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Factors explaining driver yielding behaviour towards pedestrians at courtesy crossings

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ABSTRACT

Courtesy crossings are pedestrian crossing facilities where drivers are not legally required to stop for pedestrians, but are encouraged to do so by design elements such as stripes, coloured or textured road surfaces, visual narrowings of the carriageway, and ramps. There is little empirical evidence on drivers' behaviour or guidance on how to design these crossings. This paper analysed data for 937 interactions between drivers and pedestrians at 20 crossings across England, comparing driver yielding behaviour at courtesy crossings and at zebras (marked unsignalised crossings, where drivers are legally required to stop); and identifying the design elements associated with yielding behaviour at courtesy crossings. The analysis controlled for crossing stage; characteristics and situation of pedestrians and vehicles; characteristics of the road and site; and time context. Driver yielding behaviour was analysed for each separate traffic lane that pedestrians need to cross. We found that all four design elements considered (stripes, coloured/textured surface, visual narrowing, and ramps) increased the propensity of the first vehicle to stop and of any vehicle to stop. A before-after analysis then showed that adding a new element (stripes) to a courtesy crossing led to an increase in yielding rates from 20% to 97%. Overall, we found evidence supporting the use of multiple design elements in courtesy crossings. We discuss the implications of these findings for transport policy and urban design.

1. Introduction

The provision of pedestrian crossing facilities is one of the most problematic elements of road planning. Crossing facilities allow for the movement of pedestrians across the road but also generate conflicting movements between pedestrians and motorised vehicles, often becoming hotspots of collisions. Collision risk can be removed by separating vehicles from pedestrians with bridges or underpasses, or simply reduced by controlling movements with traffic signals. However, when the volumes of pedestrians and motorised vehicles are below the level that would justify the costs of signalisation, and traffic speeds are low, marked unsignalised crossings (also known as zebras or marked crosswalks) are often used (DfT 1995, Ch.4.2.3). In many countries, drivers are legally required to give way to pedestrians at these crossings, which are identified by a standardized set of design elements, including white stripes, signs, posts with flashing lights, lighting of the crossing, dotted lines across the carriageway, and zigzag markings on the approach to the crossing (Fig. 1).

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Fig. 1. Example of zebra crossing (marked unsignalised crossing).

However, there are many instances where pedestrian and vehicle volumes do not meet the minimum criteria even for zebra crossings. Zebra crossings are also relatively expensive to install. In addition, their safety record is often poor (Gitelman, Balasha, Carmel, Hendel, & Pesahov, 2012; Morency, Archambault, Cloutier, Tremblay, & Plante, 2015; Thulin, 2007), which can be explained by the lack of compliance in yielding by drivers, and by pedestrians' unwarranted sense of safety. At the same time, simply removing zebras, without providing any other facilities, may decrease safety even more (Mitman, Ragland, & Zegeer, 2008).

For these reasons, it is increasingly common to provide informal 'courtesy crossings', which cost little to install. At these crossings, drivers are not legally required to give way to pedestrians but psychologically encouraged to do so by design

Fig. 2. Examples of elements of courtesy crossings.

elements such as stripes (with no supporting infrastructure, unlike at zebra crossings), coloured or textured surfacing, visual narrowing of the road, and ramps raising the carriageway (Fig. 2). For pedestrians, the location of courtesy crossings is identified by elements such as kerb extensions, dropped kerbs, and colour contrast or tactile warnings at the kerbside.

The hypothesis is that the design of courtesy crossings encourages drivers to respond to the presence and behaviour of pedestrians, rather than to formal traffic management elements (such as traffic signals, signs, road markings, or physical separations between kerbs and carriageway). This hypothesis is aligned with the "shared space" design approach, which aims at a more balanced distribution of space by removing formal demarcations between different types of road users, who are expected to become aware of each other. Proponents of this approach argue that it reduces the dominance of motorised vehicles and restores the role of roads and streets as social spaces, while ensuring the safety of pedestrians, as drivers will tend to drive slowly and stop for pedestrians (Hamilton-Baillie 2008a, 2008b).

However, providing courtesy crossings has proved to be a controversial practice (Forster, 2014), fuelled by reports that both drivers and pedestrians feel confused and are not sure how to behave at these crossings, and that some pedestrians would rather have signalised crossings or zebras than courtesy crossings (Moody & Melia, 2014). The discussion has been absorbed into the wider debate about the shared space approach. This approach has been criticized because it does not go far enough in reducing the dominance of motorised vehicles (Methorst, 2007) and it does not address the needs of individuals with mobility, visual, or hearing impairments (Hammond & Musselwhite, 2013; Havik, Melis-Dankers, Steyvers, & Kooijman, 2012; Havik, Steyvers, Kooijman, & Melis-Dankers, 2015; Imrie 2012, 2013).

This controversy has been compounded by the lack of guidance on the provision and design of courtesy crossings, and of a solid empirical base on how these crossings address the movement and safety of pedestrians. In the UK, the Department for Transport's guidance on shared space encouraged courtesy crossings on the grounds that "*drivers tend to treat courtesy crossings as they would a zebra crossing*" (DfT, 2011, p.37). However, the validity of the evidence base of this guidance has been questioned (Moody & Melia, 2014). The recommendations for design elements (tonal contrast, textures, bollards, and raised and narrowed carriageway) were also not based on any evaluation of their effectiveness. The guidance document was withdrawn in 2018, seeking for more research (DfT, 2018). In the same year, a document by a professional association suggested that courtesy crossings encourage drivers to "*engage with their surroundings rather than simply following traffic rules, which tends to reduce traffic speed*" (CIHT 2018, p.22, 25). The document provided evidence on design elements influencing yielding behaviour (speed reduction measures, "conspicuous treatments", locating crossings near junctions, level changes, and median strips) but also recognised the need for more research on how yielding behaviour is related to other characteristics of road design and to the characteristics of pedestrians (CIHT 2018, p.22).

The present paper set out to provide evidence on a crucial aspect of courtesy crossings: the factors that encourage driver yielding behaviour (i.e. drivers stopping to give way to pedestrians). The study was based on the cross-sectional analysis of video data for 937 interactions between drivers and pedestrians at 20 non-signalised crossings across England, and a before-after analysis at one of these crossings, where an additional design element (stripes) was introduced some years after the implementation of the crossing. Our dataset includes both zebra crossings and different types of courtesy crossings, defined by various combinations of design elements (henceforth referred to as "courtesy crossing design elements"). This allowed us to gauge how driver yielding behaviour is related to each element, while controlling for crossing stage, the characteristics and situation of pedestrians and vehicles, characteristics of the road and of the site, and time context. The study therefore provides timely empirical evidence addressing the calls made by policy-makers and professional associations and can feed into future guidelines for the provision and design of courtesy crossings.

The next section reviews the existing evidence on courtesy crossings and driver yielding behaviour. Section 3 describes the case studies and the variables collected. Section 4 tests how yielding behaviour varies with the type of crossings and with other factors. Section 5 presents logistic models explaining driver yielding behaviour. Section 6 presents a further logistic model to compare yielding behaviour at one crossing before and after an additional design element was introduced. Section 7 discusses the implications of the results for policy and research.

