Transportation Research Part F: Psychology and Behaviour 101 (2024) 78–91

Contents lists available at ScienceDirect

Transportation Research Part F: Psychology and Behaviour

journal homepage: www.elsevier.com/locate/trf

A field evaluation of an in-ground lighting intervention for safety at a road crossing

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A R T I C L E I N F O

Keywords:
Road crossing safety
In-ground lighting
Observation
Field evaluation
Pedestrian crossing behaviour

A B S T R A C T

There are limited numbers of naturalistic studies of behaviours in response to safety interventions, such as novel lighting products at road crossings. The study used a theory-based approach to evaluate behavioural responses to a novel, ground-mounted lighting intervention at a zebra crossing at a university campus. An evaluation framework was developed to explore the extent to which the intervention was implemented in practice and collect a range of data types to assess the outcomes and impacts of the lighting intervention, in terms of the responses and behaviours of crossing users.

The study was primarily observational, collecting and analysing video recordings of the road crossing episodes for people alone or in small groups (n = 269). This was supported by a small consultation exercise to help understand user-perceptions, achieved through an online questionnaire of crossing users (n = 59).

The observations contributed to understanding crossing behaviours in this location, generally demonstrating safe crossing behaviours, such as looking for traffic and walking within the marked crossing features. There was no observable indication of users noticing or responding overtly to the lighting. However, 29% of the small sample responding to the questionnaire stated that the lights had influenced the way that they used the crossing. The survey responses indicated that users understood the intention of the lighting and cited positive attributes and perceived benefits, which may improve behaviours and safety for both pedestrians and drivers. It is concluded that the lighting intervention has the potential to improve safety-related behaviours at crossings, but further investigation of its efficacy would be recommended.

Guidance is provided on how to respond to various methodological and situational challenges that have been encountered in this study, such as how to improve observational data collection for field studies in this type of context. Future development of the intervention might involve sensor-based activation and variation in the lighting (e.g., differing flash rates and colours).

1. Introduction

Crossing the road can be a risky activity at non-official crossing locations (Escobar, Cardona and Hernández-Pulgarín, 2021), but can also be problematic at established marked crossings. Although formal road crossings (e.g. zebra crossings in UK) can improve feelings of crossing safety for pedestrians (Bernhoft and Carstensen, 2008), distraction and unsafe crossing behaviours can lead to

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https://doi.org/10.1016/j.trf.2023.12.017
Received 30 January 2023; Received in revised form 17 November 2023; Accepted 25 December 2023
Available online 12 January 2024

misuse and dangerous situations (Hatfield and Murphy, 2007; Liu, Alsaleh and Sayed, 2021). For example, mobile phone use is a common source of lack of awareness of a marked crossing and almost a third of pedestrians observed at selected crossings in New York were distracted in such a way when crossing the road (Basch, Ethan, Zybert and Basch (2015).

Observational studies of pedestrians can provide a contextual understanding of behaviours in response to crossing features. Madigan, Lee and Merat (2021) provide a comprehensive list of pedestrian behaviours that can be observed at crossings, including head movements (such as looking at other road users or vehicles) and various additional factors that may influence safety at the location (e.g. weather conditions, whether people were alone or part of a group, carrying objects and potential distractions). Aghabayk, Esmailpour, Jafari and Shiwakoti (2021) observed pedestrians crossing signaled and unsignaled crossings (n = 552) and found unsignaled crossings to experience most conflicts, whilst drivers were more cautious at signaled crossings. They also noted differences in groups and individual behaviours. People in groups or using mobile phones were most likely to cross in an unsafe manner and were less likely to look left and right before crossing. A variety of observable behaviours have been considered in assessing safety in other studies. These include speed of walking or waiting times to cross (Havard and Willis, 2012), and entry and exit points and the resulting straight or diagonal crossing trajectories (Papadimitriou, Lassarre and Yannis, 2016). Other higher-risk circumstances have been described by Escobar et al. (2021), such as crossing at non-designated locations when there is traffic or stopped vehicles nearby, crossing without looking at the traffic, or with distractions (e.g. carrying objects, talking to other pedestrians, using a phone/looking at electronic devices, using headphones).

