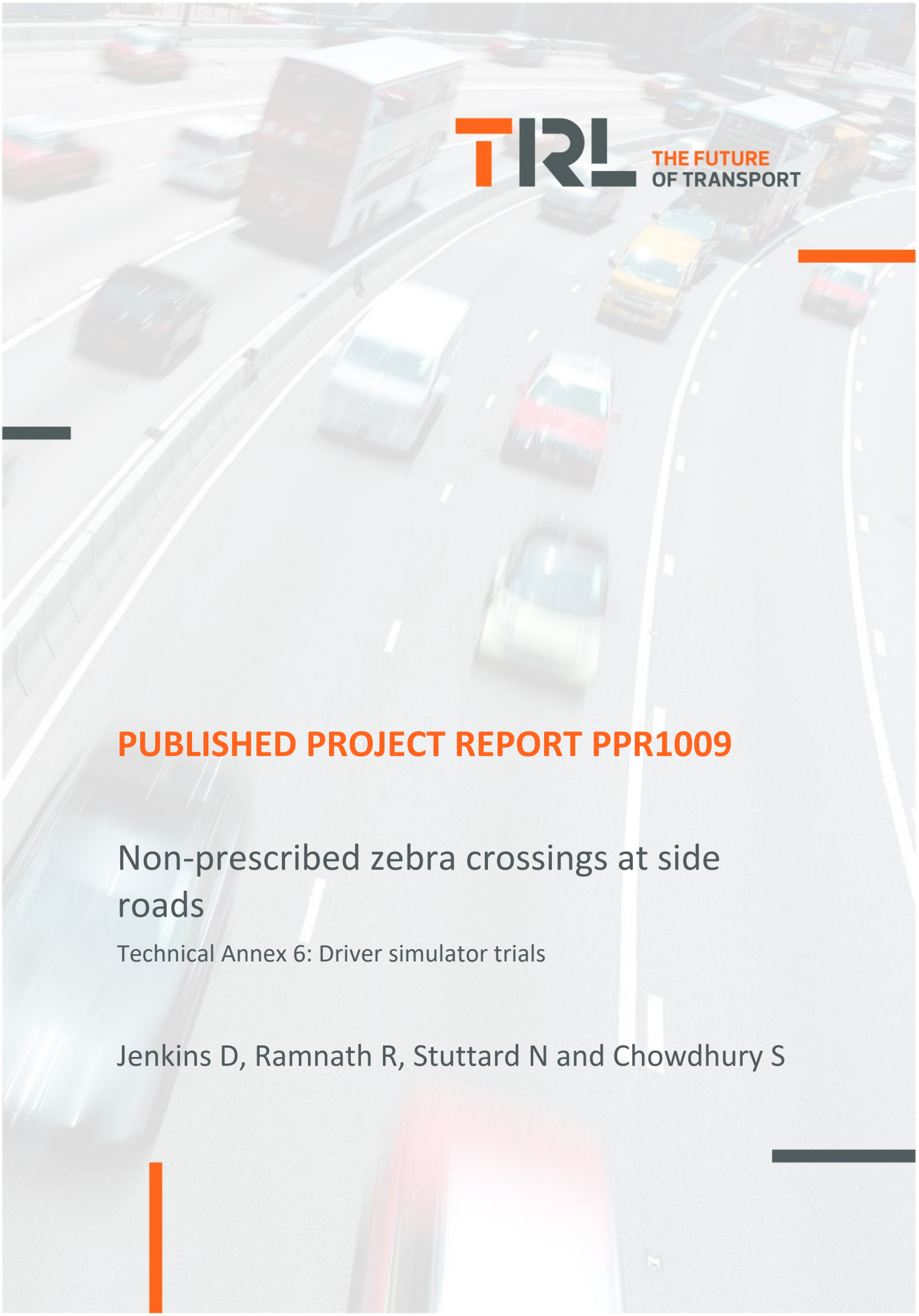

THE FUTURE OF TRANSPORT

PUBLISHED PROJECT REPORT PPR1009

Non-prescribed zebra crossings at side roads

Technical Annex 6: Driver simulator trials

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Contents

Executive Summary

This document forms a Technical Annex to the report *Trials of non-prescribed Zebra crossings at side roads: Final Report*, which presents the findings of a programme of user research and trials into the proposed use of a non-prescribed form of zebra crossing at side-roads. As part of this package of work, TRL conducted a driving simulation study in DigiCar, TRL's full mission driving simulator, to establish what effect pedestrian flow would have on driver behaviour when faced with two different non-prescribed crossing designs. This report aims to provide insight into driver comprehension of the two non-prescribed crossing designs, and whether pedestrian flow levels affected driver decisions to give way at the crossing.

Prescribed vs. non-prescribed crossings

A prescribed zebra crossing is indicated by a series of alternate black and white stripes on the carriageway with give way lines on either side; a yellow globe mounted on a black and white striped post, positioned on the pavement at each end of a zebra crossing (Belisha beacon); and the crossing area is marked with a line of studs and zigzag markings. There is no specified minimum distance that a zebra should be placed from a junction. However, in practice there is a need for a minimum of two zigzags which creates a minimum distance from a junction of about 4.8m.

A non-prescribed zebra crossing is a standard zebra crossing which uses the prescribed black and white markings without, in this case, any of the other features present on a prescribed zebra crossing. The simplified design requirements of the non-prescribed zebra crossing should lower implementation and maintenance costs for local authorities. In addition, no minimum set-back distance from a junction (due to the removal of the need for the zigzags) has an advantage of keeping pedestrians on their desired walking line, giving them a more direct route across the mouth of the junction.

Method

Two non-prescribed crossing designs, zebra and footprints, along with a conventional give way junction design with no pedestrian crossing to serve as a control, were implemented on a representative side road in a simulated urban environment. Two levels of pedestrian flow, low and high, across the side road were selected. Four specific turning variables – into the side road from the left and right, and exiting the side road from left and right – were included. Forty participants were recruited to take part in the trial and were required to complete 24 short drives, exposing them to all combinations of crossing design, pedestrian flow level and turning movement.

Main findings

The main findings from the simulator study data analysis were:

1. A non-prescribed zebra is likely to be more effective than no crossing in getting drivers to allow pedestrians to cross at side roads.
2. Any design decision need not be informed by consideration of pedestrian flow.

3. The questionnaire results show that participants unanimously comprehend that the non-prescribed zebra crossing is a form of pedestrian crossing
4. The footprints design should not be used for non-prescribed crossings.

The analysis presented in this report forms an important part of the research into non-prescribed zebra crossings but should not be considered in isolation. It is one step in a programme of research that will culminate in on-street trials. Each research project informs the design of the following ones which helps to ensure that risks are understood and managed.

2 Introduction

2.1 This document

This document forms a Technical Annex to the report Trials of non-prescribed Zebra crossings at side roads: Final Report, which presents the findings of a programme of user research and trials into the proposed use of a non-prescribed form of zebra crossing at side-roads. As part of this package of work, TRL conducted a driving simulation study in DigiCar, TRL's full mission driving simulator, to establish what effect pedestrian flow would have on driver behaviour when faced with two different non-prescribed crossing designs. This report aims to provide insight into driver comprehension of the two non-prescribed crossing designs, and whether pedestrian flow levels affected driver decisions to give way at the crossing.

2.2 Background

Transport for Greater Manchester (TfGM) commissioned TRL to undertake a programme of research looking at the use of non-prescribed zebra crossings at side roads. This programme is comprised of a number of research projects, designed to provide evidence for the Department for Transport (DfT) regarding whether this form of crossing should be given regulatory approval. The programme incorporated a number of interdependent but standalone research questions, covering areas such as public understanding, effectiveness of alternative markings, and levels of interaction before and after application. The results of the research undertaken to answer the research questions will culminate in a final report making design recommendations for side road zebra crossings.

The markings, equipment and signs used to denote a zebra crossing in the UK are prescribed in statutory government regulations. Key differences between a prescribed and non-prescribed zebra crossing are shown in Table 1. A prescribed zebra crossing is indicated by a series of alternate black and white stripes on the carriageway; a yellow globe is positioned at each end of the crossing (commonly referred to as a Belisha beacon); and the crossing area is marked with a line of studs; give ways lines and zigzag markings. The requirement for at least two zigzag markings means the minimum a zebra can be set-back from the mouth of a side road is about 5 metres.

Conversely, non-prescribed crossings exclude some or all the following: studs, zigzag markings and Belisha beacons. A simplification in the crossing could lower implementation and maintenance costs for TfGM and local authorities. In addition, removing the requirement for zigzag markings (and therefore the need for a 5-metre set-back) has the advantage of keeping pedestrians on their desired walking line, giving them a more direct route across the mouth of the junction.

Table 1: Key differences between a prescribed and a non-prescribed zebra crossing

Design feature	Prescribed zebra crossing	Non-prescribed zebra crossing
Crossing markings	Black and white stripes and give way markings	Black and white stripes
Peripheral	Line of studs	May include zigzag markings on one or both

markings	Zigzag markings	sides of the crossing
Set-back distance from junction	The requirement for at least two zigzag markings creates a minimum set-back distance of around 5 metres	No minimum distance, could be flush with the end of the side road
Additional equipment	Yellow globe on a black and white striped pole (Belisha beacon)	

Both prescribed and non-prescribed crossings are intended to give pedestrians wishing to cross the side road priority over vehicles; this applies to vehicles on the side road approaching the junction, and to vehicles on the main road wishing to turn into the side road. Drivers (and to a lesser extent pedestrians) have a short time in which to determine what to do when confronted with an unfamiliar road layout. The key to effective road markings is the ability to quickly and accurately convey the intended message to road users, so that both drivers and pedestrians can intuitively take appropriate action.

As part of the overall programme of research, this study focused on how the quantity and spacing of pedestrians (i.e. the 'pedestrian flow') approaching the crossing influenced driver behaviour, and aimed to answer the following research question:

What is the effect of different pedestrian flows on the propensity for vehicles to give way to pedestrians on side roads with alternative crossing markings?

During the development of the simulator study, a complementary work package from this programme of research, 'Non-prescribed Zebra crossings at side roads – Effectiveness of Alternative markings' (CPR2735), was completed which looked at comprehension of alternative crossing designs. Following consultation with TfGM it was agreed that the highest scoring alternative design would also be tested in the simulator trial alongside the non-prescribed zebra design. In order to incorporate the pedestrian flow as a factor and get a holistic understanding of the impact of crossing design and pedestrian flow, the two research questions were:

1. *What is the effect of alternative pedestrian crossing markings on the propensity for vehicles to give way to pedestrians on side roads?*
2. *What is the effect of different pedestrian flows on the propensity for vehicles to give way to pedestrians on side roads with and alternative crossing markings?*

3 Method

3.1 Overview

3.1.1 DigiCar driving simulator

The simulated environments were implemented in DigiCar; TRL's advanced driving simulator. DigiCar consists of a production vehicle (Peugeot 3008) with fully operational controls surrounded by curved front screens and a rear screen for a 300˚ field of view (as shown in Figure 3). The screens enable normal rear and wing mirror use. It recreates high fidelity test environments that accurately reflect real-world driving conditions. The car has electric actuators which supply motion with 3 degrees of freedom (heave, pitch and roll). Engine noise, external road noise, and traffic sounds are provided by a stereo sound system. Driver interaction with the vehicle controls was captured directly from the vehicle CAN BUS at a frequency of 20Hz. Figure 1 shows the driving simulator used.