2. Existing evidence

2.1. Yielding behaviour at courtesy crossings

Only a few empirical studies have looked at driver yielding behaviour at courtesy crossings. However, in all cases, the analysis was confounded by the fact that the courtesy crossings were integrated into wider shared space schemes. Moody and Melia (2014) found that most pedestrians used a courtesy crossing, rather than the surrounding shared space, effectively treating the courtesy crossing like a zebra crossing. However, drivers did not treat it as such: the yielding rate was just 37%. In contrast, Horrell and Jones (2014) found that the yielding rate at a courtesy crossing had more than doubled (from 30% to 62%) six months after the opening of a shared space scheme, as drivers and pedestrians became more familiar with the design. In the case studies reviewed by CIHT (2018), yielding rates varied from 5% to 97%. Overall, these results show a wide variation in the effectiveness of courtesy crossings in encouraging driver yielding behaviour, suggesting that this behaviour depends on either the characteristics of the courtesy crossings or on other crossing-specific factors. More research is therefore needed to isolate these two sets of factors.

2.2. Yielding behaviour at marked unsignalised crossings (zebras)

The design of this research on courtesy crossings can benefit from information provided by the extensive literature on driver yielding behaviour at marked unsignalised crossings (zebras), which we synthesize in Table 1. Yielding behaviour has been associated with several design elements, including crossing width; the existence of a median strip or crossing island; staggered layout; ramps/speed humps; light-based warning systems; kerb extensions; high-visibility signs and markings; advanced yield markings; and in-street signs. The evidence on the effectiveness of light-based warning systems is particularly strong and extensive. However, there is no evidence of the effect of three of the four design elements usually used in courtesy crossings, and analysed in this paper: (non-zebra) stripes, coloured/textured surface and visual narrowing of the carriageway. There is only one study providing evidence on the fourth design element (ramps).

As shown in Table 1, driver yielding behaviour at zebra crossings is also associated with non-design factors, including the characteristics of pedestrians and vehicles, the situation of both when the interaction occurs, the characteristics of the road (other than the crossing design), the characteristics of the site, and the time of day. The direction of these associations is not always clear. For example, driver yielding behaviour has been both positively and negatively associated with the number of road lanes, the presence of bus stops and of a median strip or crossing island, driving in queues/platoons, and driving in the nearside lane (closer to the kerb where the pedestrian is waiting). Some results also go against prior expectations. For example, Porter, Neto, Balk, and Jenkins (2016) found that drivers were 1.83 times more likely to stop for pedestrians when they were still on the pavement than when they had already started crossing. Another limitation of the literature is the bias towards case studies in the USA (62% of the studies in Table 1), producing results that may not apply in other parts of the world, which have different traffic regulations and tend to have more pedestrians using roads and streets.

Also relevant are studies comparing driver behaviour at marked unsignalised crossings (zebras) and unmarked crossing points (not in Table 1). Most studies (e.g. Mitman, Ragland, & Zegeer, 2008, Havard & Willis, 2012, Obeid, Abkarian, & Abou-Zeid, 2017, Gitelman, Carmel, Pesahov, & Hakkert, 2017, Craig, Morris, & Hong, 2019a) found that drivers were more likely to yield at marked crossings. In contrast, Knoblauch, Nitzburg, and Seifert (2001) found no significant differences in yielding behaviour at marked and unmarked crossings. However, the evidence base is small, as most of the research on the topic has focused on pedestrian behaviour, not on driver behaviour.

2.3. Yielding behaviour in shared spaces

Additional information could be provided by the literature on interactions between users of shared spaces. However, most of this literature is either thought pieces or evaluation studies of specific shared space schemes, not providing a comparative assessment of the effect of different design elements on driver behaviour. An exception is the study of MVA (2010), which showed that the propensity of drivers to give way to pedestrians was related to the number of pedestrians, the number of vehicles behind or in front, lack of kerbs, less definition between surface colours, presence of traffic calming measures, and an index of how "shared" the space is. Using surveys, Kaparias, Bell, Miri, Chan, and Mount (2012) found that drivers are less willing to share space when using larger vehicles and in spaces with street furniture, without bright lighting, and used by many vehicles and pedestrians (especially children and older adults). The authors interpreted these as factors increasing drivers' uneasiness, and thus their alertness, when using shared spaces, which may then affect the propensity to stop or drive slowly.

2.4. Unanswered questions and the contribution of this paper

Despite providing a useful list of factors explaining driver yielding behaviour, the results of the literatures on marked unsignalised crossings (zebras) and on shared spaces do not fully apply to courtesy crossings. In many countries, the design elements of zebras is relatively fixed and there is a legal requirement for drivers to stop. In contrast, the design of courtesy crossings is flexible, and planners can combine different elements in the hope that they will persuade drivers to stop, even though there is no legal requirement to do so. In shared spaces, driver yielding behaviour refers both to pedestrians walking along and across the road; and pedestrians can, in theory, cross anywhere. In contrast, courtesy crossings are designated places where pedestrians move across the road and their location is identified both to pedestrians and to drivers.

The current paper therefore aims at covering the gap left by the literatures on marked unsignalised crossings and shared spaces, investigating the role of the courtesy crossing design elements, while controlling for the non-design factors identified in those two literatures.

3. Data and variables

3.1. Crossings

The study analysed 20 crossings at 12 sites in urban areas in England. Some sites are junctions and others are links. Sites that are junctions have more than one crossing, on different arms of the junction. Table 2 shows the main characteristics of the crossings. The figure in the appendix to the paper shows detailed illustrations of the layouts of the crossings. The set of

Table 1
Factors explaining driver yielding behaviour at marked unsignalised crossings (zebras).