Freeman, Rakotonirainy, Stefanova and McMaster (2013) examined warning signals or lighting technologies to increase conspicuity and attract the attention of pedestrians to formal crossings. Bullough and Skinner (2017) demonstrated the acceptance of a novel vertical bollard lighting system at zebra crossings, indicating that the improved illuminance was valued by pedestrians for feelings of safety. Patella, Sportiello, Carrese, Bella and Asdrubali (2020) found that a ground-mounted LED illuminated in-road crossing was successful in slowing down drivers on approach to the crossing, even in the absence of a pedestrian waiting to cross.

Laboratory based examinations of the effects of such lighting interventions have been conducted. For example, Larue, Watling, Black, Wood and Khakzar (2020) conducted a lab-based study exploring how mobile phone users change behaviour whilst crossing the road with the presence of in-ground lighting interventions. Pedestrians accurately detected flashing LED ground-mounted lights with their peripheral vision, even when distracted. However, their reaction times were slower than those who were not participating in distraction tasks. Kim, Kim, Kwon and Shin (2020) conducted a laboratory experiment to explore the impact of in-ground lighting interventions on signal detection tasks when texting while walking on a treadmill. Participants (n = 23) demonstrated better task performance when they were presented with a higher contrast in-ground lighting intervention compared to a lower contrast one.

Experimental studies have also been conducted within a field-based context. Larue, Watling, Black and Wood (2021) reviewed the impact of in-ground lights installed at a railway crossing on pedestrian behaviour. An experimental field study was conducted with 34 participants to explore the effect of in-ground LEDs during the daytime. The findings, including eye tracking data and observations, confirmed the participants' abilities to detect the illumination of in-ground LEDs when activated: most pedestrians detected the lights at their activation, and they encouraged appropriate scanning behaviour. Larue and Watling (2021) evaluated the acceptability of their rail crossing lighting intervention with pedestrians who were distracted by using a mobile device to complete a task, finding that the lighting intervention was perceived favourably (e.g. easy to use, perceived usefulness). Boyce and Van Derlofske (2002) completed a field evaluation of flashing ground-mounted lights incorporated into a zebra crossing and found favourable results compared to a crossing with the painted stripes only. Further, Larue et al. (2020) identified a number of locations in Australia, Singapore and Germany that have trialled in-ground lighting for pedestrian safety. However, it is not clear whether formal evaluations of these interventions have been conducted.

A recent systematic review by Haghani (2020) identified that most crowd dynamic/pedestrian studies to date have been laboratory based, with the limited number of field studies largely conducted to inform pedestrian modelling approaches. The more common laboratory experiments (e.g. Kim et al., 2020; Larue et al., 2020), despite the potential for accurate quantification of impact and performance indicators, inherently lack ecological validity and their samples have been criticised for not being representative of wider pedestrian populations (Feng, Duives, Daamen and Hoogendoorn, 2021; Fotios and Johansson, 2019). As such their conclusions relating to a real-world setting are somewhat limited. More fields trials focusing on the naturalistic behaviours of real users of crossings are therefore needed. The current study aimed to examine observable behaviours in a field study at a crossing with a new lighting intervention, supplementing this with subjective responses to questions about the perceived effect of the lights on behaviour at the crossing. In this initial exploratory study, it was important to develop a method that could be applied with some flexibility to be able to respond to emerging findings about what data can and should be collected, and how to do this effectively, in this type of real-world evaluation context. Commentary is provided on a number of methodological and practical challenges that were encountered in developing and applying the approach to evaluation in this field study.

2. Methods

2.1. The lighting intervention

The development of the lighting intervention was informed by an extensive review of the behaviourally-orientated intervention literature (e.g. Hallewell, Ryan, Hughes and Coad, 2023; Hughes et al., 2020; Kallberg and Silla, 2017; Ryan et al., 2021), to identify the types of lighting cues that could be used to influence behaviours in the anticipated study environment. This was followed by a series of engagement activities with transport stakeholders and led to the development of functional specifications for lighting in this type of transport context (detailed in Hallewell et al., 2023). Important features of the lighting-based intervention include the ability to alert a distracted person to their proximity to a potentially dangerous area, in this case, inducing them to stop and look at the road before crossing, as well as encouraging crossing at the official location, using a pre-defined trajectory.

