in busy town centre traffic.

- 3% higher for Zebra separation than white line separation when no cyclists were present in the lane.
- 4% higher for kerb separation than the white line separation for scenarios where 1 cyclist was present in the lane.
- 16% higher for kerb separation than the white line separation when drivers were asked to imagine travelling in busy town centre traffic.
- 3% higher for kerb separation than white line separation when no cyclists were present in the lane.

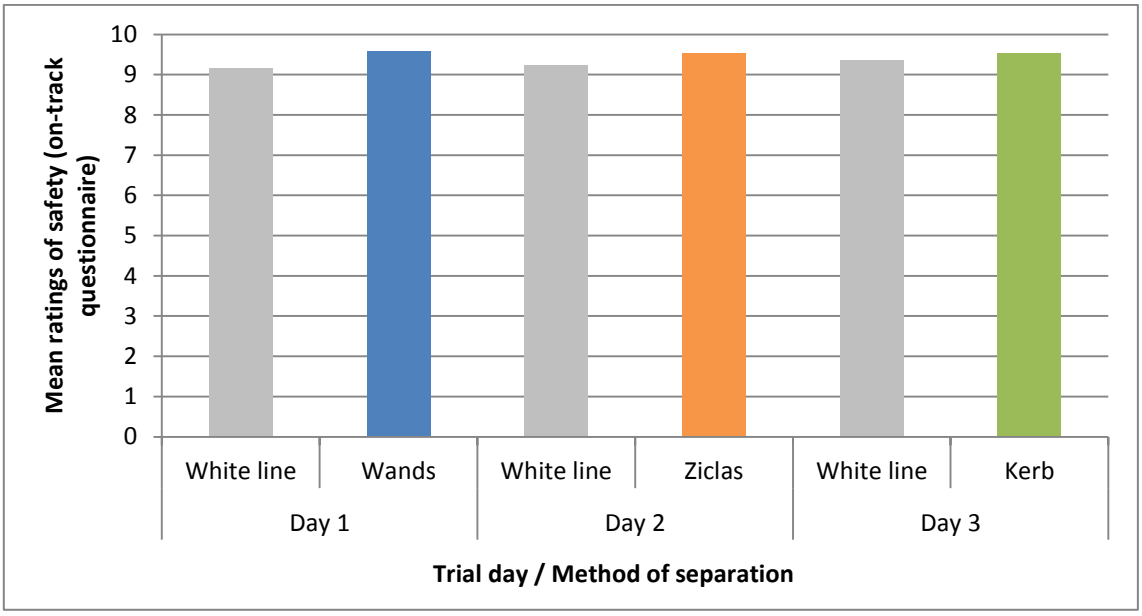

Figure 12 Mean on-track car driver ratings of safety for each method of separation (grouped across all types of vehicle interaction).

Motorcyclists

Like the car drivers, it is clear from Figure 13 that mean safety ratings (from the on-track questionnaire) from the motorcyclist group were also fairly high (> 9.19) for all methods of separation. However, comparison within each trial day shows that ratings of perceived safety seemed to only differ between the white line and the wand separation, but not between the Zebras and white line, or kerb and white line. Statistical analysis confirmed this trend, showing on-track safety ratings 2% higher for the wand separation than the white line separation but no other significant differences.

Responses to the off-track questionnaire indicated that:

- Ratings of safety were 9% higher for the wand separation than the white line separation, when drivers were asked to imagine travelling in busy town centre traffic.
- Ratings of safety were 4% lower for the Zebra separation than the white line separation, when no cyclists were present in the lane.
- Ratings of safety were 5% lower for the Zebra separation than the white line separation, when drivers were asked to imagine travelling in busy town centre traffic.

- Ratings of safety were 8% lower for the kerb separation compared to the white line, when no cyclists were present in the lane.
- Ratings of safety were 5% lower for the kerb separation compared to the white line, where 1 cyclist was present in the lane.