Factor associated with yielding behaviour	Sign of the association	Studies
Crossing design elements		
Crossing width	+	Stapleton, Kirsch, Gates, and Savolainen (2017)
Median strip/crossing island	+	Pulugurtha, Vasudevan, Nambisan, and Dangeti (2012)
	–	Porter, Neto, Balk, and Jenkins (2016), Stapleton, Kirsch, Gates, and Savolainen (2017)
Staggered crossing ('Danish offset')	+	Pulugurtha, Vasudevan, Nambisan, and Dangeti (2012)
Ramps/speed humps	+	Gitelman, Carmel, Pesahov, and Chen (2017
Light-based warning systems	+	Schroeder and Rouphail (2011), Foster, Monsere, and Carlos (2014, Porter, Neto, Balk, and Jenkins (2016), Al-Kaisy, Miyake, Staszcuk, and Scharf (2017), Stapleton, Kirsch, Gates, and Savolainen (2017), Høye and Laureshyn (2019)
Kerb extensions	+	Bella and Silvestri (2015)
High-visibility signs and markings	+	Pulugurtha, Vasudevan, Nambisan, and Dangeti (2012), Fisher and Garay-Vega (2012), Sandt, Marshall, Rodriguez, Evenson, Ennett, and Robinson (2016)
Advanced yield markings	+	Fisher and Garay-Vega (2012), Bella and Silvestri (2015)
In-street signs	+	Strong and Ye (2010), Schroeder and Rouphail (2011), Bennett, Manal, and Van Houten (2014), Stapleton, Kirsch, Gates, and Savolainen (2017)
Pedestrian characteristics		
Presence of children	+	Al-Kaisy, Miyake, Staszcuk, and Scharf (2017), Sucha, Dostal, and Risser (2017)
Presence of elderly	+	Al-Kaisy, Miyake, Staszcuk, and Scharf (2017)
Same age group as driver	+	Rosenbloom, Nemrodov, and Eliyahu (2006)
Disability	+	Harrell (1992), Geruschat and Hassan (2005)
Ethnic minority	+	Goddard, Kahn, and Adkins (2015), Schneider, Sanatizadeh, Shaon, He, and Qin (2018), Coughenour, Clark, Singh, Claw, Abelar, and Huebner (2017)
Pedestrian situation		
Number of pedestrians	+	Figliozzi and Tipagornwong (2016), Sucha, Dostal, and Risser (2017), Al-Kaisy, Miyake, Staszcuk, and Scharf (2017), Malenje, Zhao, Li, and Han (2019), Obeid, Abkarian, and Abou-Zeid (2017)
Conspicuity/Assertive behaviour	+	Harrell (1993), Schroeder and Rouphail (2011), Schneider, Sanatizadeh, Shaon, He, and Qin (2018)
Distracted behaviour	–	Sucha, Dostal, and Risser (2017)
Friendliness	+	Guéguen, Eyssartier, and Meineri (2016)
Waiting away from kerb	–	Al-Kaisy, Miyake, Staszcuk, and Scharf (2017), Sucha, Dostal, and Risser (2017)
Already crossing (not waiting)	+	Gorrini, Crociani, Vizzari, and Bandini (2018
	–	Porter, Neto, Balk, and Jenkins (2016)
Crossing from opposite pavement (not nearside)	+	Gorrini, Crociani, Vizzari, and Bandini (2018)
Second stage of crossing (at a staggered crossing)	+	Foster, Monsere, and Carlos (2014)
Vehicle characteristics		
Cars	+	Porter, Neto, Balk, and Jenkins (2016), Figliozzi and Tipagornwong (2016)
Buses	+	Craig, Morris, and Hong (2019b)
Vehicle situation		
Traffic density	–	Sucha, Dostal, and Risser (2017)
Speed	–	Geruschat and Hassan (2005), Sucha, Dostal, and Risser (2017)
Change in speed before approaching crossing	–	Figliozzi and Tipagornwong (2016)
Vehicle had stopped at traffic lights before approaching crossing	+	Figliozzi and Tipagornwong (2016)
Travelling in queues/platoons	+	Sucha, Dostal, and Risser (2017)
	–	Schroeder & Rouphail, 2011)
In nearside lane (closer to kerb)	+	Schroeder and Rouphail (2011)
	–	Stapleton, Kirsch, Gates, and Savolainen (2017)
Another vehicle yield in adjacent lane	+	Schroeder and Rouphail (2011), Figliozzi and Tipagornwong (2016)
Road characteristics		
Junction (not link)	+	Sandt, Marshall, Rodriguez, Evenson, Ennett, and Robinson (2016)
Road width/crossing distance	–	Schneider, Sanatizadeh, Shaon, He, and Qin (2018)
Number of lanes	+	Craig, Morris, and Hong (2019a)
	–	Sandt, Marshall, Rodriguez, Evenson, Ennett, and Robinson (2016), Malenje, Zhao, Li, and Han (2019)
Traffic levels	–	Schneider, Sanatizadeh, Shaon, He, and Qin (2018)
Speed limits	–	Sandt, Marshall, Rodriguez, Evenson, Ennett, and Robinson (2016), Schneider, Sanatizadeh, Shaon, He, and Qin (2018)
Kerbside parking	–	Obeid, Abkarian, and Abou-Zeid (2017)
Site characteristics		
Bus stop	+	Schneider, Sanatizadeh, Shaon, He, and Qin (2018

(continued on next page)

Table 1 (*continued*)

Factor associated with yielding behaviour	Sign of the association	Studies
	–	Craig, Morris, and Hong (2019b)
City population	–	Sandt, Marshall, Rodriguez, Evenson, Ennett, and Robinson (2016)
Time context		
Morning (vs. afternoon)	+	Sandt, Marshall, Rodriguez, Evenson, Ennett, and Robinson (2016)

crossings includes 3 marked unsignalised crossings (zebras) and 17 courtesy crossings with different combinations of four courtesy crossing design elements: stripes, colour/texture treatment, visual narrowing, and ramps. This allowed us to assess the influence of each design element on driver yielding behaviour. The crossings also had a variety of different infrastructure characteristics (total number of lanes and presence vs. absence of a median strip) and traffic regulations (one-way vs. two-way traffic).

Video surveys were conducted at all crossings between August 2014 and July 2015. In Crossing 8, the survey was conducted in 2009. In Crossing 7, two surveys were conducted, in August 2014 and February 2015, before and after the characteristics of the crossing changed, with the introduction of (non-zebra) stripes. The duration of the survey was 14–18 min in Crossings 8, 11B, 11C, and 7 (in 2015) and around 30 min in all other crossings. Some surveys were conducted on weekdays, others on a Saturday, at different times of day. In four crossings, the exact time of day is unknown. In the analysis that follows, dummy variables were created for surveys on weekdays, Saturdays, peak-time (defined as the 6:30–10:00 and 16:30–20:00 periods), not peak-time, and an unknown time of day.

The number of motorised vehicles traversing the road per minute ranged from 3.3 to 15.5 and the total number of pedestrians per minute ranged from 0.4 to 13.6. These numbers are relatively low, which is consistent with the requirements of zebras and courtesy crossings. There were different combinations of volumes of vehicles and pedestrians. Some crossings had more than 20 times more vehicles than pedestrians, but others had a balanced number of pedestrians and vehicles or even more pedestrians than vehicles. The total number of pedestrians tracked across all crossings was 2476.

A series of crossing-specific variables was also collected from the video footage, measuring:

- Road characteristics: location (on a junction with inbound traffic, junction with outbound traffic, or link, i.e. away from junction); speed limit (20mph or 30 mph); and whether the kerb was raised or not. Raised kerbs are relevant because they are formal demarcations between vehicles and pedestrians and may influence drivers' yielding behaviour.
- Site characteristics: whether there were shops and services along the footway or not.