The chosen intervention was therefore influenced by the functional requirements, as well as its readiness for deployment, in this case, using an existing commercial lighting product that is manufactured and used in other contexts by one of the partner organisations involved in the study. The intervention consists of a ground mounted light strip which flashes red, with the intention of attracting attention to the crossing (see images of the intervention and its positioning in Fig. 1 and Fig. 2). The unit has the capability to be programmed to display various colours and flash at various rates, though was set to flash at a consistent rate and display the single colour red for the purpose of this initial trial. Evidence suggests that warmer colours (red-toned) can perform better than neutral and cooler colours (blue toned) for use during wayfinding (Hidayetoglu, Yildirim and Akalin, 2012). Red also has cultural/social significance as a warning measure for road users in many countries.

2.2. Trial site

The intervention was installed by approved contractors on a private road, at a new crossing, outside a public health centre at The University of Nottingham's University Park campus. A single trial site was selected, to make best use of finite resources available for this initial evaluation field study. This is typically a busy location, with a mix of university staff, students and members of the public visiting the health centre and nearby university buildings, along with delivery drivers accessing the health centre and an attached retail outlet. There is a taxi drop-off bay and a public bus stop located within 100 m of the crossing, and a car park for the health centre is also accessed from this road.

The evaluation was conducted within the context of the COVID-19 pandemic and restrictions, which had several implications. For instance, the health centre was offering COVID-19 vaccines at the time of the study, attracting more members of the public who would not normally visit the area. However, university students and staff access to the campus was lower than usual. Thus, footfall and traffic in the area were unpredictable. As a result of prior COVID-19 restrictions at the site, the intervention was installed and in use approximately 6 months before researchers were permitted to be on campus to collect data.

2.3. Approach to the evaluation study

There are many forms of evaluation studies (Hills and Junge, 2010). Evaluation studies often collect before-and-after data or compare outcomes at intervention and control locations. Whilst these study designs have value, there are practical reasons why alternatives can be needed by researchers (Hills and Junge, 2010). In this case, there was no existing crossing at the trial location and there were no comparable sites that could be used in a controlled study. There are various forms of implementation research (Seward et al., 2021) that can enable researchers to work around practical problems that they face in real-world settings, whilst also collecting sufficient information to support the continued development of a safety intervention. In implementation research, it is critical to understand the context of the implementation of the intervention, the extent of implementation of an intervention and resulting outcomes. Therefore, a theory-based approach to evaluation (Hills and Junge, 2010; Pedersen, Nielsen, & Kines, 2012) was applied to understand how, why and in what circumstances the lighting intervention would work in a real-world setting at a functional road crossing. This required the development of an intervention theory, outlining how the intervention was expected to work in the

Fig. 1. The road crossing and lighting installed at the campus.