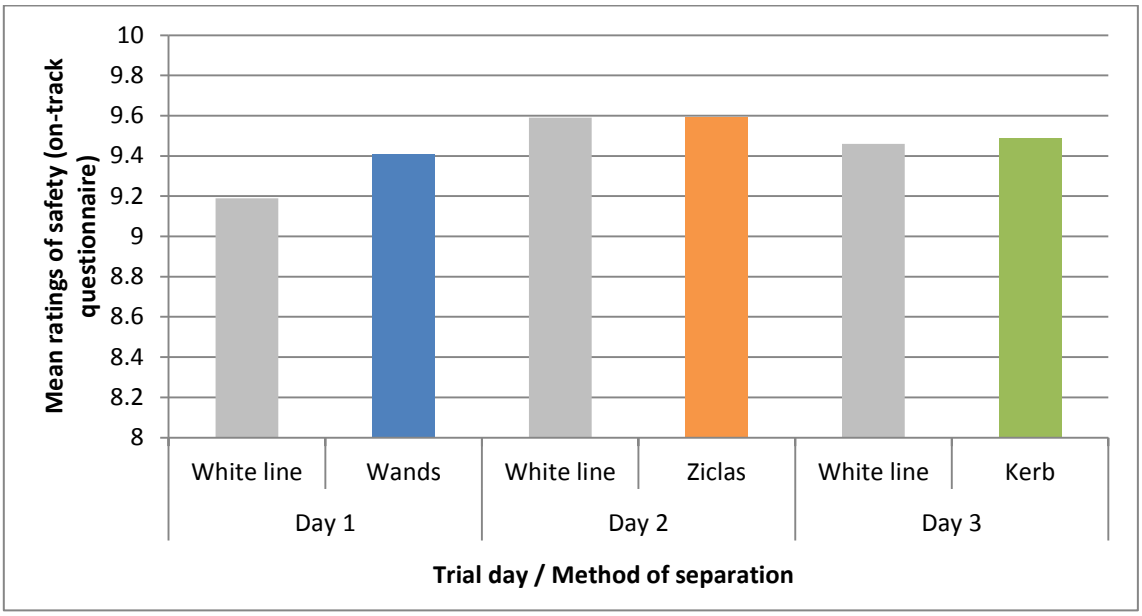

Figure 13 Mean on-track motorcyclist ratings of safety for each method of separation (grouped across all types of vehicle interaction).

HGV drivers

Responses to the on-track questionnaire revealed no statistically significant differences for the HGV driver group.

However, analysis of the off-track questionnaire showed:

- 8% higher safety ratings for the wand separation than the white line separation where 1 cyclist was present in the lane.
- 7% higher safety ratings for the wand separation than the white line separation when drivers were asked to imagine travelling in busy town centre traffic.
- 15% lower safety ratings for Zebra separation than for the white line separation when drivers were asked to imagine travelling in busy town centre traffic.

Findings from both the on-track and off-track questionnaires indicate that, compared to the white line separation, perceptions of safety were greater with all types of physical separation methods for car drivers, but only greater with the wand separation for motorcyclists and HGV drivers.

Findings from the motorcyclist and HGV user groups indicate that they perceived the Zicla and kerb separation methods as less safe than the white line separation.

3.3.1.2 *Effect of type of physical separation*

As discussed previously, each separation method was trialled on a separate day, so it is important to remember that each trial day represents a different sample of participants (except for HGV drivers, who experienced all separations). Each group of participants therefore experienced the white line section and only one out of the three physical separation methods. For each day, therefore, a comparison is made between the perceived safety scores for white lines and the method of physical separation (as discussed in section 3.2.1.1). To allow comparisons of the ratings of safety between days (i.e. between physical separation methods), difference scores must be calculated relative to the ratings of the white line separation (see Equation 1). This is fundamental to the design since it cannot be assumed that different groups of participants would have rated each separation method in a similar fashion.

Analysis of the difference scores for each user group revealed no significant effect of type of physical separation on safety ratings (from the on-track questionnaire) for car drivers, motorcyclists or HGV drivers.