3.2. Crossing stages

We considered that a separate interaction between drivers and pedestrians may occur at each crossing stage, defined as each road lane that pedestrians need to cross. We distinguished between crossing from/to the footway and crossing from/to the median strip, when the road has one. We also distinguished between the first and the second lane on the way from/to the footway or median strip. This provides extra detail to the analysis of driver yielding behaviour, which, in the majority of studies (including those in Table 1), analysed a single driver–pedestrian interaction per pedestrian. Almodfer, Xiong, Fang, Kong, and Zheng (2016) and Zhang, Zhou, Chen, and Chen (2017) studied lane-based driver–pedestrian interactions, but focused on busy roads with marked unsignalised crossings (not courtesy crossings) and assessed interactions in terms of proximity between drivers and pedestrians (not driver yielding behaviour).

The left side of Table 3 (all columns except the last three) shows how crossing stages were defined, for all combinations of infrastructure characteristics (presence of median strip and total number of lanes for motorised traffic) and traffic regulations (one-way or two-way traffic):

- If the road had no median strip and one lane, there was just one stage: from footway to footway.
- If the road had no median strip and two lanes, there were two stages: the first and the second lane. We distinguished the case when the road has one-way traffic (i.e. both lanes have traffic in the same direction) and two-way traffic (i.e. the second lane has traffic in the opposite direction of the first lane).
- If the road had a median strip and two lanes, there are two crossing stages: from the footway to the median and from the median to the footway.
- If the road had a median strip and three lanes, there are three crossing stages: the first lane from the footway, the first lane from the median, and the second lane (either on the way from the footway to the median or from the median to the footway).

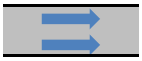
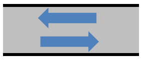
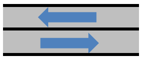
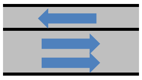
In the analysis that follows, two dummy variables were created for crossing stages from the median and to the median (regardless of the lane number). The omitted category is "from footway to footway". Another two dummy variables were created for the second lane and second lane with traffic in the opposite direction (regardless of whether it is from or to the median or from footway to footway). The omitted category is the first lane.

Table 2
Crossings included in the study.

Crossing ID	Site	Total number of lanes	One-way traffic	Median strip	Zebra	Courtesy crossing design elements				Video			Traffic		
						Stripes (not zebra)	Colour/texture treatment	Visual narrowing	Ramps	Day of week	Time of day	Duration (minutes)	Number of vehiclesper minute	Number of pedestrians per minute	Total number of pedestrians
1A	Arnsberg Way, Bexleyheath	2				x	x		x	Saturday	11:08	32	10.9	1.8	57
1B		2		x		x	x		x		11:38	30	7.6	3.1	92
2	Albion Road, Bexleyheath	3		x		x			x	Saturday	14:16	30	10.7	7.7	230
3	Promenade, Blackpool	2			x					Tuesday	N/A	28	15.5	7.5	216
4	Shenley Road, Borehamwood	2		x					x	Friday	17:20	26	10.9	3.3	86
5A	Gosford Street, Coventry	2					x			Thursday	14:54	32	6.7	3.0	98
5B		2					x				14:54	32	5.4	1.7	54
6	Hamilton Road, Felixstowe	2				x	x		(x)	Wednesday	10:21	25	3.3	9.5	239
$7_{(2014)}$	Kimbrose Triangle, Gloucester	2						x		Wednesday	11:01	30	13.3	7.8	233
$7_{(2015)}$		2				x		x		Tuesday	N/A	18	11.5	11.3	204
8	King Edward Road, Knutsford	3		x	x					Friday	N/A	15	11.7	13.6	206
9A	Fountain Place, Poynton	2					x	x	(x)	Friday	16:00	25	15.1	0.9	23
9B		2					x	x			14:49	29	15	1.5	43
10A	Park Lane, Poynton	2					x	x	x	Friday	15:26	27	13.7	1.1	30
10B		2					x	x	x		N/A	25	10.9	0.4	10
11A	Fishergate, Preston	1	x				x	x		Wednesday	11:15	28	7	4.5	129
11B		1	x				x	x			10:26	17	6.5	2.5	43
11C		1	x		x						10:54	14	1.6	4.8	68
12A	Regent Circus, Swindon	2	x				x		x	Tuesday	09:12	30	8.1	5.0	150
12B		1	x				x		x		09:12	30	5.3	3.5	104
12C		1	x				x		x		09:12	30	9	5.4	161
All													**9.6**	**4.4**	**2476**

Notes: In Crossings 6 and 9A, ramps were present in one direction only. Exact time of day is unknown in crossings 3, $7_{(2015)}$, 8, and 10B.

Table 3
Road characteristics, crossing stages, and events.

Median	Number of lanes	Traffic directions	Road andtraffic representation	Number of crossings	Number of pedestrians	Crossing stage	Number of events	Number of events with interaction	Interaction rate
No	1	One-way		1	505	Footway → Footway	302	105	35%
	2	One-way		5	150	Footway → Footway Lane 1	94	36	38%
						Footway → Footway Lane 2	94	11	12%
		Two-way		10	1207	Footway → Footway Lane 1	639	292	46%
						Footway → Footway Lane 2 (opposite)	639	276	43%
Yes	2	Two-way		2	178	Footway → Median	65	30	46%
						Median → Footway	65	31	48%
	3	Two-way		2	436	Footway → Median Lane 1	102	76	75%
						Footway → Median Lane 2	20	5	25%
						Median → Footway Lane 1	102	51	50%
						Median → Footway Lane 2	82	24	29%
All				**20**	**2476**		**2204**	**937**	**43%**

We did not consider crossing direction. As an example, in a road aligned from West to East, with no median strip, crossing from the North to the South footway was captured in the same variable ("from footway to footway") as crossing from the South to the North footway.

3.3. Events and interactions

We defined an **event** as the presence of a pedestrian or group of pedestrians starting a crossing stage, i.e. attempting to cross a road lane. Table 3 above shows the number of events by crossing stage for each type of crossing. There were 2204 events across all crossings during the survey periods. The total number of events is smaller than the number of pedestrians because in some events pedestrians crossed as a group.

We considered that there was **interaction** in an event if the pedestrian(s) crossed and at least one vehicle was approaching, and therefore the driver had to make the decision to give way or not. No interaction was the case when the pedestrian(s) crossed the road with no approaching vehicles or between already stationary vehicles. Across all crossings, there was interaction in 937 events - an interaction rate of 43%. As shown in Table 3, the interaction rate was always lower in the second lane of traffic moving in the same direction, compared with the first lane. Events where there was no interaction were excluded from further analysis.

We then recorded, for each event with interaction, whether the first vehicle approaching the crossing, and whether any vehicle (the first or any of the subsequent vehicles), gave way to pedestrians.

A series of variables specific to each event was also collected, including:

- Pedestrian situation: number of pedestrians crossing together (transformed into dummy variables for "single pedestrian" and "group", i.e. more than one pedestrian") and whether there was another pedestrian or group of pedestrians crossing ahead or crossing from the other side.

- Pedestrian characteristics: sex (male/female), approximate age (child: younger than 12; younger adult (aged 12–70) and older adult (aged above 70), and presence of mobility restrictions (wheelchair or walking stick user; and pedestrians walking with a pram (baby carriage), luggage, or dogs).
- Vehicle situation: whether the vehicle was followed by another one or not.
- Vehicle characteristics: larger vehicle (Heavy Goods Vehicle or bus) vs. small vehicle (car or motorcycle).