Figure 1: TRL's DigiCar driving simulator

3.1.2 Test route

An existing urban route model was identified from TRL's library of simulator environments as a suitable basis for the development of the scenarios required. The route was generic in nature (i.e. not based on an actual location) however all features within the model were accurate in line with current road design regulations and principles. This meant that all lane

widths, road markings and other visual characteristics were as a participant would experience them in the real world.

Within this route, one side road was selected as the location for incorporating the crossing designs. The side road was open to two-way traffic and exiting onto the main road to which it adjoined. When exiting the side road, sightlines determined by the presence of building and slight curvature of the road meant that participants would be required to slow considerably before reaching the junction. When turning into the side road from the main road, standard height kerbs obscured the mouth of the junction, and therefore the presence of the crossing, until the participant was relatively close. When approaching from the left the main road displayed some curvature prior to the side road. When turning into the side road from the right, the approach was straight.

3.1.3 Participants

Forty participants completed the study, recruited from the TRL participant database, social media channels and friends and family of TRL staff. The study was due to start as the second national lockdown started in November 2020. As a result, TRL's Compliance department advised it would not be appropriate to ask members of the public to attend the TRL offices to participate in the study. Therefore, it was agreed with TfGM that the first 10 participants could be TRL staff, providing they had no previous knowledge of the project and did not work within the departments involved in the study. The remaining 30 participants were members of the public.

Participants were required to meet the following criteria:

- Holder of a current drivers' licence
- Minimum 3 years' driving experience
- Regular drivers (at least once a week)
- Aged between 21 – 70 years old

In addition, we aimed to recruit an approximately equal split of males and females.

Participants were offered a £30 online shopping voucher as compensation for their time.

3.1.4 Research Questions

The combination of the four vehicle movements, two pedestrian flow levels and three crossing types created a total of 24 different conditions. Each condition was tested in a separate drive in the simulator. A repeated measures study design was employed, whereby all participants experienced all 24 conditions. Each participant therefore completed 24 trial drives in total, plus a familiarisation drive

To understand the impact of the crossing types and pedestrian flow, the main research question was split into two research questions. The first question looked to understand the impact of the crossing type, independent of pedestrian flow. The second research question concerned the impact of pedestrian flow along with the crossing type. For both questions, each turning movement was investigated independently. For each question, we present the null (H_0) and alternative hypotheses (H_1).

Research Question 1: What is the effect of pedestrian crossing markings on the propensity for vehicles to give way to pedestrians on side roads?

> **H_0**: There will be no change in propensity for vehicles to give way to pedestrians irrespective of the presence or absence of crossing markings.
>
> **H_1**: There will be a change in propensity for vehicles to give way to pedestrians with and without crossing markings.

Research Question 2: What is the effect of different pedestrian flows on the propensity for vehicles to give way to pedestrians on side roads with and without pedestrian crossing markings?

> **H_0**: There will be no change in propensity for vehicles to give way to pedestrians irrespective of the pedestrian flow.
>
> **H_1**: There will be a change in propensity for vehicles to give way to pedestrians at different pedestrian flows.

3.2 Variables

Three dependent variables, and one control variable were present in all drives. The variables and their levels are presented in Table 2, below.

Table 2: Variables for the driving simulator study

Variable	Levels	No. Levels
Crossing type	Footprints Non-prescribed zebra No crossing (control)	3
Vehicle movement	Left turn into side road Right turn into side road Left turn out of side road Right turn out of side road	4
Pedestrian flow	Low High	2
Vehicle flow (control variable)	Vehicle following behind participant vehicle High flow traffic on main road for both right turn movements	N/A
Total number of conditions		24

The combination of the four vehicle movements, two pedestrian flow levels and three crossing types created a total of 24 different conditions. Each condition was tested in a separate drive in the simulator. A repeated measures study design was employed, whereby

all participants experienced all 24 conditions. Each participant therefore completed 24 trial drives in total, plus a familiarisation drive.

3.2.1 Crossing types

There were three crossing type conditions:

- A control condition with no formal crossing;
- A condition with a non-prescribed zebra crossing. The non-prescribed zebra crossing consisted of black and white stripe markings only, with no other supporting markings or features. It aligned with pedestrians desired walking line, flush with the mouth of the side road; and
- A condition with an alternative crossing design (a 'footprints' crossing – see below).

The alternative crossing design was selected based on an earlier phase of the project, 'Effectiveness of Zebra Marking Alternatives' (CPR2735). This involved a participant response time trial to images of different crossing designs, followed by a questionnaire, to identify which designs were most identified as crossings. The non-prescribed zebra crossing was used in the simulator study because it performed best in the image-based study on all measures, including recognition, identification and safety. The design that was most clearly understood of the alternative designs was one made up of solid footprint patterns of various sizes. On this basis it was decided to include the footprints design in the simulator study as an additional crossing variable to see if the findings of the two research questions aligned

There were three crossing type conditions. A control condition where no formal pedestrian crossing is present and a condition with a non-prescribed zebra crossing. A non-prescribed zebra crossing consists of black and white stripe markings only. It is aligned with pedestrians desired walking line, either flush with the mouth of the side road or in line with the footpath.

3.2.2 *Pedestrian flow*

Pedestrian flow was set at two levels, 'low' and 'high'. Low pedestrian flow consisted of a group of four pedestrians, evenly spaced and walking at a constant pace. High pedestrian flow consisted of two groups of four pedestrians, with a gap set between the two groups. The gap was set to be large enough for a car to fit through and was designed to present participants with the opportunity to proceed to drive over the crossing in between the two pedestrian groups.

Movement of a pedestrian group towards the crossing was triggered when the driven vehicle reached a pre-set distance from the crossing. This distance differed depending on the turning manoeuvre (although it was the same for both left and right turns out of the side road). In each case it was designed, given an average approach speed, such that the participant would arrive at the crossing at the same time as the first pedestrian was preparing to cross.

Once the first pedestrian of a group started to cross, the other three pedestrians in the group were programmed to follow them, with only a small gap (1.2 metres) between them, insufficient for a vehicle to fit through. In low flow scenarios, once all four pedestrians had

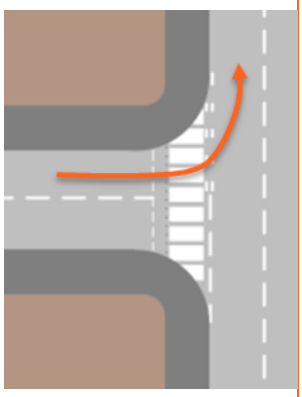
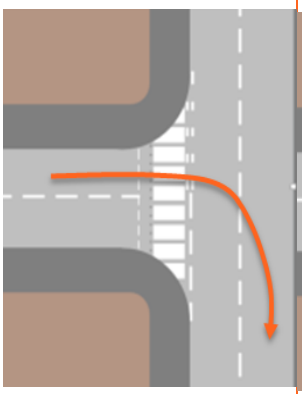
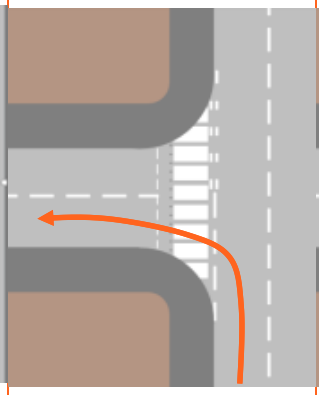
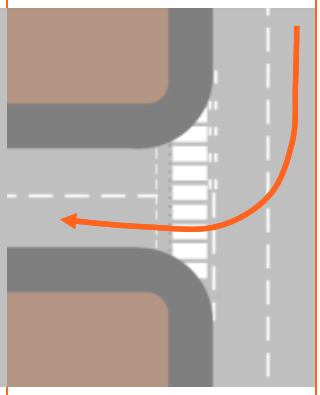
crossed they continued to walk a short distance beyond the junction before turning round and approaching the crossing again. For high flow scenarios, once both groups had traversed the crossing they both travelled a short distance beyond the crossing before both turning and approaching the crossing again. The distance between each group of pedestrians in the high flow scenario was 8.6 metres. Figure 2 below shows an example of two groups of pedestrians crossing.

Figure 2: Example pedestrian crossing scenario showing the gap between two groups of pedestrians and the gap between individual pedestrians

3.2.3 *Vehicle movements*

There were four vehicle movements. Table 3 below visually presents and describes the movements.

Table 3: Description of the four different vehicle movements (non-prescribed zebra shown as an example in each case).

1. Out of side road (left)	1. Out of side road (right)	2. Into side road (left)	3. Into side road (right)
			
The participant approaches the junction from the side road and turns left onto the main road.	The participant approaches the junction from the side road and turns right onto the main road.	The participant makes a left-hand turn from the main road into the side road.	The participant makes a right-hand turn from the main road into the side road.

3.2.4 *Vehicle flow*

To help create a realistic urban environment, traffic was introduced in all scenarios. When turning right out of the junction, participants were faced with traffic approaching from the right. When turning right into the junction, participants encountered traffic coming towards them. Traffic was triggered at the same point for all participants, based on their distance away from the junction. When turning out of the junction, traffic was triggered 85 metres before the crossing. When turning into the junction, traffic was triggered 120 metres prior to the crossing.

In addition, for all scenarios, a vehicle was present behind the participant's vehicle, visible to the participant through the side and rear-view mirrors of the DigiCar simulator. This following vehicle was designed to further increase realism and to create an element of pressure when making a decision about whether to turn or not.

3.3 Data analysis

3.3.1 Simulator data

3.3.1.1 Visual presentation of results

The results from the simulator study have been presented in the form of boxplots. Boxplots display the variation in the sample through their quartiles. The central line within a boxplot

shows the median and the two ends of the box show the first and third quartile respectively. All outliers are presented outside the box.

The red point for each group shows the mean of the group whereas the black points show the time spent in the ZOI for each individual participant.