Likewise there was no significant effect on difference scores for the off-track safety ratings for either the car driver or HGV driver groups. However, Figure 14 shows a clear trend for negative mean difference scores from Motorcyclist ratings of the Zebras and the kerb and positive mean difference scores for the wands. This suggests that motorcyclists viewed the Zebra and kerb methods as less safe than the painted white line. Statistical analysis confirmed this trend, showing that motorcyclists' difference scores were:

- Higher for wand separation (M = 0.19) than for Zebra separation (M = -0.16) where 1 cyclist was present in the lane.
- Higher for wand separation (M = 0.30) than for Zebra separation (M = -0.25) when drivers were asked to imagine travelling in busy town centre traffic.
- Higher for wand separation (M = 0.06) than for kerb separation (M = -0.38) when no cyclists were present in the lane.

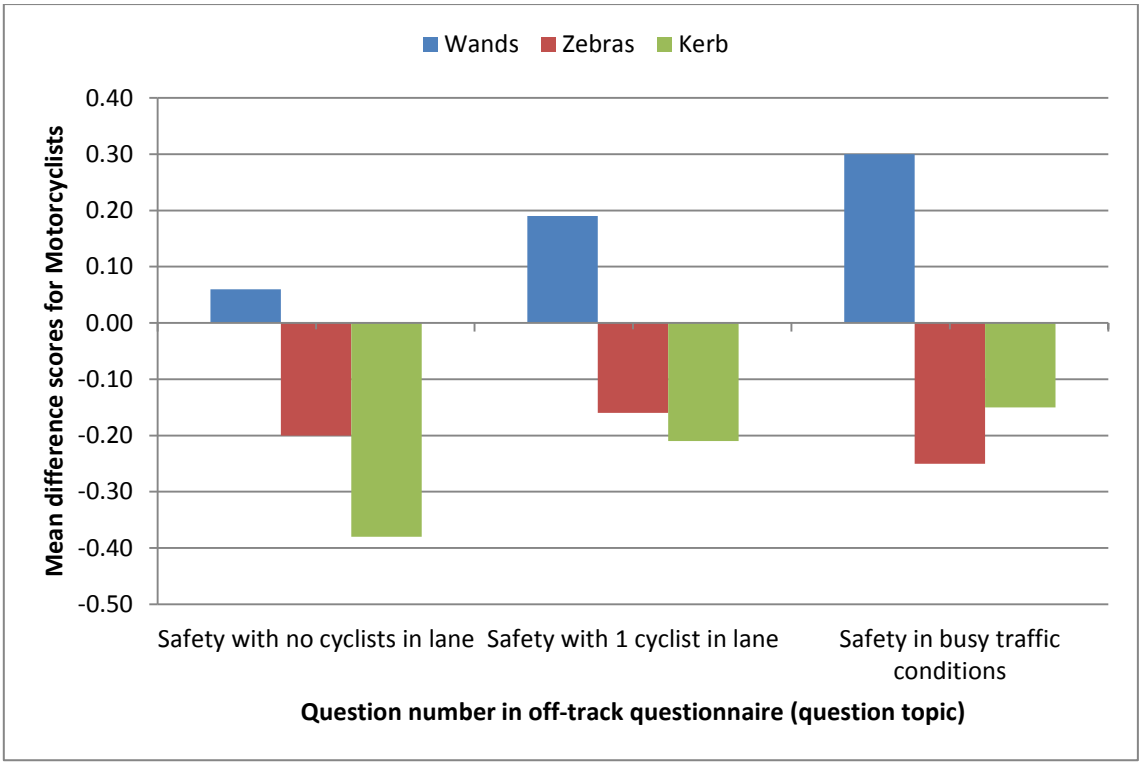

Figure 14 Mean difference scores for off-track questionnaire ratings of safety for each method of separation (positive difference indicates physical method rated safer than white line, negative differences indicates the opposite).

These results indicate that the method of physical cycle lane separation made little difference to the safety perceptions of car drivers and HGV drivers, but some difference to the perceptions of motorcyclists. The wands were viewed by motorcyclists as more beneficial to safety than the Ziclas and the kerb.