The classification of the situations and characteristics listed above was done by a single assessor. The classification was straightforward in almost all cases. While there is always an unavoidable degree of subjectivity and uncertainty in the classification of sex and age of pedestrians, the quality of the footage was good enough to minimize this issue.

4. Yielding rates

The first vehicle yielded to pedestrians in 72.8% of all events and at least one vehicle yielded in 80.9% of all events in all crossings. Among the three zebra crossings, these proportions were 88.0% and 96.4% and among the 20 courtesy crossings, they were 68.9% and 76.9%, respectively. Table 4 shows yielding rates disaggregated by type of crossing, defined by whether the crossing is a zebra crossing or a courtesy crossing, and if the latter, by combinations of courtesy crossings design elements. The table also shows the number of crossings and events for each type of crossing. The table is sorted in ascending order of the yielding rates of the first vehicle.

Two courtesy crossings had higher yielding rates than the set of zebra crossings. These were the crossing with (non-zebra) stripes and visual narrowing (first vehicle stopped in 96.9% of events and at least one vehicle stopped in 99.4% of events) and the crossing with stripes and colour/texture treatment (94.7% in both cases).

The table also shows a wide variation in yielding rates by type of crossing. For most types of crossings, the rates were above 50%. In contrast, the set of two courtesy crossings that have colour treatment as the only courtesy crossing design element had very low yielding rates of only 4.3% and the courtesy crossing with visual narrowing as the only design element had courtesy rates of 20.2% (first vehicle stops) and 41.6% (any vehicle stops).

Table 5 shows the yielding rates in the sets of all 3 zebra crossings and all 20 courtesy crossings disaggregated by segments of the sample. These segments were defined by crossing stage, pedestrian and vehicle situation and characteristics, road and site characteristics, and time context. The table also shows (in the columns labelled "n") the frequency of each segment in the whole sample and at zebras and courtesy crossings separately. Differences in yielding rates in different segments were tested using a Chi-square test of proportions. The differences that were significant at least at the 10% level are marked in the table.

Looking first at the frequencies of each segment, the majority of events occurred in crossing stages from footway to footway; in the first lane of traffic; without other pedestrians crossing ahead or from the opposite side; without children, older adults, and pedestrians with mobility restrictions in the group; and where the vehicle was a small one. Most of events were on weekdays and in roads with 20mph speed limit and raised kerbs. The other sample characteristics were relatively balanced.

Looking at yielding rates, pedestrians crossing from footway to footway and pedestrians crossing the second lane with traffic in the opposite direction experienced the highest yielding rates at zebra crossings, with yielding rates equal or close to 100%. In contrast, those pedestrians experienced the lowest yielding rates at courtesy crossings.

Yielding rates in the presence of other pedestrians crossing ahead or from the opposite side were significantly higher than in other situations, but only at courtesy crossings. In contrast, the presence of women and children was only significant at zebra crossings. The number of pedestrians was only significant at the 10% level at zebra crossings and the presence of

Table 4
Yielding rates per type of crossing.

Zebra	Courtesy crossing design elements				Number of crossings	Number of events	% events where first vehicle stops	% events where any vehicle stops
	Stripes (not zebra)	Colour/texture treatment	Visual narrowing	Ramps				
		x			2	47	4.3	4.3
			x		1	89	20.2	41.6
		x	x		4	41	53.7	53.7
		x	x	x	3	27	66.7	77.8
				x	1	37	75.7	91.9
		x		x	3	129	76	83.7
	x	x		x	4	193	78.2	87.6
x					3	192	88.0	96.4
	x	x			1	19	94.7	94.7
	x		x		1	163	96.9	99.4
Whole sample					23	937	72.8	80.9

Notes: Differences in the sample were significant using chi-square test ($p < 0.001$). Total number of crossing adds to 23 because Crossing 7 had different characteristics at two moments in time and Crossings 6 and 9A had different characteristics per traffic direction (see note to Table 2).

Table 5
Yielding rates per segment.

Variable	n	Zebras					Courtesy crossings				
		n	First vehicle stops (%)		Any vehicle stops (%)		n	First vehicle stops (%)		Any vehicle stops (%)	
			%	p	%	p		%	p	%	p
Crossing stage											
From median strip to footway	111	31	80.7	<0.001***	90.3	0.013**	80	80.0	0.006***	90.0	<0.001***
From footway to median strip	106	34	67.7		91.2		72	79.2		88.9	
From footway to footway	720	127	95.3		99.2		593	66.1		73.7	
First Lane	621	113	82.3	0.002***	95.6	0.069*	508	69.5	0.149	78.0	0.199
Second Lane	40	18	83.3		88.9		22	91.7		91.7	
Second Lane (opposite direction)	276	61	100		100		215	66.1		73.5	
Pedestrian situation											
Single pedestrian	430	28	78.6	0.096*	92.9	0.285	402	66.9	0.215	74.6	0.109
Group	507	164	89.6		97.0		343	71.1		79.6	
No others	743	168	86.9	0.208	96.4	0.884	575	64.0	<0.001***	73.6	0.001***
Others crossing ahead	101	24	95.8		95.8		77	84.4		87.0	
Others crossing from opposite side	85	0			96.3		85	84.7		88.2	
Pedestrian characteristics											
Female > 0	569	141	92.2	0.003***	97.2	0.320	428	69.6	0.599	79.0	0.121
Female = 0	368	51	76.5		94.1		317	67.8		74.1	
Child > 0	124	52	96.2	0.034**	100	0.099*	72	66.7	0.673	81.9	0.286
Child = 0	813	140	85.0		95.0		673	69.1		76.4	
Adult (older) > 0	97	22	95.5	0.254	100.0	0.332	75	58.7	0.044**	72.0	0.287
Adult (older) = 0	840	170	87.1		95.9		670	70.0		77.5	
No mobility restrictions	835	169	88.8	0.301	96.5	0.781	666	69.7	0.205	76.7	0.630
With pram/bags/luggage/dogs > 0	79	21	81.0		95.2		58	65.5		81.0	
With wheelchair/walking stick > 0	21	0					21	52.4		71.4	
Vehicle situation											
Followed by another vehicle	435	67	83.6	0.166	98.5	0.244	368	78.5	<0.001***	88.0	<0.001***
Not followed	502	125	90.4		95.2		377	59.4		66.1	
Vehicle characteristics											
Small vehicle (Car/motorcycle)	905	184	88.6	0.247	96.2	0.547	721	69.8	0.003***	77.8	0.001***
Large vehicle (HGV/bus)	32	8	75.0		100		24	41.7		50.0	
Road characteristics											
Link	322	127	95.3	<0.001***	99.2	0.013**	195	70.3	0.831	78.5	0.531
Junction, inbound traffic	312	34	70.6		91.2		278	69.1		78.1	
Junction, outbound traffic	303	31	77.4		90.3		272	67.7		74.6	
Speed limit = 20 mph	763	123	95.1	<0.001***	99.2	0.005***	640	69.5	0.328	77.5	0.348
Speed limit = 30 mph	174	69	75.4		91.3		105	64.8		73.3	
Raised kerb	685	192	88.0		96.4		493	68.4	0.679	75.9	0.341
Not raised kerb	252	0					252	69.8		79.0	
Site characteristics											
Shops/services along footway	464	127	95.3	<0.001***	99.2	0.003***	337	74.8	0.002***	82.5	0.001***
No shops/services	473	65	73.9		90.8		408	64.0		72.3	
Time context											
Peak time	166	0		0.456		0.694	166	75.9	<0.001***	85.5	<0.001***
Not peak time	414	4	100		100		410	55.9		65.1	
Unknown time	357	188	87.8		96.3		169	93.5		97.0	
Weekday	766	192	88.0		96.4		574	66.6	0.013**	73.9	<0.001***
Saturday	171	0					171	76.6		87.1	
All	**937**	**192**	**88.0**		**96.4**		**745**	**68.9**		**76.9**	