3.3.1.2 Statistical tests

Appropriate statistical tests were used to test for significant differences in the time drivers spent in the ZOIs during each drive:

- A one-way repeated measures ANOVA was used to test for significant differences between crossing types (non-prescribed zebra, footprints or no crossing - control) (Research Question 1).
- A two-way repeated measures ANOVA was used to test for significant differences between crossing types (control, non-prescribed zebra and footprints) and pedestrian flow (high or low) (Research Question 2). Where significant main effects were identified from these tests, post-hoc comparisons using paired t-tests or Wilcoxon (non-parametric alternative) were applied to compare each factor level.
- Note: ANOVAs are reliant on parametric data assumptions being met, including the data having a normal distribution. In some cases, this assumption was not met, and as such a non-parametric alternative (the Friedman test) was applied instead.

Results were classified as 'statistically significant' if the p-value was less than 0.05 (a common standard in behavioural science). The p-value is a measure of probability, and a value of less than 0.05 implies that any differences between the groups being tested has a less than 5% chance that the difference occurred at random.

While p-values obtained from statistical tests are used to inform whether an effect exists, they do not give much information about the size of the effect. In such cases, an effect size is calculated to measure the magnitude of the phenomenon or the degree of association between two variables. Generally, an effect size of less than 0.09 denotes a small effect, between 0.1 and 0.25 is a medium effect and over 0.26 denotes a large effect (Gravetter & Wallnau, 2013). Throughout the report, the effect size has been reported if any result is statistically significant to understand the magnitude of the relationship between two variables.

3.3.2 Post-trial questionnaire data

The post-trial questionnaire (PTQ) was made up of quantitative, multiple choice questions as well as qualitative, open questions (see Appendix A). This mixed methods approach allowed rich data to be captured and analysed in an effective manner with quantitative data analysis providing measurable and comparable results and qualitative data providing context and deeper understanding of participants' responses.

The questionnaire was designed to examine how easy or difficult the participants found it to give way to pedestrians crossing the road; these data were compared between the two different crossing designs (and the control condition with no crossing), and between vehicle movements (approaching from the main road and approaching from the side road). The

questionnaire also examined whether the participants understood that the crossing designs were pedestrian crossings (i.e. by measuring the self-reported ease of identifying the presence of a crossing). Images taken directly from the driving simulator environment were presented in the questionnaire to provide context.

The quantitative questionnaire data were analysed and tabulated/graphed for each question by crossing design (non-prescribed zebra design vs footprints design vs no crossing) and approach (side road vs main road). Pedestrian flow was not considered in this analysis, as this was not measured or controlled in the post-trial questionnaire.

The qualitative data, from the open questions, were collected and analysed in order to confirm the findings from the quantitative questionnaire data. This allowed for additional feedback and insight into the participants' quantitative answers. Quotes are provided after the summary of each of the quantitative questions, to give examples of participants' responses. Demographics of the overall sample are also presented.

4 Results

4.1 Demographics of the sample

In total, forty participants completed the study. Table 4 presents the age and gender distribution in the sample.

Table 4: Age and gender distribution of the sample (drivers)

Age	Female	Male	Total
17-24 years	0	1	1
25-34 years	6	6	12
35-44 years	4	6	10
45-54 years	0	5	5
55-64 years	2	5	7
65-70 years	2	3	5
Total	**14**	**26**	**40**

There was a good spread across most age groups, although there was only one participant in the 17-24 years old group. 65% of the sample were male.

4.2 Driver behaviour: Simulator data results

This section presents the results of driving behaviour of the participants at the different crossing types. As mentioned in section 3.2 each participant completed 24 drives (four different turning movements, three crossing types, two levels of pedestrian flow).

Zones of interest were created for each drive, at the point in the road where participants would be expected to wait before going over the crossing. The time spent in these zones of interest (ZOI) was the primary metric used to understand the propensity of participants to give way to pedestrians at different crossing types.

4.2.1 *Research Question 1*

This section looks at the effect of crossing types (non-prescribed zebra, footprints and no crossing) on the propensity for vehicles to give way to pedestrians on the side road. The results are presented in boxplots where the red point is the mean for the crossing type and the black points refer to each individual participant.

4.2.1.1 *Turning right out of the side road*

Figure 3 shows the distribution of time spent within the ZOI by each participant (black points) and the average for each group (red points), when drivers turned right out of the side road onto the main road.

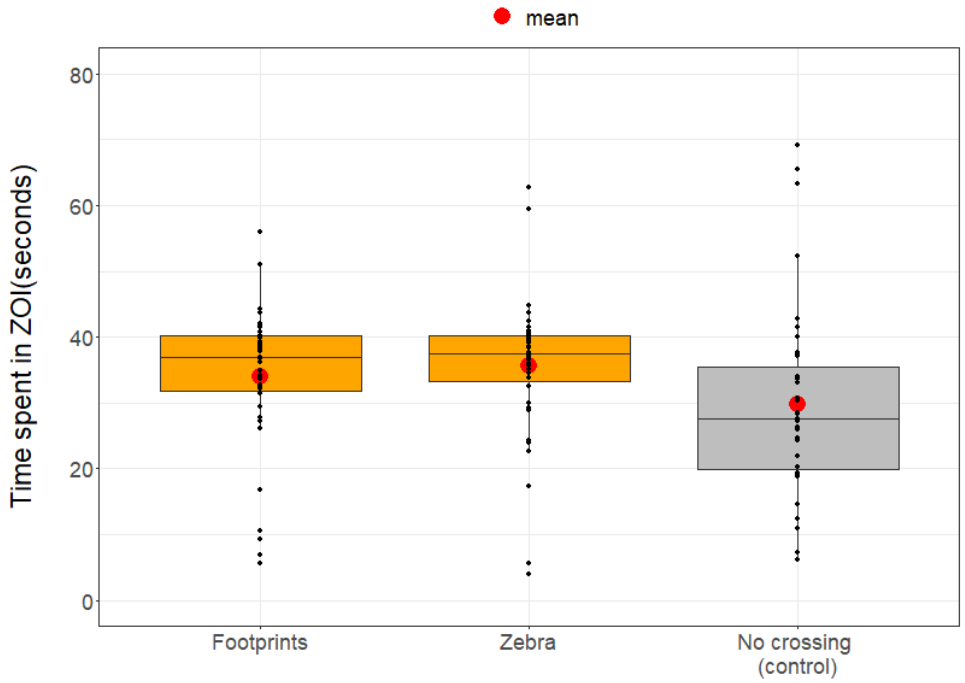


Figure 3: Distribution of time spent in ZOI by crossing type when turning right out of the side road

On average, participants spent less time (29 seconds) in the ZOI for the control drive compared to drives with the footprints (34 seconds) and non-prescribed zebra (35 seconds) crossings at the junction. However, the variation in time spent in the ZOI was much larger for the control drive with no crossing compared to the drives with a crossing.

Statistical tests showed a significant difference in time spent in the ZOI by crossing type (p=0.03) with a small effect size of 0.08. Pairwise comparison showed a significant difference between the no crossing condition and the footprint crossing condition (p=0.04), and between no crossing and zebra crossing conditions (p=0.03); however, there was no significant difference between the zebra and footprints crossing conditions (p=0.93). This suggests that participants propensity to give way to pedestrians was higher for both non-prescribed zebra and footprints crossing compared to the control no crossing condition.

4.2.1.2 *Turning right into the side road*

The distribution of time spent within the ZOI for each crossing type when drivers turned right into the side road from the main road is shown in Figure 4.

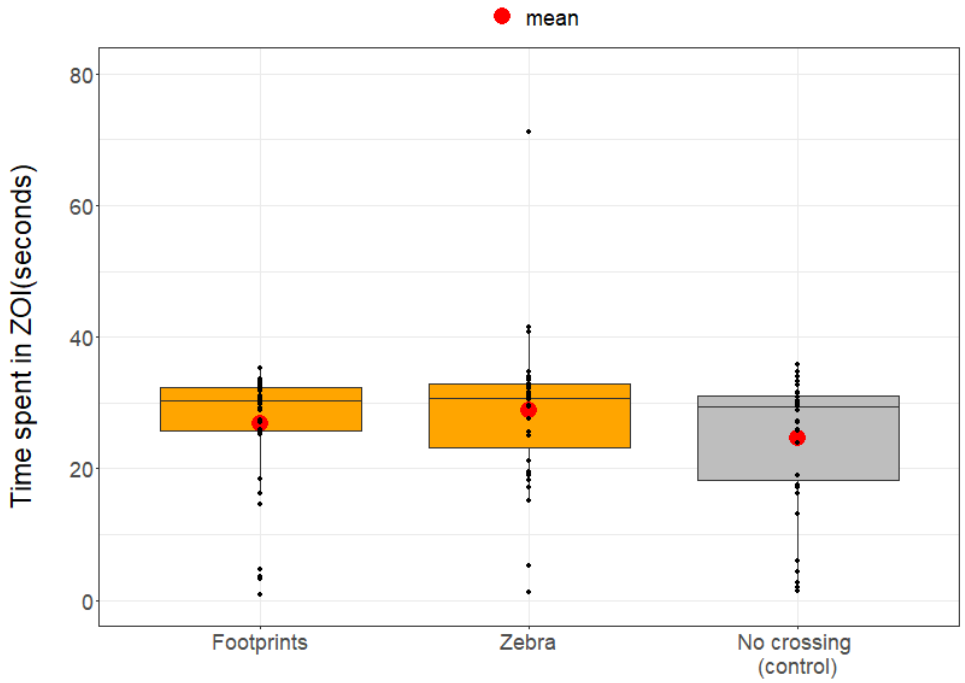


Figure 4: Distribution of time spent in ZOI by crossing type when turning right into the side road

The average time spent in the ZOI was shortest for the no crossing condition (24 seconds), followed by footprint crossing (26 seconds) and non-prescribed zebra crossing (28 seconds) conditions, but the mean values were similar.

Statistical tests confirmed there was no significant difference in time spent in the ZOI by crossing type (p=0.27). This suggests that when turning right into the side road from the main road, the propensity to give way to pedestrians did not differ by crossing type.

4.2.1.3 *Turning left into the side road*

Figure 5 shows the distribution of time spent within the ZOI when drivers turned left into the side road from the main road. Individual driver points are shown in black and the average is shown in red.