3.3.2 Lateral position of vehicles within lane

The lateral position of drivers within the road (i.e. the distance between the right-hand edge of the cycle lane separation and the right-hand wheel on the vehicle, in metres) was measured using traffic counters. Lateral position was calculated by subtracting the mean position measurement on the white line cycle lane from position measurements on the physically separated cycle lanes (see Equation 5).

Equation 5:	*Position difference = Treatment position - Mean control position*

…where the treatment positions were individual measurements of lateral position (m) on the main carriageway adjacent to the physically separated cycle lanes (i.e. wands, Zebras, kerb) and the mean control positions were the mean position (m) measurements on the main carriageway adjacent to the non-physically separated cycle lane (i.e. the white line).

Statistical analysis revealed a significant overall effect of separation method on the lateral position of all driver groups. The position differences as calculated by Equation 5 may be equated to absolute positions of drivers in the road by normalising the means relative to a baseline. Table 6 shows these position measurements under the assumption that this baseline is equal to the mean position of drivers when navigating past the white

line separation method (i.e. 2.3 m, 1.2 m and 2.5 m from the cycle lane separation for car drivers, motorcyclists and HGV drivers, respectively).

Table 6 Mean absolute lateral position (m) of drivers in road (distance from cycle lane separation), normalised to mean position with the white line separation.

Participant type	Normalised absolute position (m) [White line (i.e. 2.3/1.2/2.5 m) + mean difference]			
	White line	Wands	Zebras	Kerb
Car drivers	2.3	2.62	2.39	2.49
Motorcyclists	1.2	1.67	1.55	1.78
HGV drivers	2.5	2.83	2.66	2.65

Relative to this baseline position, car drivers travelled, on average, around 230 mm further away from the wands than from the Zebras. Similarly, motorcyclists travelled 230 mm further from the edge of the kerb separation, and 170 mm further from the wand separation compared to when driving past the Zebras. HGV drivers travelled around 120 mm further from the wands than the Zebras.

All driver groups allowed a wider clearance between the wand separation and the vehicle than when passing the cycle lane separated by Zebras. Relative to the white line separation, motorcyclists travelled closer to the Zebras than the other physical separation methods and travelled furthest from the kerb. Motorcyclists rated the Ziclas as less safe than the wands yet tended to travel closer to the Zebras than the other methods.

3.4 Further comments

Qualitative comments about each of the methods of cycle lane separation obtained from the off-track questionnaire are listed in the Appendices document. From these comments it was possible to identify a number of common themes:

- Car drivers generally preferred to use the route with physical separation between the main carriageway and the cycle lane, as the separation improved the feeling of safety.
- Conspicuity of the Zebras may be improved through use of white paint or reflective material.
- Some concern was expressed over the impact of separated lanes on congestion in busy areas.
- More than 20 participants (majority motorcyclists) considered the Zebras to be a potential hazard for cyclists and motorcyclists, with an increased risk of injury.
- The exit of the cycle lane caused confusion due to lack of signing, for both car drivers and motorcyclists. Some participants expressed concern that drivers may speed up to 'beat' cyclists to the end of the cycle lane, causing risk of conflict.
- Concerns were raised by some motorcyclist participants over the potential for road narrowing if cycle lanes were introduced.

3.5 Summary and conclusion

The key findings related to each driver group are summarised below.

Car drivers

- Physical separation improved car driver understanding of the cycle lane markings over non-physical separation, but no substantial differences were observed between the three physical methods.
- Car drivers found navigating the route was easier with all kinds of physical separation compared to when the cycle lane was separated only by a painted white line.
- Compared to the white line separation, car drivers' perceptions of safety were greater with all types of physical separation.
- Measurements of the lateral position of cars within the road showed that drivers allowed a wider clearance from the wands and the kerb than from the Zebras.
- Qualitative comments received from car drivers stated that the exit of the cycle lane caused confusion due to lack of signing and ambiguity over who has right-of-way. Some participants also suggested that drivers may speed up in order to 'beat' cyclists to the end of the cycle lane, increasing the risk of conflict.