Notes: Chi-square test significance levels: ***: 1%, **:5%, *:10%. p: probability; n: number

pedestrians with mobility restrictions was not significant at either type of crossing. Surprisingly, events with at least one older adult had significantly lower yielding rates than other groups at courtesy crossings.

At courtesy crossings, drivers in small vehicles and in vehicles followed by another vehicle gave way to pedestrians more often than those in large vehicles and those not followed by another vehicle. The explanation for the lower propensity of vehicles that are not followed might be that the driver knows that after they clear the crossing, the pedestrian will be able to cross.

Yielding rates were also significantly higher at peak-times and on Saturdays at courtesy crossings. In contrast, the location of the crossing (junction or link) and the road's speed limit were only significant at zebra crossings. In both types of crossings, yielding rates were higher at sites with shops and services along the footway.

The segment differences affecting the propensity of the first vehicle to stop were generally similar to the differences in the propensity of any vehicle stopping. However, at zebra crossings, the differences in the propensity of any vehicle stopping were almost always significant at a lower level.

Overall, the results of this section highlight some differences between the factors explaining driver yielding behaviour at courtesy crossings and at zebra crossings, with different roles played by the crossing stage and the vehicle and pedestrian characteristics and situation.

5. Modelling yielding behaviour

Statistical models were estimated to explain how yielding behaviour in each event (i.e. every interaction between driver and pedestrians in each road lane that pedestrians need to cross) relates to the courtesy crossing design elements, when controlling for other factors.

Four models were specified, two for the propensity of the first driver stopping (Models 1 and 3) and two for the propensity of any driver stopping (Models 2 and 4). Models 1 and 2 include all crossings (zebras and courtesy crossings). The main explanatory variables are whether the crossing is a courtesy crossing (and not a zebra crossing) and the presence of the four courtesy crossing design elements. The reference case is a zebra crossing. Models 3 and 4 include only courtesy crossings. The main explanatory variables of these models are the four courtesy crossing design elements. The reference case is a hypothetical courtesy crossing with none of the four specified design elements. The data from the second video survey at Crossing 7 (after the design of the crossing was changed) was not included in any model. The sample sizes are therefore 774 events in Models 1 and 2 and 582 events in Models 3 and 4.

In all models, the control variables identify crossing stage, pedestrian and vehicle characteristics and situation, road and site characteristics, and time context. Independence between explanatory variables was checked using variance inflation factors. This led to the exclusion of the dummy variable for Saturdays. Using a bidirectional elimination process, we then excluded variables that were not significant in the model at the 10% level.

The models used a logistic specification. The dependent variables are the log odds of the first vehicle stopping (in Models 1 and 3) or any vehicle stopping (in Models 2 and 4) vs. not stopping. The standard errors of the model coefficients were clustered by crossing, to account for possible correlation in the errors for events occurring in the same crossing.

Table 6 shows the estimated models. The models fitted well with the data, as shown in the three goodness of fit statistics reported at the bottom of the table. In particular, the models for the propensity of any vehicle stopping for pedestrians correctly predicted the outcome (stop vs. not) in 85%-87% of the cases.

The coefficients of the four courtesy crossing design elements were positive in all models and significant at the 1% level (in Models 2 and 4) and at the 5% level (in Models 1 and 3 - except colour treatment, significant at the 1% level in Model 1). This result means that each additional design element contributed to a higher propensity of drivers yielding to pedestrians. The impacts of each element on the propensity of the first driver stopping (Models 1 and 3) had similar magnitudes, with only a slightly higher impact for stripes in Model 3. The impacts on the propensity of any driver stopping (Models 2 and 4) were less balanced, with visual narrowing having a considerably larger impact than the other elements.

The impact of combinations of courtesy crossing design elements is given by the sum of the coefficients of those elements. In Model 1, combinations of any three courtesy crossing design elements had a higher impact on the propensity of the first vehicle stopping for pedestrians than zebra crossings, as the sum of the coefficients of any three elements was higher, in absolute value, than the (negative) coefficient for courtesy crossings (vs. zebras). In Model 2, combinations of any three design elements that include visual narrowing also had a higher impact on the propensity of any vehicle stopping for pedestrians than zebra crossings. The 3-element combination of design elements with the highest impact, in both models, is the one with visual narrowing, ramps, and stripes.

In all models, there was a higher propensity for yielding behaviour when (i) pedestrians were crossing from or to the median strip, (ii) with other pedestrians crossing from the other side, (iii) the vehicle was followed by another vehicle, (iv) the road had a 20mph speed limit, and (v) there were shops along the footway.

Additional variables were significant in Models 1 and 3. The propensity of the first driver giving way to pedestrians was higher when (i) pedestrians were crossing the second lane with traffic in the same direction, (ii) were crossing in a group, (iii) with other pedestrians crossing ahead, and (iv) the crossing was on a link (not a junction). In Model 1, the propensity was also higher when (i) pedestrians were crossing the second lane with traffic in the opposite direction and (ii) there was at least one woman in the group. In Models 2 and 4, the presence of a woman in the group was also significant.

With regards to the magnitude of coefficients in the same group of variables, the coefficients were higher for: i) crossing from the median strip, compared with crossing to the median strip, and ii) other pedestrians crossing from the other side, compared with others crossing ahead or crossing together in the same group. Where significant, the coefficients of inbound and outbound traffic on a junction were similar.

Table 6
Models of driver yielding behaviour.