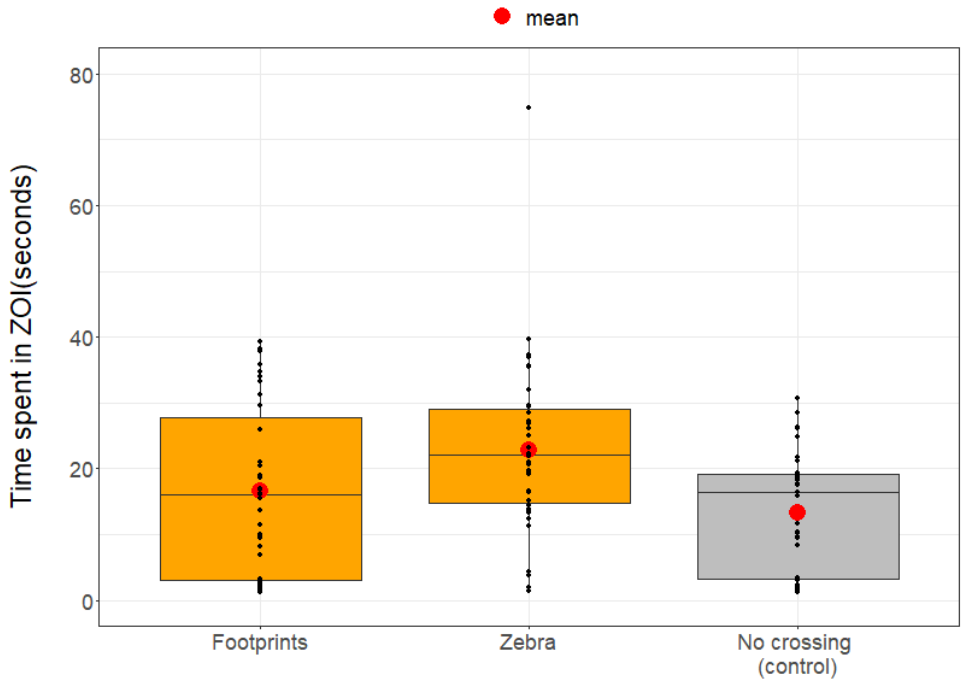


Figure 5: Distribution of time spent in ZOI by crossing type when turning left into the side road

The average amount of time spent in the ZOI was shortest for the no crossing condition (13 seconds), followed by the footprint crossing (16 seconds) and non-prescribed zebra crossing (22 seconds) conditions. In this case, the participant level variation in time spent within the ZOI was higher for the junctions with a footprint crossing compared to a junction with no crossing.

Statistical tests showed a significant difference in time spent within the ZOI by crossing type ($p<0.01$) with a small effect size of 0.22. Post-hoc comparisons showed that there was a significant difference between the no crossing condition and non-prescribed zebra crossing condition ($p=0.02$) and between the non-prescribed zebra crossing condition and footprints crossing condition ($p<0.01$). However, the difference between non-prescribed footprints and no crossing condition was not significant ($p=0.25$). This suggests that when turning left into the side road, participant's propensity to give way to pedestrians was higher for the non-prescribed zebra crossing condition compared to the footprints crossing condition, and higher than the control no crossing condition.

4.2.1.4 *Turning left out of the side road*

Figure 6 shows the distribution of time spent within the ZOI by crossing type when the participant's car turned left out of the side road.

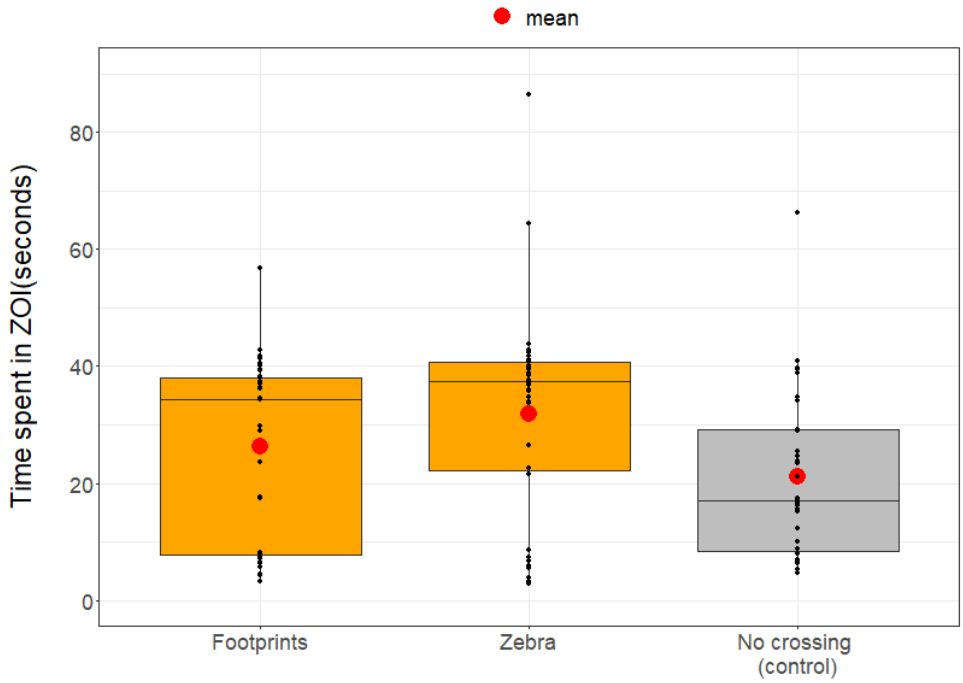


Figure 6: Distribution of time spent in ZOI by crossing type when turning left out of the side road

On average, the time spent within the ZOI was shortest for the no crossing condition (21 seconds), followed by the footprints (26 seconds) and non-prescribed zebra crossing (31 seconds) conditions. Participant level variation was the highest for the footprints condition; here one subset of participants spent less than 10 seconds in the ZOI whereas another group spent over 30 seconds. This may be due to the fact that some participants drove past the crossing before any pedestrians passed through whereas others waited for longer expecting more pedestrians to pass before driving through.

Statistical tests showed a significant difference in time spent within the ZOI by crossing type ($p<0.01$) with a medium effect size of 0.11. Post-hoc comparisons showed a significant difference between the non-prescribed zebra crossing condition and the control condition with no crossing ($p<0.0.009$). However, there was no significant difference between the non-prescribed zebra crossing and footprints ($p=0.70$); and non-prescribed footprints and control conditions with no crossing ($p=0.07$). This suggests that participants propensity to give way to pedestrians was higher for the non-prescribed zebra crossing condition compared to the control condition. However, that was not the case for the footprints crossing condition when compared to the control condition.

4.2.2 *Research Question 2*

This section looks at the effect of pedestrian flow on the propensity for vehicles to give way to pedestrians on side roads with and without crossings. The propensity to give way is determined by looking at the time spent within the zone of interest. The graphs in this section are similar to those in section 4.2.1 (Research Question 1), however, they include an additional variable, pedestrian flow.

4.2.2.1 *Turning right out of the side road*

The distribution of time spent within the ZOI for drivers turning right out of the side road is shown in Figure 7 below.

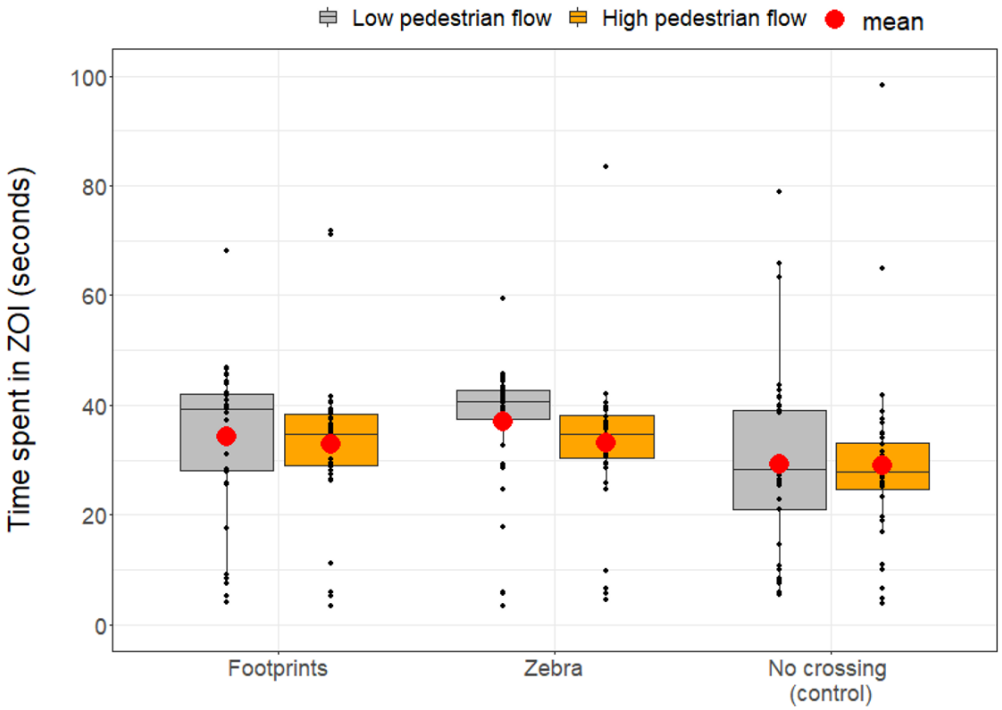


Figure 7: Time spent in ZOI by crossing type and pedestrian flow when turning right out of the side road

As shown in research question 1, the time spent in the ZOI was the lowest for the control drive with no crossings compared to a non-prescribed zebra and footprints crossing.

Although, the average waiting time was slightly lower for the drives with higher pedestrian flow (31 seconds on average) compared to lower pedestrian flow (33 seconds) as seen from Figure 7, statistical tests showed no significant difference in time spent within the ZOI across crossing type (p=0.37) and pedestrian flow (p=0.7) or the interaction between the two (p=0.87). This might suggest that crossing type and pedestrian flow did not affect participants' propensity to give way when turning right out of side roads.

4.2.2.2 *Turning right into the side road*

Figure 8 shows the distribution of time spent within the ZOI when drivers turned right into the side road.