Motorcyclists

- The wand separation was seen as a useful measure for distinguishing the cycle lane for motorcyclists, but the Zebra and kerb separation were not rated as highly.
- Contrary to car drivers, motorcyclists preferred the markings on the white line separation over the kerb separation.
- Compared to the white line separation, motorcyclists found it easier to navigate the route when the cycle lane was separated by wands, but not when separated by Zebras or a kerb. The white line separation was rated higher by motorcyclists than both the Zebras and the kerb, suggesting the addition of these separation methods increased the difficulty of the riding task.
- Motorcyclists only showed greater safety ratings with the wand separation compared to the white line separation. Zebra and kerb separation was perceived to be less safe by motorcyclists than the white line, supporting the finding that motorcyclists found it harder to navigate the route with these separations.
- Motorcyclists allowed a wider clearance from the wands and the kerb than from the Zebras.
- Motorcyclists rated the Zebras as less safe than the wands yet tended to travel slower past the wands and closer to the Zebras than the other methods. This suggests that motorcyclists did not adjust their riding behaviour to compensate for their reduced feeling of safety.
- Qualitative comments received from motorcyclists indicated that the exit of the cycle lane caused confusion due to lack of signing and confusion over who has right-of-way. In addition, a large number of participants considered the Zebras as potential hazards for cyclists and motorcyclists, with an increased risk of collision

and injury. It was also noted by some participants that the conspicuity of the Zebras may be improved through the use of white paint or reflective material.

HGV drivers

- HGV drivers showed a preference for the wands over the Zebras, but few statistically significant effects were found.
- HGV drivers considered the wands to be safer than the white line but the Zebras to be less safe than the white line.
- HGV drivers allowed a wider clearance from the wands than from the Zebras.

Generally, ratings of perceived safety and usability were high, indicating drivers felt fairly safe and found it fairly easy to navigate past the cycle lanes. However, analysis of driver behaviour and responses from this trial indicated small but significant differences between the separation methods.

- Car drivers considered physical separation methods to be easier to navigate past and safer than non-physical methods; the type of physical separation did not appear to greatly impact on car driver perceptions but it did influence the choice of lane position.
- The choice of cycle lane separation method may significantly impact on the behaviour of motorcyclists, with some evidence that Zicla and kerb separation reduces the ease of navigating past the lane and reduces feelings of safety.
- Possibly, motorcyclists are aware of a greater risk of injury from collision with physical separation methods compared to car drivers, thereby increasing the cognitive load of the riding task and reducing their perceptions of safety.

Due to a reduced participant sample, data from the HGV driver group is not as robust as the other road users; however there is some evidence to suggest that HGV drivers favoured the wands over the Zebras.

4 Pedestrians

4.1 Introduction

This section presents the findings from the pedestrian behaviour trials, which investigated the influence of the method of cycle lane separation on the user behaviour and safety of 125 participant pedestrians when crossing the road.

This study took place separately from the cyclist and driver trials, in conditions with no vehicles or cyclists present. Participant pedestrians were asked to cross over the road at four alternative locations on the TRL test track. Each location contained either no cycle lane or a cycle lane separated by;

- a kerb with 365 mm hard margin (full continuous segregation with physical barrier);
- 1-m high marker posts: Jislon™ 'wands' (intermittent separation with high profile barriers); and
- bolt-on delineators: the Zicla Zebra 9™ (a type of intermittent separation with low profile barriers).

Perceptions of usability and safety were assessed via an on-track questionnaire (see Appendices) administered during the trial. This questionnaire obtained ratings related to the ease of crossing and perceived safety when crossing over one of the four sections of road (i.e. no cycle lane, wand separation, Zebra separation and kerb separation). This section collates data from this questionnaire in order to establish key findings for the pedestrian user group.

4.2 What impact did the method of cycle lane separation have on pedestrian usability?

Ratings of the ease of crossing the road were found to be significantly dependent on the method of cycle lane separation present in the crossing. Figure 15 shows the mean ratings of usability (where 1 = very hard and 5 = very easy) given by pedestrians when crossing over the road at each of the four locations. This figure shows a general trend of higher ratings (i.e. it was easier to cross) with no physical separation in the road than when there was either kerb, Zebra or wand separation present. Statistical analysis confirmed this trend revealing significantly lower ratings for the kerb separation than for the Zebra separation and wand separation. This suggests that when the cycle lane was physically separated from the main road, pedestrians found it most difficult to cross the road with the kerb separation than the other methods.