Variable	All crossings						Courtesy crossings					
	Model 1 First vehicle stops			*Model 2* Any vehicle stops			*Model 3* First vehicle stops			*Model 4* Any vehicle stops		
	Coeff.	SE		Coeff.	SE		Coeff.	SE		Coeff.	SE	
Constant	−0.89	0.76		−3.26	1.47	**	−4.31	1.02	***	−9.04	2.16	***
Courtesy crossing design elements												
Any (Courtesy crossing)	−4.20	0.65	***	−5.68	0.66	***						
Stripes (not zebra-like)	1.49	0.63	**	1.90	0.59	***	1.68	0.79	**	1.80	0.62	***
Colour treatment	1.47	0.50	***	1.03	0.39	***	1.35	0.57	**	1.11	0.34	***
Visual narrowing of carriageway	1.55	0.64	**	2.91	0.81	***	1.38	0.66	**	3.00	0.94	***
Ramps	1.53	0.73	**	2.07	0.54	***	1.47	0.75	**	2.21	0.55	***
Crossing stage												
From median strip to footway	2.41	0.65	***	4.79	1.26	***	2.29	0.78	***	5.14	1.48	***
From footway to median strip	1.38	0.46	***	4.19	1.41	***	1.36	0.75	*	4.60	1.93	**
Second lane	1.25	0.53	**				0.67	0.24	***			
Second lane (in opposite direction)	0.90	0.27	***									
Pedestrian situation												
Group	0.43	0.24	*				0.58	0.26	**			
Others crossing ahead	1.17	0.26	***				1.39	0.37	***	0.63	0.33	*
Others crossing from other side	1.98	0.53	***	1.39	0.31	***	1.96	0.58	***	1.39	0.33	***
Pedestrian characteristics												
Female > 0	0.52	0.23	**	0.85	0.22	***				0.83	0.22	***
Vehicle situation												
Followed by another vehicle	0.82	0.25	***	1.61	0.42	***	0.69	0.25	***	1.41	0.41	***
Other infrastructure characteristics												
Junction, inbound traffic	−1.47	0.63	**				−1.29	0.75	*			
Junction, outbound traffic	−1.49	0.70	**				−1.37	0.82	*			
Speed limit = 20mph	1.44	0.54	***	4.26	1.05	***	1.14	0.55	**	4.31	1.32	***
Site characteristics												
Shops	1.09	0.52	**	2.61	0.60	***	0.90	0.55	*	2.40	0.67	***
Number of observations	774			774			582			582		
McFadden's Pseudo R^2	0.32			0.41			0.30			0.43		
Count R^2	0.68			0.87			0.61			0.85		
Adjusted Count R^2	0.40			0.44			0.46			0.48		

Notes: Significance levels: ***: 1%, **:5%, *:10%; Coeff: coefficient; SE: standard error. Omitted categories: zebra crossings [Model 1 and 2], courtesy crossing with none of the specified design elements [Models 3 and 4]; from footway to footway; first lane; no others crossing together, ahead, or from other side; no women in the group, vehicle not followed; link (not junction); speed limit = 30mph; no shops along footway. Goodness of fit statistics: McFadden's Pseudo R^2 is the reduction in log-likelihood of final model compared with intercept-only model; Count R^2 is the proportion of correct predictions; Adjusted Count R^2 is the proportion of correct predictions beyond what would be correctly predicted by assigning the most frequent outcome to all observations.

Insignificant variables, tested in preliminary runs of the models and excluded from all final models, included whether the group includes a child, an older adult, or a pedestrian with mobility restrictions, size of vehicles, whether the kerb is raised, and time of day.

The results of the models were generally consistent with the bivariate analysis reported in Table 5. However, some significant differences between segments became insignificant when controlling for other variables in the logistic regression. This includes the unexpected result in Table 5 of lower yielding rates at courtesy crossings when there were older adults in the group. A few insignificant differences between segments also became significant in the logistic regression (e.g. speed limit at courtesy crossings).

6. Impact of adding a design element to an existing crossing

There were changes to the design of one of the crossings (Crossing 7, Kimbrose Triangle, Gloucester), which allowed us to test how driver yielding behaviour responds to the addition of a new design element to an existing courtesy crossing (Fig. 3). When the crossing was originally completed in 2011, the only courtesy crossing design element was the visual narrowing of the carriageway. Stripes were added in early 2015, following requests by users and a consultation process. The stripes have some resemblance to zebra crossing stripes, but the crossing is not a formal zebra crossing, as drivers are not legally required to stop. In addition, the crossing does not have the required standardized design elements of zebras, such as signs, posts with flashing lights, and zigzag markings.

Fig. 3. Kimbrose Triangle: before and after, Source: CIHT (2018) Creating better streets: Inclusive and accessible places. CIHT, London., p.97. Reproduced with written permission from the publisher.

Table 7
Yielding rates in Kimbrose Triangle crossing by segment, before and after adding stripes.

Variable	N		% first vehicle stops			% any vehicle stops		
	Before	After	Before	After		Before	After	
Crossing stage								
First Lane	44	83	15.9	96.4	***	38.6	98.9	***
Second Lane (in opposite direction)	45	80	24.4	97.5	***	44.4	100	***
Pedestrian situation								
Single pedestrian	37	78	21.6	98.7	***	37.8	100	***
Group	52	85	19.2	95.3	***	44.2	98.8	***
No others	69	90	15.9	94.4	***	37.7	98.9	***
Others crossing ahead	3	30	33.3	100	***	66.7	100	***
Others crossing from oppposite side	17	51	35.3	100	***	52.9	100	***
Pedestrian characteristics								
Female > 0	60	86	21.7	95.4	***	48.3	98.8	***
Female = 0	29	77	17.2	98.7	***	27.6	100	***
All	89	163	20.2	96.9	***	41.6	99.4	***

Notes: Chi-square test significance levels: ***: 1%, **:5%, *:10%. Age of pedestrians and vehicle situation and characteristics not shown because of small samples in the "after" situation of groups with children or older adults, large vehicles, and vehicles not followed by another vehicle.

Two sets of video surveys were conducted at this site, before (August 2014) and after (February 2015) the addition of the stripes. Driver yielding behaviour and event-specific variables were recorded for both situations, using the methods described in Section 3.

The proportion of events where the first vehicle stopped for pedestrians increased dramatically from 20.2% to 96.9% and the proportion where any vehicle stopped increased from 41.6% to 99.4%. These increases happened in all segments of the sample, as shown in Table 7. The yielding rates after the change were 100% for several segments. The differences between the before and after yielding rates were significant at the 1% level in all segments.

Logistic models were estimated on a dataset merging data for the before and after situation in this crossing. The dependent variables represent the case of the first vehicle stopping (Model 1) and any vehicle stopping (Model 2). The main explanatory variable is a dummy for the presence of stripes (i.e. the "after" situation). The control variables identify pedestrian and vehicle situation and characteristics and crossing stage - in this case, defined only by second lane with traffic in the opposite direction, as the crossing has no median strip.

Table 8 shows the estimated models. The two models fitted well with the data, as shown in the three goodness of fit measures reported. The coefficient identifying stripes was positive and significant at the 1% level in both models, which means that the presence of stripes was associated with driver yielding behaviour, even when controlling for other factors affecting this behaviour.

Among the control variables, the probability of the first driver stopping was higher when there were pedestrians crossing from the opposite side and the vehicle was followed by another vehicle or was a small vehicle (although in this last case, the level of significance was only 10%). The probability of any driver stopping was higher when there were pedestrians crossing from the opposite side, there were women in the group, and the vehicle was followed by another vehicle. Where significant, the signs of the significant variables were the same as the signs in the cross-sectional models in Table 6.