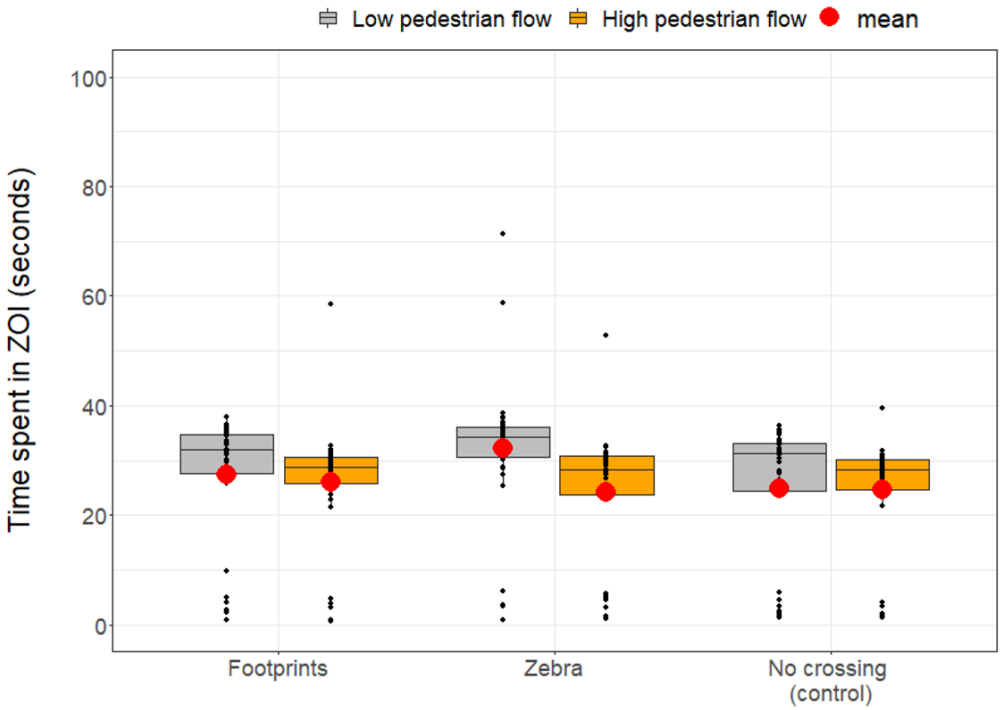


Figure 8: Time spent in ZOI by crossing type and pedestrian flow when turning right into the side road

Across all crossing types, the average time spent within the ZOI was lower for the drives with higher pedestrian flow (25 seconds) compared to lower flow (28 seconds) as shown in Figure 8. Although the average was slightly different, statistical tests showed no significant difference in time spent within the ZOI by crossing type (p=0.53) and pedestrian flow (p=0.18) and the interaction between the two (p=0.09). This suggests that both crossing type and pedestrian flow did not have an impact on the participants' propensity to wait.

4.2.2.3 *Turning left into the side road*

The distribution of time spent waiting within the ZOI when drivers turned left into the side road is shown in Figure 9.

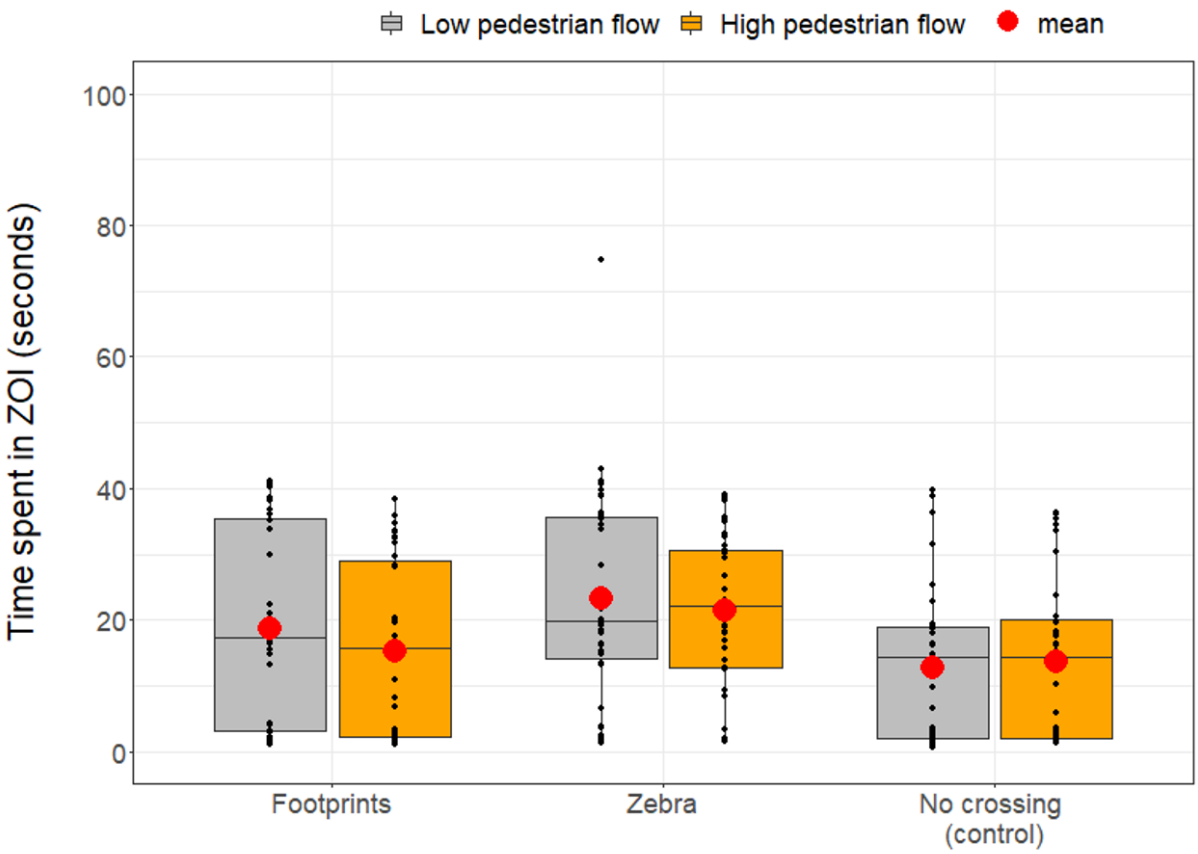


Figure 9: Time spent in ZOI by crossing type and pedestrian flow when turning left into the side road

Figure 9 shows that the amount of time spent within the ZOI was similar across all three crossing types. Furthermore, the average time spent in the ZOI was similar for both pedestrian flow types (around 18 seconds).

There was no significant difference in time spent within ZOI for crossing types (p=0.22), pedestrian flow(p=0.43) or the interaction effect (p=0.87). Similar to previous results, this suggests that pedestrian flow did not have an impact on participants' propensity to give way.

4.2.2.4 *Turning left out of the side road*

Figure 10 shows the distribution of time spent within the ZOI when drivers turned left out of the side road. Each individual point is shown in black whereas the group average is shown in red.

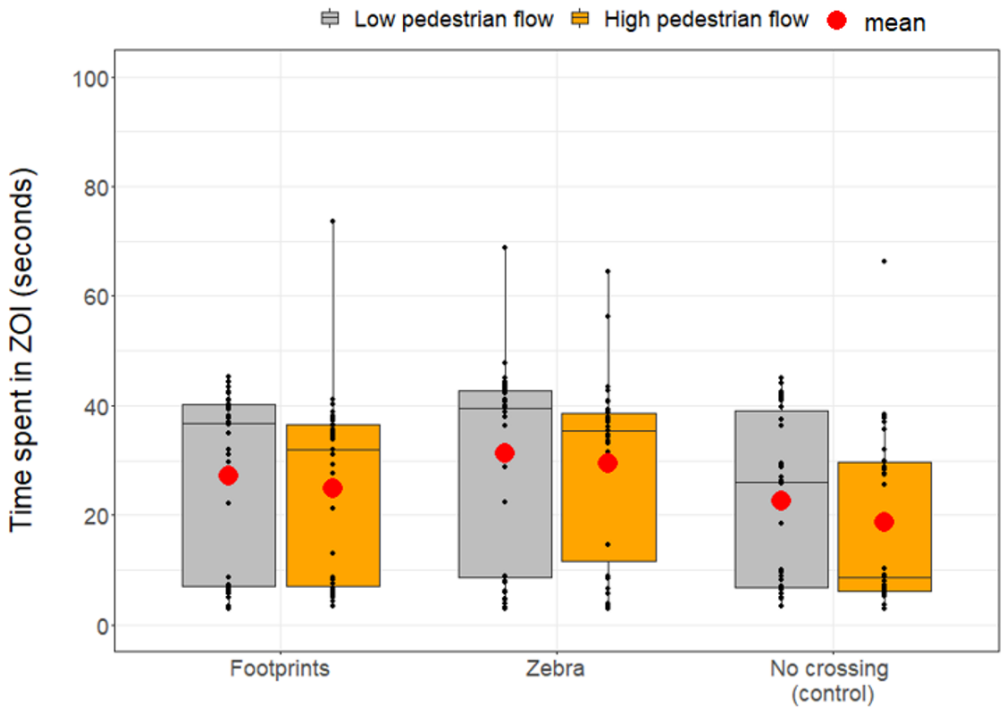


Figure 10: Time spent in ZOI by crossing type and pedestrian flow when turning left out of the side road

Similar to the previous results, the amount of time spent within the ZOI was fairly similar for both pedestrian flows, 27 seconds for lower flow and 24 seconds for higher flow.

Statistical tests showed no significant difference by pedestrian flow (0.22) and the interaction effect (p=0.39). There was a significant difference by crossing type (p<0.04), although the effect size was extremely small (0.04). This suggests that although there was a significant difference by crossing type, the effect size was extremely small and this difference may be driven by outliers. In general, pedestrian flow did not have an impact on participants' propensity to give way to pedestrians.

4.3 Driver perceptions: Post-trial questionnaire results

This section presents the findings from the post-trial questionnaire and is broken down into four main parts.

4.3.1 Perceptions when approaching on the side road

Participants were asked to rate how difficult or easy it was to identify if a crossing was present on the side road, in general, when approaching from the side road. The distribution of responses is shown in Figure 11.

Around 65% (26) of participants found it very or quite easy to identify if a crossing was present when approaching from the side road, 10% (4) found it to be neither easy nor difficult, and 25% (10) found it to be quite difficult. No participants reported that it was very difficult to identify if a crossing was present.

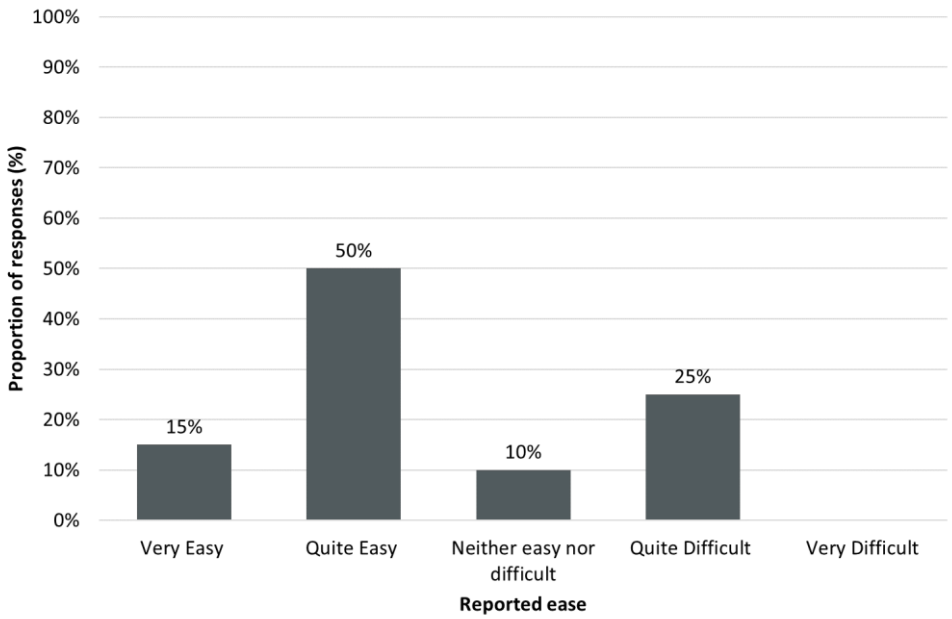


Figure 11: Responses to question: "When approaching from the side road, how easy or difficult did you find it was to identify a crossing on the side road?"