As indicated by Figure 15, usability ratings for the crossing with no physical cycle lane separation were the highest of all the crossings, and were found to be significantly greater than ratings for the Zebras, wands, and kerb. This suggests that, as expected, pedestrians found it easiest to cross the road when there were no physical barriers present.

These findings are supported by participants crossing preferences, as the crossing with kerb separation was ranked lower than both the crossing with Zebra and the crossing with no physical separation. However, no differences between pedestrian ranking of the wands and the kerb separations were found. Whilst differences in the means appear

small this finding suggests that pedestrians least favoured crossing the road where the kerb separated the cycle lane from the main carriageway.

4.3 What impact did the method of cycle lane separation have on pedestrian safety?

Pedestrians were also asked to rate their feelings of safety when crossing the road at each of the locations. Figure 15 shows mean ratings of safety (where 1 = very unsafe and 5 = very safe) given by pedestrians when crossing over the road at each of the four locations. Significant differences in safety ratings were only found between the kerb separation and the crossing where no physical separation was used. Whilst no other significant differences in perceived safety were found, this suggests that pedestrians felt less safe when crossing over the kerb separation than when crossing where no physical barrier was present. This finding is supported by participants crossing preferences, as the crossing with no physical separation was ranked higher than the crossing with kerb separation, suggesting that pedestrians preferred to cross the road where the cycle lane was not physically separated from the main carriageway.

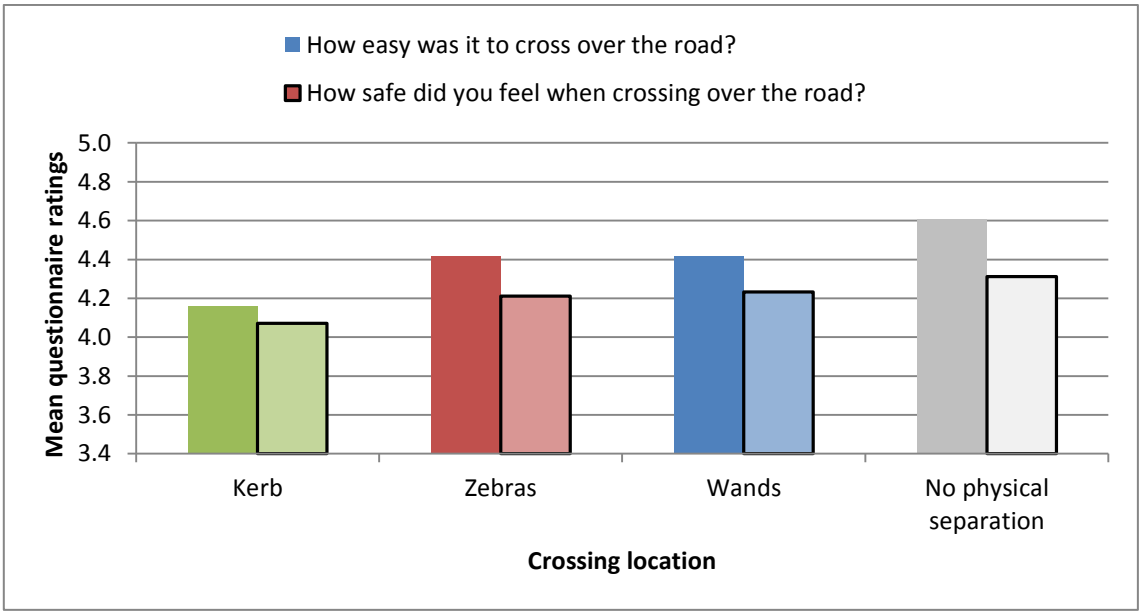

Figure 15 Mean ratings of usability (1 = very hard, 5 = very easy) and safety (1 = very unsafe, 5 = very safe) given by pedestrians when crossing the road at each of the four locations.