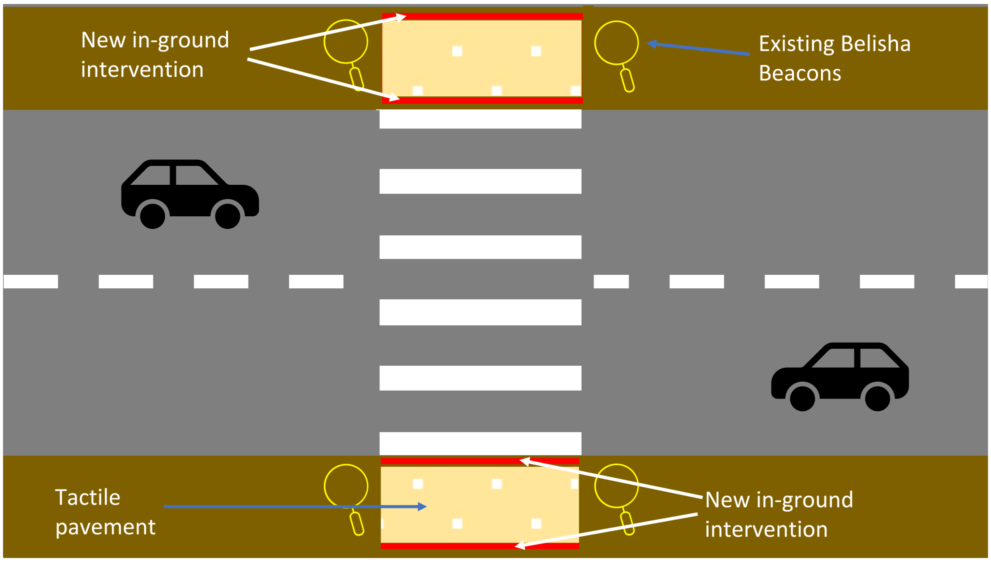

Fig. 2. Positioning of the lighting intervention on the crossing.

complexity of this real-world context. The evaluation framework for the study was adapted from Hills and Junge (2010), using a "logic mapping" approach to identify outcomes and impacts that can be realised in short- to longer-term timeframes. A series of questions were identified that corresponded with various timeframes. The evaluation framework identified the following questions around short-term outcomes:

1. Are the lights functioning as intended?
2. Do pedestrians take notice of the lighting?
3. Do pedestrians understand the purpose of the lighting?
4. Do pedestrians respond appropriately to the crossing?
5. Do pedestrians progress when safe to do so?

The following medium- to longer-term impacts of the lighting intervention were identified:

6. Whether the behaviours shown at this location could be considered safe/unsafe.
7. Whether the lighting intervention appears to be influencing the relative safety of behaviours.
8. Consideration of whether the lighting intervention could increase safety over a longer time.

The impacts in 6–8 above, are logical extensions of positive responses in 1–5 above. For example, if the lights function as intended, people notice these and understand their purpose and respond appropriately, only progressing when safe to do so. Behaviours in the location would be considered as safe and potentially influenced by the lighting. The data collection was carried out over a short period of time in this initial study, so it was not possible to collect safety related data to examine these medium- and longer-term impacts. Some commentary is provided on the potential for safety improvement arising from the lighting, based on the responses from the survey of crossing users.

Data were therefore collected in an exploratory observational study to examine pedestrian responses and attitudes to the lighting intervention, using the following methods:

- Direct observation: a video camera was placed near to the crossing for a series of observation periods, to record people using the crossing.
- Questionnaire: An online survey, advertised to staff and students across campus, and to members of the public, via notices in buildings and close to the crossing.

The study was approved by the University of Nottingham, Department of Engineering Ethics committee.

3. Observation

The observation part of the study focused on both general behaviours at the crossing and any specific observable behaviours in response to the lighting intervention.

3.1. Procedure and materials

video recordings were captured during in-person visits to the crossing site. A map, detailing the crossing area, is shown in Fig. 3. A researcher directed a video camera towards the crossing from one of three locations within the study area, either secured to a tripod or positioned inside a vehicle (Fig. 4). The video recording was constantly running during the observation visits, providing a total of 8.2 h of footage, collected over eight visits on five days during April 2021, with recording times in each session between 27 and 112 min. The videos were collected during the morning, at midday and in the early afternoon. No footage was collected outside of business hours, as movements at these times were limited. Photographs were taken of the lights in different lighting conditions, to observe their functioning.

Viewpoints A, B and C are shown in Fig. 4. Initially, observations were taken from Viewpoint A, to explore details of pedestrian behaviour. This view enabled observation of pedestrian behaviours on the crossing but allowed a limited view of activity on the road surrounding the crossing. Viewpoints B and C were subsequently added for wider views of the environment and behaviours in conjunction with incoming cars. Cameras were positioned in locations that would not obstruct or influence pedestrian movements or drivers in the area.

3.2. Participants

From the combined footage, 269 short extracts of crossing episodes were captured, containing either group or individual crossings.