Next, participants were presented with an image of each crossing design (non-prescribed zebra and footprints crossing) on the side road and were asked to rate how easy or difficult they felt it was to identify this as a pedestrian crossing on the side road, when approaching from the side road. The results are shown in Figure 12.

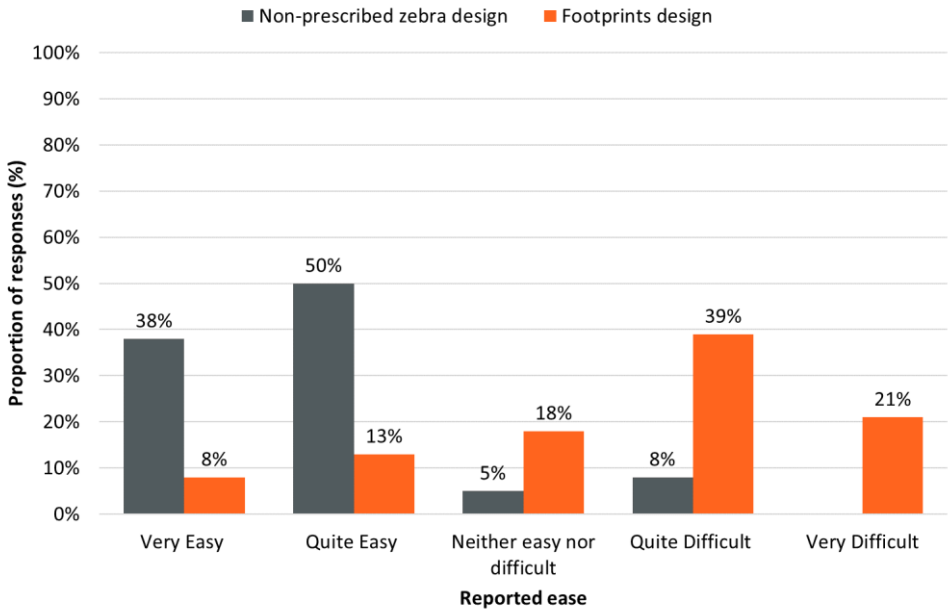


Figure 12: Responses to question: "On approach to the junction from the side road, how easy or difficult did you find it to identify this as a pedestrian crossing on the side road?" for non-prescribed zebra and footprints crossings

As Figure 12 shows, participants generally rated the non-prescribed zebra as either very easy (38%) or quite easy (50%) to identify. In contrast, a lower number of participants rated the footprints crossing as very easy to identify (8%). Statistical tests showed a significant difference in the distribution of responses ($p<0.01$) with a strong effect size of 0.57. Participants found the footprints crossing to be significantly more difficult to identify compared to the zebra crossing.

The qualitative evidence provided by participants supports this finding. For example, comments related to the zebra crossing included:

> *"Easy to distinguish due to the geometry (thickness) of the bars, aligned for the pedestrian's path and direction of travel"*
>
> *"Clear black and white stripes with no confusion"*

4.3.2 Perceptions when approaching on the main road

Participants were required to rate how easy or difficult it was to identify if a crossing was present on the side road, when approaching from the main road. Results are shown in Figure 13.

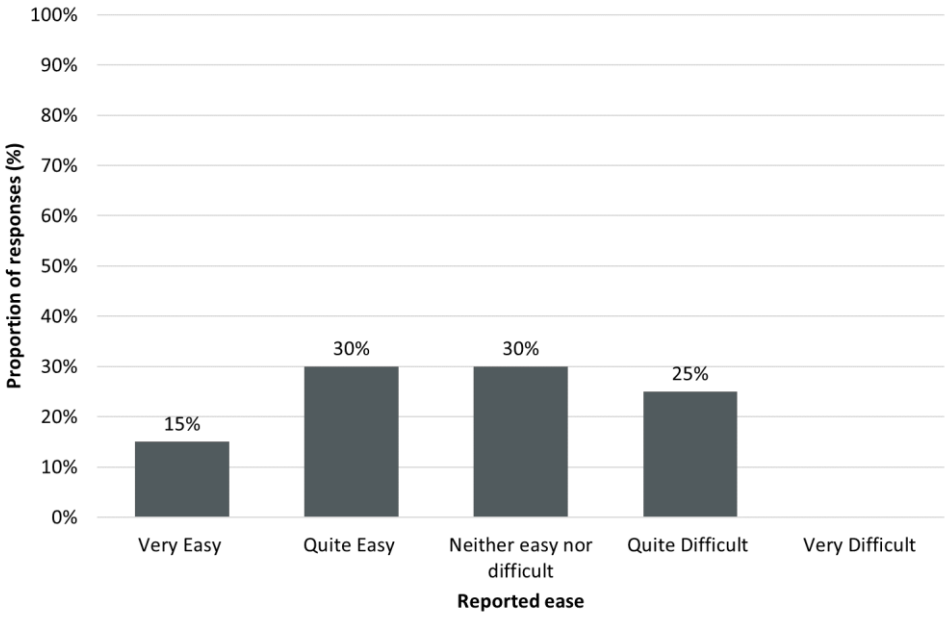


Figure 13: Responses to question: "When approaching from the main road, how easy or difficult did you find it was to identify a crossing on the side road?"

As Figure 13 shows, participants' responses suggest that the crossing was fairly easy to identify on the side (45% scored either very easy or quite easy), with 25% (10) participants rating it as quite difficult to identify if a crossing was present.

Participants were presented with an image of each crossing design laid across the side road and were asked to rate how easy or difficult they felt it was to identify this as a pedestrian crossing on the side road, when approaching from the main road. This is presented in Figure 14.

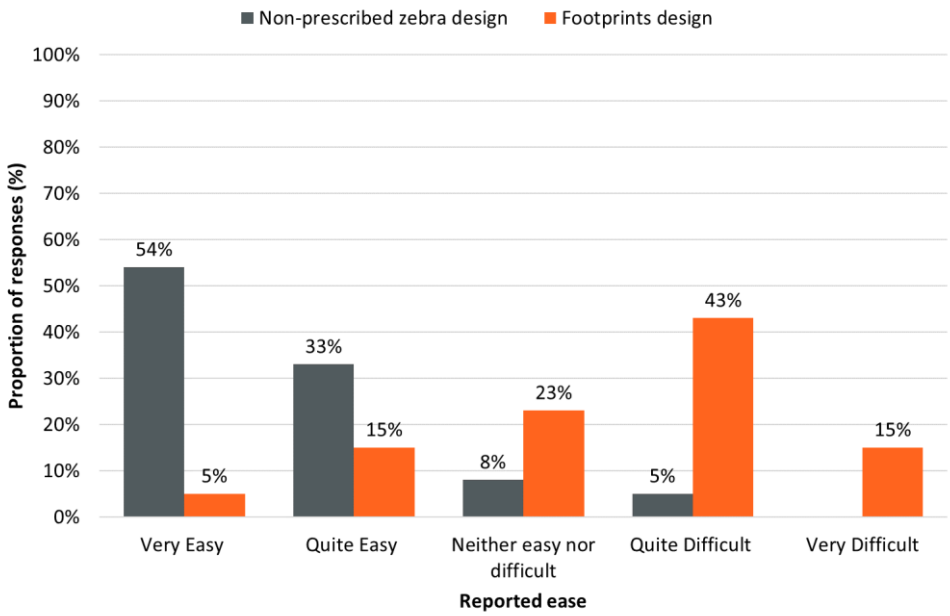


Figure 14: Responses to question: "On approach to the junction from the side road, how easy or difficult did you find it to identify this as a pedestrian crossing on the main road?" for non-prescribed zebra and footprints crossings

The results suggest that the non-prescribed zebra design was easier for participants to identify, with 54% (21) of participants rating this as very easy and 33% (13) of participants rating it was quite easy. These proportions were much lower for the footprints crossing design, with only 15% (6) rating it as quite easy to identify the design as a pedestrian crossing. Statistical tests showed a significant difference in responses between the two crossing types ($p<0.01$) with a large effect size of 0.8. As such this supports the findings in section 4.3.1 with regard to the approach on the side, providing further evidence that participants found the non-prescribed zebra design to be easier to identify than the footprints design.

The comments provided by participants support this finding. For example:

> *"As above, it is a known crossing type and is easily distinguishable from a give way line etc"*
>
> *"Clearly a marked zebra crossing"*
>
> *"Same as above, the markings stood out"*

4.3.3 *Give way behaviour*

Participants were presented with an image showing each crossing design laid across the side road and were asked to rate how easy or difficult it was to decide to give way to pedestrians crossing the road (referring back to the scenarios experienced in the simulator).

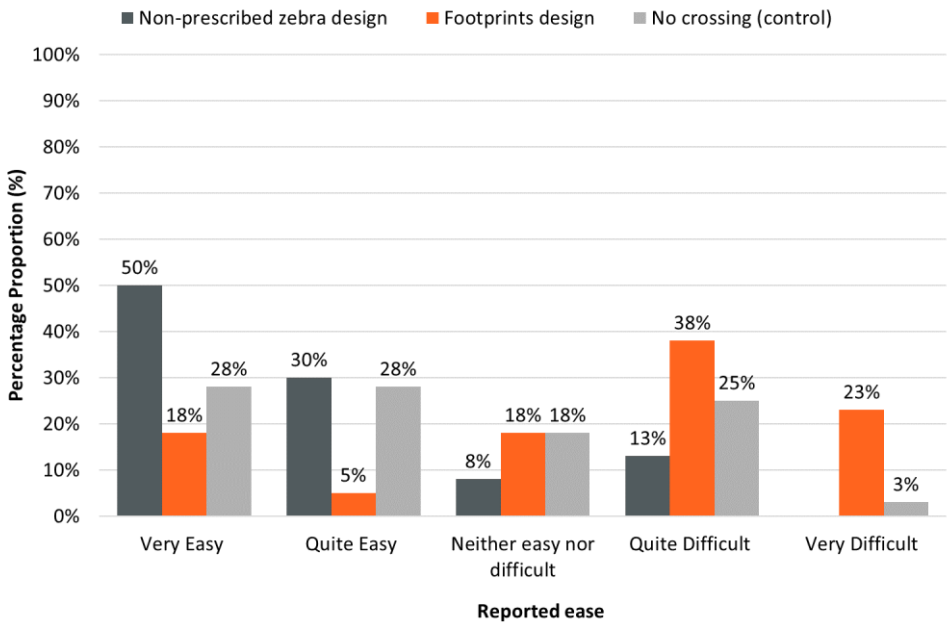


Figure 15: Responses to question: "How easy or difficult did you find it to decide whether to give way to pedestrians crossing the road?" for non-prescribed zebra, footprints crossing and no crossing (control)

As Figure 15 shows, the majority of participants found it very easy to decide to give way to pedestrians crossing the road when presented with the non-prescribed zebra crossing design. Fewer participants found it easy with the footprints design, with only 18% (7) of participants rating it as being very easy to decide to give way, and 38% (15) of participants rating it as quite difficult, compared to 13% (5) for the non-prescribed zebra crossing design. Statistical tests showed a significant difference ($p<0.01$) with a small effect size of 0.2. Post-hoc tests found a significant difference ($p<0.01$) between zebra and footprints design but no difference in responses between zebra and control ($p=0.08$) and footprints and control ($p=0.12$). This suggests that participants found it easiest to decide when the crossing was a non-prescribed zebra crossing and the most difficult when there was a footprint crossing. In the case of the control no crossing condition, responses were evenly distributed from very easy to quite difficult. The in trend in Figure 15 is clear, however the lack of significance observed is likely due to insufficient statistical power.