4.4 Further comments

Qualitative comments about each of the methods of cycle lane separation obtained from the on-track questionnaire are listed in the Appendices document. From these comments it was possible to identify a number of common themes:

- The physical separation methods were viewed as potential trip hazards when crossing the road.
- It was viewed that mobility impaired users who are partially sighted or require the use of wheelchairs or walking aids may find crossing difficult/impossible with the physical separation methods, particularly the kerb (although this trial did not explicitly include any mobility impaired users).

- If crossing the road in a busy crowd, the wands may hinder pedestrian flow and cause congestion.
- It would be very difficult to cross over with the physical separation methods if pushing a pram or pulling a trolley/suitcase.
- The kerb separation was considered beneficial over other methods by some pedestrians in that it may help to act as an intermittent 'island' between road traffic and cycle lane traffic.
- The perceptions of usability and safety may be different if asked to cross the road in the presence of cyclists and vehicles; variables which were not included in this trial.

4.5 Summary and conclusion

Differences in the mean ratings of usability and safety were small, but statistically significant. It is clear from the questionnaire responses that the majority of pedestrians preferred to cross the road in the location where there was no physical barrier separating cycle lane and main carriageway, i.e. pedestrians found it easiest to cross at this location and felt most safe when doing so. When faced with one of the three methods of physical separation (i.e. wands, Zebras or a kerb), pedestrian ratings indicated that the kerb separation was least favourable due to increased difficulty of crossing and lower safety.

Qualitative data obtained during the trial highlighted a number of concerns expressed by participants with crossing over the physical separation methods, including that there might be increased difficulty for mobility impaired pedestrians and those pushing prams or wheeling trolleys.

Use of physical separation methods in areas with a high pedestrian flow on the footway would require consideration of dedicated controlled or uncontrolled crossing points to allow pedestrians to safely and easily cross over the cycle lane and road.

5 Summary and conclusion

The research presented in this report investigated the influence of the method of separating cycle lanes from the main carriageway on the perceptions and behaviours of cyclists using the cycle lane, drivers navigating past the cycle lane, and pedestrians crossing the road and cycle lane. Measures of usability and safety were obtained for all road user groups via subjective questionnaires and traffic survey counters whilst simulating simple traffic scenarios on mock sections of road on the TRL test track. The study found small but statistically significant effects of the type of cycle lane separation on the safety and usability of cyclists, drivers and pedestrians. Findings from multiple measures (e.g. on- and off-track questionnaires, and traffic counters) showed a consistent pattern enabling clear conclusions to be drawn.

In general, cyclist, driver and pedestrian ratings of perceived usability and safety were high for all separations (wands, Zebras, kerb and white line) indicating that all four methods were viewed as fairly safe and fairly easy to use. Nonetheless, statistically significant differences were found between the methods, indicating small but distinct variations in the perceptions and behaviour of the different road users.. These differences are summarised below.

5.1 Cyclist behaviour

The use of physical separation methods can offer a significant benefit to the usability and safety of cyclists.

- Continuous separation of the cycle lane from the main carriageway via a solid kerb with a 365 mm hard margin was viewed as the easiest to use by cyclists. In support of this finding, cyclists also travelled fastest through the kerb separated cycle lane.
- The kerb separation, as well as intermittent separation via 1-m high wands, also provided an increased perception of safety for cyclists, particularly when cyclists were asked to imagine using the separated lanes in busy town centre traffic.
- Cyclists generally used more of the available cycle lane (i.e. travelled closer to the main carriageway) when using wand separation than when using both the Zebra and kerb separation, supporting the findings from the questionnaire ratings suggesting that they felt safest when protected by wands. There was, however, some evidence to suggest that the amount of space used by cyclists travelling in the wand cycle lane reduced in the presence of a passing car.

5.2 Driver behaviour

The usability and safety of car drivers may also be improved through the use of physical separation methods, but the same does not apply to motorcyclists.

- Car drivers consider physical separation methods to be easier and safer to navigate past than a cycle lane separated by a painted white line.
- There is little evidence to suggest that the type of physical separation greatly impacts on car driver perceptions, but wand separation may reduce speed and increase the lateral clearance between vehicle and cycle lane.