Insignificant variables, tested in preliminary runs of the model and excluded from the final model, include crossing the second lane with traffic in the opposite direction, pedestrians crossing in a group, other pedestrians crossing ahead, and whether the group included a child, an older adult, or a pedestrian with mobility restrictions.

Table 8
Before-after model, Kimbrose Triangle crossing.

Variable	Model 1			Model 2		
	First vehicle stops			Any vehicle stops		
	Coefficient	Standard error		Coefficient	Standard error	
Constant	−2.08	0.43	***	−1.72	0.52	***
Courtesy crossing characteristics						
Stripes [“after” situation]	4.54	0.64	***	4.83	1.08	***
Pedestrian situation						
Others crossing from other side	1.45	0.60	**	1.16	0.60	**
Pedestrian characteristics						
Female > 0				0.98	0.50	**
Vehicle situation						
Followed by another vehicle	0.98	0.57	**	1.46	0.51	***
Vehicle characteristics						
Large vehicle (HGV/Bus)	−3.44	1.50	*			
Number of observations	252			252		
McFadden’s Pseudo R^2	0.54			0.54		
Count R^2	0.88			0.88		
Adjusted Count R^2	0.43			0.43		

Notes: Significance levels: ***: 1%, **:5%, *:10%. Omitted categories: no stripes, no others crossing from other side, no women in the group, vehicle not followed by another, small vehicle. Interpretation of goodness of fit statistics: see Table 6.

7. Discussion

7.1. Synthesis and relation to previous literature

There is a movement towards the provision of more courtesy crossings, where drivers are not legally required to stop but may do so out of courtesy. However, there is still little quantitative evidence on how different design elements of courtesy crossings influence driver yielding behaviour to pedestrians. This study has filled this gap by comparing driver yielding behaviour at courtesy crossings and marked unsignalised crossings (zebras), and identifying the design elements associated with yielding behaviour at courtesy crossings. Unlike most previous studies on vehicle–pedestrian interactions, we analysed driver yielding behaviour in each separate traffic lane that pedestrians need to cross.

Using cross-sectional data from 20 different crossings, we found that all four design elements of courtesy crossings considered (stripes, coloured or textured surfacing, visual narrowing of the road, and ramps) significantly increased yielding behaviour. This was further confirmed in the analysis of before-after data in a location where an additional element (stripes) was added to an existing courtesy crossing.

The results also provided insights into the motivations of driver yielding behaviour in response to factors other than the design of the crossings, highlighting how those motivations differed in courtesy crossings and in zebras. This is evident in the differences between yielding rates at the two types of crossings (as shown in Table 5) and in how other results for courtesy crossings compare with those in the previous literature on marked unsignalised crossings (listed in Table 1). In some cases, our results confirmed those in the literature. For example, drivers stopped more often when the speed limit was lower and when pedestrians were crossing the second lane of traffic. In other cases, the results add evidence regarding factors for which previous evidence was mixed. For example, yielding rates were higher when pedestrians were crossing from or to a median strip and when the vehicle was followed by another vehicle. Yet, in other cases, the results did not confirm previous evidence. For example, we found only weak or no evidence that yielding rates increased with the number of pedestrians crossing in each event and when there were children, older adults, and pedestrians with mobility restrictions in the group.

7.2. Implications for policy and practice

Our results address the calls for evidence requested by policy-makers and professional associations on the design of courtesy crossings. Based on the results found, we recommend that the design of courtesy crossings includes all four design elements analysed, where possible. Median strips and lower speed limits are additional elements that could increase driver yielding behaviour. In fact, these elements could be considered in themselves as courtesy crossing design elements. These recommendations are made with the caveat that the supporting results were obtained in the specific context of the UK. Whether the recommendations apply in other countries depends on regulations, availability of other types of crossings, and perhaps on demographic and cultural factors.

Our results also have implications for the location of courtesy crossings, i.e. in which type of roads and which particular places these crossings could be installed. For example, the results in the models in Table 6 suggest that yielding rates at courtesy crossings were significantly higher at sites where there are shops and services along the footway.

Finally, the results add to the debate on "shared space". We found that marginal differences in the road design influence the behaviour of drivers of motorised vehicles, which suggests that these differences increase drivers' feeling that they should share the space with pedestrians - one of the main assumptions of courtesy crossings and the wider shared space philosophy. Some combinations of design elements (in fact, any combination of three of the four design elements studied) are even more effective in inducing yielding behaviour than traffic regulations (i.e. the legal requirement to stop at zebra crossings). As such, road design alone can contribute to the reduction of the dominance of motorised vehicles, addressing some of the needs of pedestrians and people using roads and streets for place activities. These results may also apply to other users of non-motorised transport, such as cyclists and people using skateboards or scooters.

7.3. Directions for future research

The other main assumption of courtesy crossings and of the wider shared space approach – that it effectively addresses pedestrian safety – needs further evidence. While yielding rates could be understood as an indicator of pedestrian safety, more solid conclusions on this aspect require measuring the relationships between courtesy crossing design elements; yielding behaviour; and collision risk or pedestrian perceptions of risk. In addition, yielding rates alone do not fully capture driver behaviour: the speed of vehicles approaching the crossings, regardless of whether they stop for pedestrians or not, is also important. Evidence suggests that zebra crossings do not effectively reduce vehicle speeds even in roads with a speed limit of 30kph (18.6 mph) (Johansson, Gårder, & Leden, 2003), a result that may also apply to courtesy crossings.

We also note that this paper looked at driver behaviour at different types of crossings, which is only one side of the problem. The choice over the most suitable type of crossings also depends on pedestrian perceptions and behaviour, which may be influenced by different design elements. It is particularly important to study the degree to which courtesy crossings address the mobility and safety of pedestrians with mobility, visual, or other physical impairments.

The role of time in changing yielding behaviour can also be further explored. Our before-after analysis considered the change over two points in time (with a year interval). A more regular monitoring of yielding rates (together with opinion surveys) could explain the process of how drivers and pedestrians adapt to changes in the crossing design. A monitoring period longer than one year can also identify any possible rebound in yielding rates after the initial adjustment.

A few methodological refinements could be introduced in future research. For example, due to limitations arising from the location of the video cameras, we could not account for the full range of attributes of factors affecting driver behaviour, such as the trajectory followed by vehicles (e.g. curves, deviations, turning movements at junctions). The use of automated video analysis could also improve the identification of all possible driver-pedestrian interactions as pedestrians move across the road (Laureshyn, Svensson, & Hydén, 2010), rather than only at the start of each road lane. Using a larger sample of crossings, the set of design elements could also be disaggregated into different types of stripes, colours, and textures. To have a better understanding of yielding behaviour, it would also be beneficial to validate model results with surveys or focus groups to capture nuances in driver perceptions, attitudes, and preferences.

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Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Appendix A. Detailed designs of the case study crossings

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