3.3. Analytical approach for the observations

An observation schedule listed items identified from relevant literature as either safe or unsafe behaviours, or factors that may influence these (e.g. Escobar et al., 2021; Hatfield & Murphy, 2007; Havard & Willis, 2012; Koh, Wong, & Chandrasekar, 2014; Madigan et al., 2021). Initial observations of the videos were used to refine the final observational checklist for the classification of the observable behaviours at this location. The recorded extracts were analysed with NVivo 12.0 to produce codes that describe pedestrian behaviours (how they cross the road, if they are looking into the crossing and if they are approaching the road when it is safe to do so, whether they were crossing individually or as part of a group, absence or presence of a vehicle, and weather conditions). Cross-tabulation and Chi-square analyses (Pearson Chi-Square 2-sided) were used to explore potential associations between various observed activities or environmental conditions (e.g. carrying objects / not carrying objects, weather conditions) and crossing behaviours (e.g. the trajectory of movement or looking or stopping behaviours).

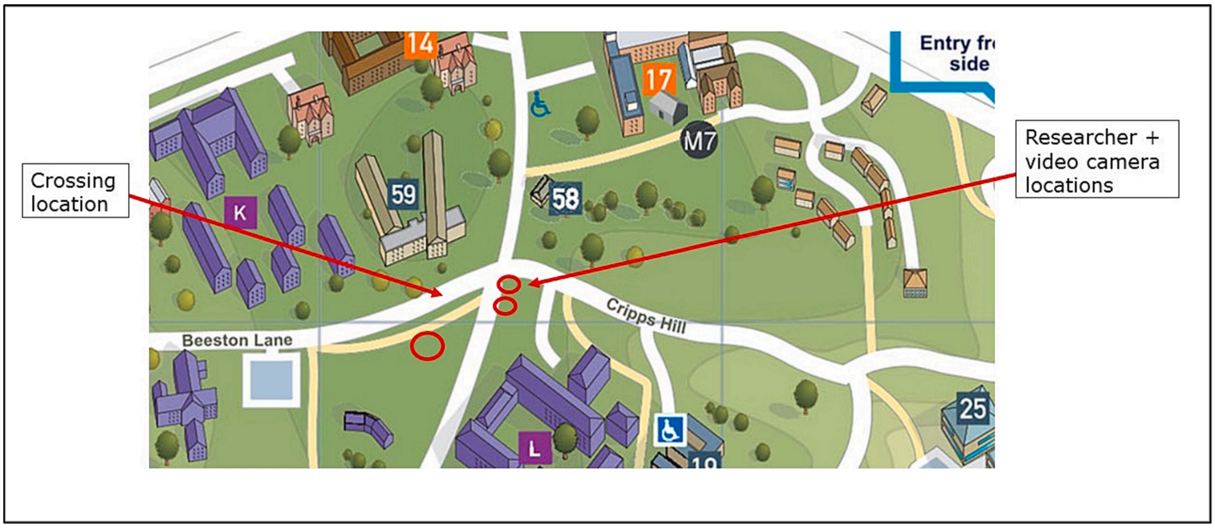

Fig. 3. Location of video recording sites.

Fig. 4. Viewpoints for recording activity on the crossing.

3.4. *Pedestrian questionnaire*

3.4.1. *Procedure and materials*

The questionnaire part of this study used an online survey to focus on whether pedestrians noticed the lighting and understood the purpose of the lighting.

Posters containing QR code links to the survey were positioned in the vicinity of the crossing, and emails were sent to members of staff and students at the University. Since the lights had been installed alongside a new zebra crossing in the location, the advertising materials and questionnaire included images of the lighting intervention, along with specific instructions to think about the ground-mounted light product, rather than any of the other standard zebra crossing features and infrastructure (i.e., the stripes and Belisha beacons). The questionnaire contained 14 questions, with a mixture of fixed response options and open-ended questions. The questions covered six themes: Experience with the crossing; Conspicuity of the new lights; Perception of the lights (i.e. purpose and overall feeling); Perceived effects on safety; General opinion; and Demographic information. The survey took on average 5–6 min to complete.

3.5. *Participants*

Respondents of the questionnaire are described in Table 1.

Table 1
Description of questionnaire participants.