- For motorcyclists, there is evidence to suggest that Zebra and kerb separation may be viewed as worse than separation in the form of a painted white line, with reductions in ease of navigating the route and reductions in perceived safety.

5.3 Pedestrian behaviour

Unsurprisingly, pedestrians preferred to cross the road in a location where no physical barrier was used to separate the cycle lane from the main carriageway, i.e. they found it easiest to cross and felt most safe when doing so.

- The kerb separation was least favourable due to increased difficulty of crossing and reduced safety.
- Generally, the physical separation methods were associated with increased difficulty for mobility impaired pedestrians and those pushing prams or pulling trolleys.

5.4 Implications

Clearly, there is a need to balance the requirements of all road users if physical separation methods were employed in busy town centres with a high volume and diversity of road traffic and pedestrian footfall.

- Cycle lanes with continuous kerb separation or intermittent wand separation may offer the greatest benefits to cyclists, without negatively impacting on the behaviour and perceptions of car drivers.
- Intermittent Zebra separation may offer some benefits for safety and usability of cyclists compared to a mandatory solid white line the extent of those benefits is smaller than with alternative methods of physical separation.
- Zebra separation, as well as kerb separation, may be negatively viewed by motorcyclists suggesting that the use of 1 m high wands may be optimum for the majority of road users.
- The observation that cyclists ride further out in lanes separated with wands means that they are using a greater proportion of the road space that has been re-allocated to them with this method of separation. This finding can be expressed by the 'separation efficiency ratios' shown in Table 7, which is simply the ratio of the position of the cyclist in the lane to the total road space required to create the lane. The higher ratio achieved by the wands is because they require less space in the road compared to other methods and cyclists use more of that space. This shows that the wands may be helpful in creating separated lanes where space is more constrained. However, kerb separation is typically set at 500 mm to enable physical clearance between cyclists and vehicles with large wing-mirrors (such as trucks and buses). Therefore, the implications of reducing the width of the physical 'buffer' between cyclist and traffic must also be considered, especially considering the finding that cyclists travelled closer to the wands than the kerb.
- Examining the effect of the width of the cycle lane on the ease of overtaking or passing obstructions within the lane was not within the scope of this study. Therefore, it is not possible to comment on the ease with which cyclists could navigate in-between individual wands or Zebra units.

- Use of the wands in areas with a high pedestrian flow on the footway would require consideration of dedicated crossings to allow pedestrians to safely and easily cross over the cycle lane and road. (This has been investigated in a separate TRL trial examining pedestrian crossing behaviour at a bus-stop with a cycle lane bypass).

Table 7 Road space required with each physical separation method and amount of space used by cyclists.

Physical separation method	Width of separation (m)	Total space required by separation (with 2 m cycle lane)	Average distance between cyclists and road edge (m)	Separation efficiency ratio (Position of cyclist / Total space required by separation)
Wands	0.100	2.100	1.190	**0.57**
Zebras	0.164	2.164	1.050	0.49
Kerb	0.365	2.365	1.110	0.47

Given the limitations of any off-street trial, it cannot be assumed that the same findings would be replicated in a real street environment, so further study through on-street trials is needed before definitive design recommendations can be made.

Although on-street trials of the Zicla Zebra are already under way, it is necessary to take account of the negative perceptions and behaviours from some road users, particularly cyclists and motorcyclists, observed in this off-street trial. A precautionary approach could restrict trials to streets with low traffic speeds and flows, and where road space is not constrained, to assess the extent to which concerns raised in this off-street trial are born out in practice before applying the methods in more challenging locations.

For on-street trials of any of the three methods, consideration should be given to the confusion over priorities at the end of the separated sections reported by road users in this off-street trial. This may require additional signage or markings, or wider awareness raising campaigns to ensure that all road users understand. Furthermore, when implementing any form of separated cycle lane, consideration must be given to the needs of pedestrians crossing the road, ensuring suitable gaps are provided to enable safe and comfortable crossing on key desire lines where there are no formal pedestrian crossings.

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