The qualitative data obtained provide further insight. Participants stated that it was easy to decide to give way to a pedestrian on the non-prescribed zebra crossing for two main reasons. Firstly, the markings were familiar to them as they are used to seeing zebra crossings and secondly, participants perceived that the pedestrians had right of way. For example, comments included:

"Similar to zebra crossing"

"It's natural to stop at a zebra crossing"

"They have right of way"

"I think the highway code says give way to pedestrians"

4.3.4 *General questions*

Participants were presented with an image of the zebra crossing design and the footprints design and were asked if they understood if the designs were pedestrian crossings. As Figure 16 shows, for the non-standard zebra crossing design, all forty participants agreed that the crossing design was in fact perceived to be a pedestrian crossing. However, there were mixed responses for the footprints crossing design where half of the participants (20) agreed that the crossing design was perceived to be one whereas the other half disagreed.

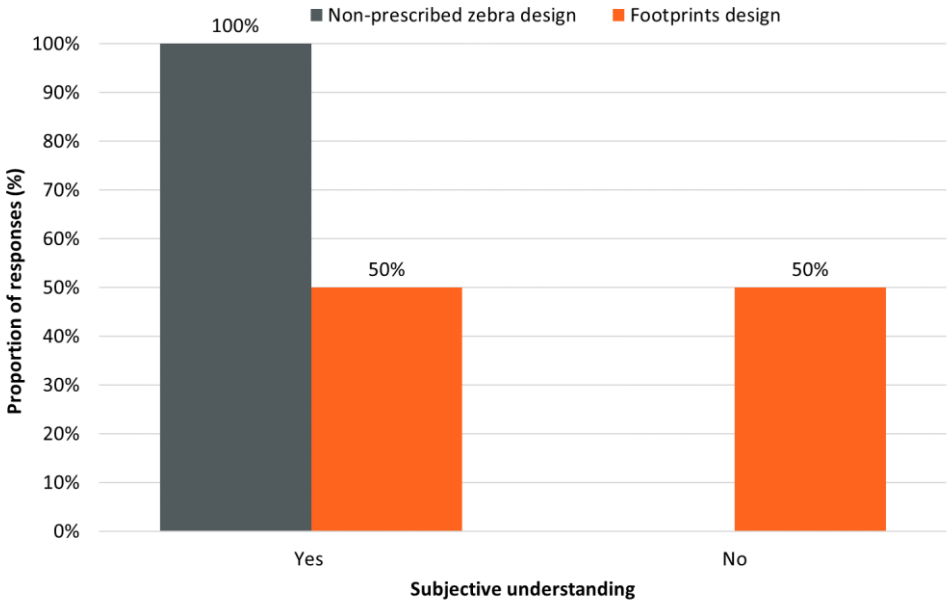


Figure 16: Responses to question "Did you understand that this was a pedestrian crossing?" for non-prescribed zebra and footprints designs

Finally, participants were asked the following question "Which one of the two crossings provided the clearest information to you as a driver?" and were asked to choose out of the non-prescribed zebra crossing, the footprints crossing or that they were both the same. Out of the 40 participants, 39 participants indicated that the non-prescribed zebra crossing was the clearest, apart from one who said both crossing designs were equally clear.

4.3.4.1 Open ended feedback

Participants were asked to indicate if there were any improvements or modifications which they might like to see at the two types of side road crossings. Suggestions to improve the non-prescribed zebra crossing included adding lights, specifically the well-recognised orange belisha beacons or improved road markings for when the road is dark. Example comments included:

"Belisha beacons will help identify it as a crossing"

"Orange flashing belisha beacons and possibly better markings on the road if it were dark"

For the footprints crossing design, participants suggested that the design was unclear and unfamiliar to them. Example comments relating to the footprints crossing included:

“I wouldn't use the footprints as they are unclear and ambiguous to the driver”

“The new one is unclear and looks like a jumble of splodges. I definitely would not change”.

5 Limitations

When looking at the results of this study it is important to understand any possible limitations and their potential impact on interpretation and generalisation of the results.

One potential limitation of the study concerned the design of the simulator scenario. Participants noted that, whilst waiting to turn into the side road, the pedestrians looked straight ahead whilst 'walking', rather than visually interacting with the driver. It is possible that this influenced driver decision-making; in a real-world setting, pedestrians tend to make eye contact or turn their heads in the direction of oncoming traffic and this can serve as a cue to drivers that they wish to cross the road. In the simulated environment, it was not possible to replicate this type of eye-gaze behaviour or head movements with the simulated pedestrians due to limitations of the simulation software. As such, this may impact the behaviours observed in the simulator may not be fully generalisable to real-world side road crossing situations. However, the limitation in simulated pedestrian behaviour was consistent across all conditions tested in this study, and therefore any bias would have been applied consistently between zebra, footprints and control conditions. The validity of the differences identified between crossing types is therefore unaffected.

Although present as a control variable, vehicle traffic occasionally interfered with drivers' ability to complete the required manoeuvre – especially during right turns, when at times participants were giving way for other vehicles rather than pedestrians. However, the same traffic levels were experienced by all participants, and traffic levels were designed to be in line with what participants would experience in the real world.

The Zones of Interest (ZOIs) were set up to capture information on where drivers stopped and waited when completing the turns into and out of the side road. In some isolated cases, participants stopped outside these zones, much further away from the junction than a vehicle would typically be expected to stop. These incidences were treated as missing data. In total, around 5% of the total dataset were missing, having negligible impact on the final sample or the results.

6 Summary

The purpose of this study was to explore the propensity of drivers to give way to pedestrians at different crossing types with different levels of flow.

To understand driver behaviour, participants undertook 24 short drives in TRL's driving simulator. The data from these drives, and the post-trial questionnaire they completed has been analysed to answer the research questions.

The first research question tackled the propensity of drivers to give way to pedestrians based on crossing type. Across all four turning movements, participants on average spent the least time in the ZOI when there was no crossing, followed by the footprints crossing, and spent the most time in the ZOI when faced with a non-prescribed zebra crossing.

Overall, there was a significant difference in participants propensity to give way to pedestrians. This was mainly significant for the non-prescribed zebra crossing condition when turning left out or into the side road, compared to the control crossing. When turning right out of the side road, propensity to give way was higher for both crossing types compared to control. However, when turning right into the side road there was no difference in propensity to give way by either crossing types. Turning right into the side road was the only condition where the drivers had to wait for AI traffic in the oncoming lane - that is likely to have affected their waiting times in the ZOI which may be why there were smaller differences between crossing conditions. It is noteworthy that there was still a trend in the same direction for this turning movement (right turn into side road), that is shorter waiting times with no crossing compared with zebra. However, the size of the difference was smaller than with the other turning movements and it was not detected as statistically significant with our sample.

The second research question looked at the effect of pedestrian flow on the propensity for vehicles to give way to pedestrians on side roads with and without crossings. Across all four turning movements, it was found that pedestrian flow did not have a significant impact on drivers' propensity to wait across the three crossing types. However, it is noteworthy that for the scenarios that involved turning out of the side road, slightly less time was spent waiting by participants during high pedestrian flow drives compared to low pedestrian flow drives. This may be because some participants were prepared to wait for a single group of pedestrians, but when they could see that another group of pedestrians was soon to be approaching the crossing, they utilised the gap available to them between the groups.

Overall though, it can be summarised that pedestrian flow did not impact participants' propensity to give way to pedestrians for all the four approach types.

Table 5 summarises the results from the post-trial questionnaire, highlighting the findings for each crossing design. The main findings were:

- **Give way behaviour**. Participants found it easiest to decide when the crossing was a non-prescribed zebra crossing and the most difficult when there was a footprint crossing.
- **Approaching from the side road.** Participants found the footprints crossing to be significantly more difficult to identify compared to the zebra crossing.

- **Approaching from the main road.** Participants found it easier to identify the non-prescribed zebra, compared to the footprints design.

Table 5: Summary of post-trial questionnaire findings

	Reported ease of identifying the crossing		Give way behaviour	Open ended question
Crossing type	**Main road perspective**	**Side road perspective**		
Non-prescribed zebra design	87% of participants rated it as either very easy or quite easy to identify this as a pedestrian crossing.	88% of participants rated it as either very easy or quite easy to identify this as a pedestrian crossing.	80% of participants rated it as very easy or quite easy to decide whether to give way to pedestrians crossing the road	100% of participants answered "yes" to indicate that they understood that this was a pedestrian crossing.
Footprints crossing design	20% of participants rated it as either very easy or quite easy to identify this as a pedestrian crossing.	21% of participants rated it as either very easy or quite easy to identify this as a pedestrian crossing.	23% of participants rated as being very easy or quite easy to decide whether to give way to pedestrians crossing the road	50% of participants answered "no" and 50% answered "yes" to indicate that they understood that this was a pedestrian crossing.
No crossing	N/A	N/A	56% of participants rated as being very easy or quite easy to decide whether to give way to pedestrians crossing the road	N/A

7 Conclusion

This study has highlighted a number of implications relating to the use of non-prescribed zebra crossings.

1. A non-prescribed zebra is likely to be more effective than no crossing in getting drivers to allow pedestrians to cross at side roads.
2. Any design decision need not be informed by consideration of pedestrian flow.
3. The questionnaire results show that participants unanimously comprehend that the non-prescribed zebra crossing is a form of pedestrian crossing
4. The footprints design should not be used for non-prescribed crossings.

Based on these results, the recommendations are:

1. Any non-prescribed crossing should be based on the standard zebra crossing design.
2. Any findings in relation to pedestrian flow should be further evidenced through video observations of on-street trials to be conducted at a later phase in the programme, which will, respectively, investigate interactions before and after the application of a non-prescribed zebra, and examine if there is an increased propensity for vehicles to give way to pedestrians once zebra markings are applied.

Appendix A Post-trial questionnaire

1. Please enter your participant number *

2. General Questions

Q2. When approaching from the side road, how easy or difficult did you find it was to identify a crossing on the side road? *

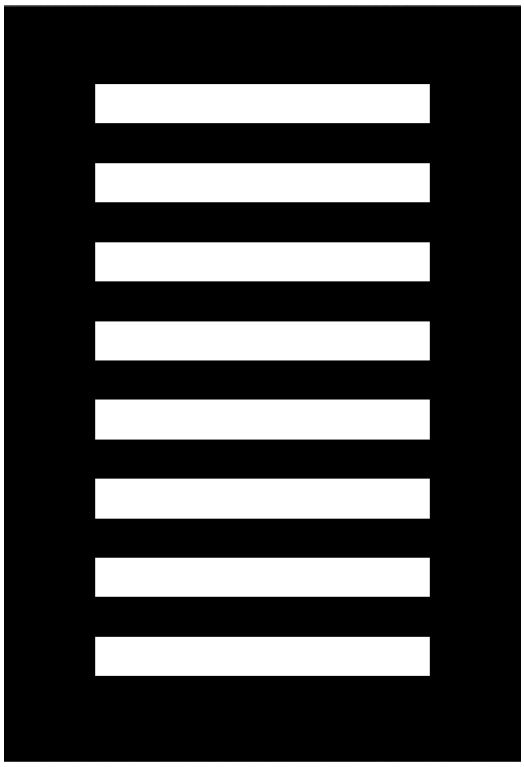
Very easy	Quite easy	Neither easy nor difficult	Quite difficult	Very difficult
☐	☐	☐	☐	☐

Q3. When approaching from the main road, how easy or difficult did you find it was it to identify a crossing on the side road? *

Very easy	Quite easy	Neither easy nor difficult	Quite difficult	Very difficult
☐	☐	☐	☐	☐

3. Non-prescribed zebra crossing

Q4. Please examine the image below and answer the following question. How easy or difficult did you find it to decide whether to give way to pedestrians crossing the road? *



Very easy	Quite easy	Neither easy nor difficult	Quite difficult	Very difficult
☐	☐	☐	☐	☐

Please give a reason for your answer

Q5. Please examine the image below and answer the following question. On approach to the junction from the main road, how easy or difficult did you find it to identify this as a pedestrian crossing on the side road?

Very easy	Quite easy	Neither easy nor difficult	Quite difficult	Very difficult
☐	☐	☐	☐	☐

Please give a reason for your answer

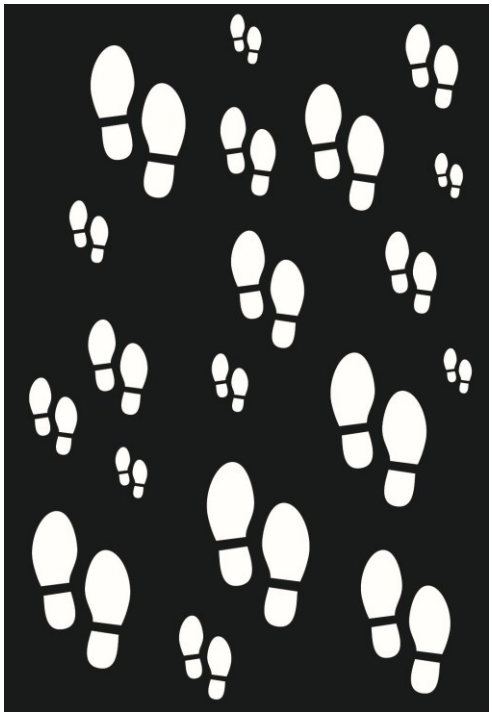
Q6. Please examine the image below and answer the following question. On approach to the junction from the side road, how easy or difficult did you find it to identify this as a pedestrian crossing on the side road?

Very easy	Quite easy	Neither easy nor difficult	Quite difficult	Very difficult
☐	☐	☐	☐	☐

Please give a reason for your answer

4. Footprints Crossing

Q7. Please examine the image below and answer the following question. How easy or difficult did you find it to decide whether to give way to pedestrians crossing the road? *



Very easy	Quite easy	Neither easy nor difficult	Quite difficult	Very difficult
☐	☐	☐	☐	☐

Please give a reason for your answer

Q8. Please examine the image below and answer the following question. On approach to the junction from the main road, how easy or difficult did you find it to identify this as a pedestrian crossing on the side road?

Very easy	Quite easy	Neither easy nor difficult	Quite difficult	Very difficult
☐	☐	☐	☐	☐

Please give a reason for your answer

Q9. Please examine the image below and answer the following question. On approach to the junction from the side road, how easy or difficult did you find it to identify this as a pedestrian crossing on the side road?

Very easy	Quite easy	Neither easy nor difficult	Quite difficult	Very difficult
☐	☐	☐	☐	☐

Please give a reason for your answer

5. No crossing

Please examine the image below and answer the following question

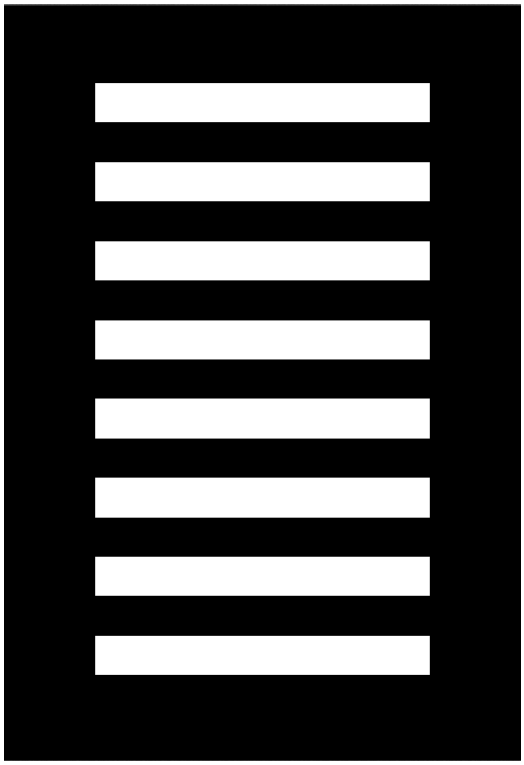
Q10. Please examine the image below and answer the following question. How easy or difficult did you find it to decide whether to give way to pedestrians crossing the road?

ry easy	Quite easy	Neither easy nor difficult	Quite difficult	Very difficult
☐	☐	☐	☐	☐

Comments:

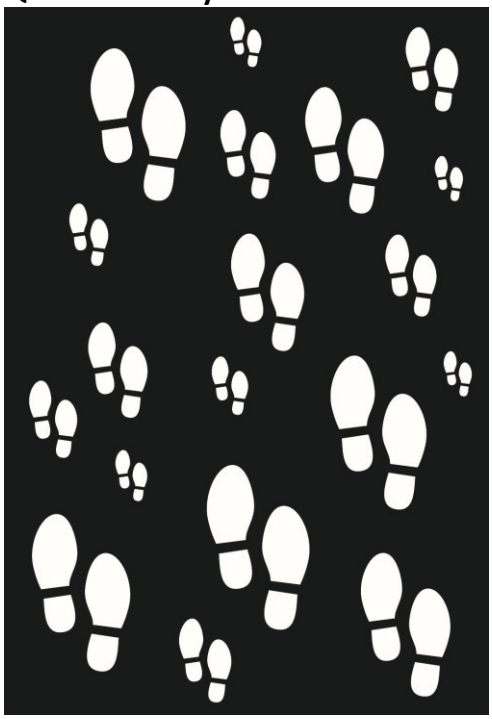
6. Subjective measures

Q11. There were two types of pedestrian crossing present. Did you understand that this was a pedestrian crossing? *



- [ ] Yes
- [ ] No

Q12. Did you understand that this was a pedestrian crossing? *



- [ ] Yes
- [ ] No

Q13. Which one of the two crossings provided the clearest information to you as a driver? *

- [ ] Zebra crossing
- [ ] Footprints crossing
- [ ] Both the same

Q14. Are there any improvements/modifications you would like to see at these types of crossings? *

Q15. Do you have any additional comments about anything you experienced during the trial?

Non-prescribed zebra crossings at side roads

Technical Annex 6: Driver simulator trials

Transport for Greater Manchester (TfGM) is seeking to understand how non-prescribed zebra crossing markings, positioned flush against the mouths of side roads in urban areas, can be used to provide direct but safe crossing options for pedestrians. As part of this package of work, TRL conducted a driving simulation study in DigiCar, TRL's driving simulator, to explore the propensity of drivers to give way to pedestrians at two different non-prescribed crossing designs, in comparison with junctions with no crossings; and how this was affected by pedestrian flow.

Willingness to give way was greater with the non-prescribed crossing than with no crossing or with an alternative experimental marking. Willingness to give way was not affected by pedestrian flow, but drivers turning into side roads were less likely to give way than when turning out.

Titles in this subject area

PPR1003 Non-prescribed zebra crossings at side roads. Final Report. Jones M., Matyas M. and Jenkins D. 2021

PPR1004 Non-prescribed zebra crossings at side roads. Technical Annex 1: Analysis of collision records at existing sites. Hammond J. and Simms G. 2019

PPR1005 Non-prescribed zebra crossing at side roads. Technical Annex 2: User surveys at existing sites. Verwey L., Novis K., Wallbank C. and Stuttard N. 2020

PPR1006 Non-prescribed zebra crossing at side roads. Technical Annex 3: Effectiveness of alternative markings. Novis K., Hyatt T., Stuttard N. and Wallbank C. and Verwey L. 2020

PPR1007 Non-prescribed zebra crossing at side roads. Technical Annex 4: Road user perceptions and understanding. Blunden A., Gupta B., Matyas M., Mazzeo F., Wallbank C. and Wardle A. 2021

PPR1008 Non-prescribed zebra crossing at side roads. Technical Annex 5: Implications for people with disability. Blunden A., Gupta B., Verwey L., Butler, R. and Wallbank C. 2021

PPR1009 Non-prescribed zebra crossing at side roads. Technical Annex 6: Driver simulator trials. Jenkins D., Ramnath R., Stuttard N. and Chowdhury S. 2021

PPR1010 Non-prescribed zebra crossing at side roads. Technical Annex 7: Observations of conflict and giving-way during on street trials. Greenshields S., Ognissanto F., Lee R. and Macgregor E. 2021

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