Descriptor	Characteristic	Count	Percentage of sample*
Gender	Woman	36	61
	Man	21	36
	Non-binary	1	2
	Prefer not to say	1	2
Age	18–24	24	41
	25–34	20	34
	35–44	7	12
	45–54	6	10
	55–64	2	3
	65–74	0	0
	75+	0	0

* Percentages may not total to 100 due to rounding.

3.6. Analytical approach for questionnaire data

Quantitative data were summed and converted to percentages to show the proportions of responses in categories. Responses to open questions were analysed thematically, in which semantic links were sought between responses to identify key ideas. For example, when asked what they thought was the purpose of the lighting, often the participant suggested only one purpose (e.g. the statement “Just to look good” would be coded under the theme of “aesthetics”). Other participants gave multiple suggested purposes, which would be given two or more codes. For example, the statement, “Alert people to look if a car is incoming, especially if they are looking at the ground or their phone…also allows people hard-of-seeing to have a clear signal to pay attention when crossing”, would be coded with the themes “warning for distracted participants”, “influence crossing behaviour” and “assistance for visual impairment”. Where participants included more than one idea in their response, each was coded as a unique response. Quantities of responses within the theme were then converted to percentages of responses to the question. Percentages are presented for total unique responses per theme, rather than by participants.

4. Results

4.1. Overview of the observational data

The characteristics of the 269 observed crossings are displayed in Table 2. Weather conditions were quite balanced throughout the five days, more individual than group crossings were captured, and there were roughly equal numbers of crossings in the presence and absence of a vehicle on the road.

A key finding here is that there was no direct observation of any instances of pedestrians obviously looking at the lights in the ground, so there was no evidence of an observable reaction to the lights. This finding may have been the result of many factors, including the limited sensitivity of the observation method, the background lighting conditions and the fact that the lights had been installed for some time before the observational study could start and the lights were not novel to the pedestrians observed.

The coding of the recordings of the crossing episodes provided an understanding of the crossing behaviour, including those that are typically thought to be safe or unsafe (Escobar et al., 2021). In most cases, people crossed the road in a straight line in alignment with the road crossing (i.e. directly from the designated dropped kerb on one side to the dropped kerb on the other side, n = 242 = 89 %). Some deviated slightly, depending upon their destination, but mostly stayed within the road crossing features. Most pedestrians were seen to be looking for vehicles on the road before crossing (n = 229 = 85 %). Very few were talking on the phone (n = 7 = 1 %), or looking at their phone (n = 23 = 8 %), prior to arrival at the crossing. 115 (43 %) were carrying an item other than a phone. Few people came to a full stop before they started crossing (n = 25 = 9 %), displaying natural behaviours in circumstances where it is perceived there is no risk from any nearby traffic. Cross-tabulation and Chi-square analyses, presented in Table 3, were used to explore whether there were any associations between the observed activities or environmental conditions and observed crossing behaviours. The Chi square analyses showed that there is no indication in these trials with the new lighting intervention, that behaviours that are typically considered to be safe (e.g. direct crossing paths, looking for traffic etc.), were impacted by various hazardous activities or environmental conditions (carrying of loads, phone use, crossing alone or in groups, weather type).

4.2. Overview of the survey data

Table 4 shows a summary of findings from the fifty-nine respondents to the online survey. All participants confirmed that they had recently used the crossing. In contrast to the observational results, in which no observable reactions to the lighting were noted, 68 % of people reported noticing the lights, though a quarter (25 %) said they had not noticed them.

Table 2
Summary of characteristics of crossing episodes analysed.

Category	Sub-category	Count	% of episodes/cases
Presence of vehicle	Present	126	46
	Absent	143	54
Group size	Individual	221	82
	Group	48	18
Weather conditions	Sunny	136	50
	Cloudy	132	50
Load	Carrying an object (other than phone)	115	43
	Carrying a phone	12	4
	None	142	53
Trajectory	Crossing in a straight/direct path	243	89
	Crossing in a non-straight path (e.g., diagonally or change of course)	26	11
Attention during crossing	Looking at a phone	21	8
	Looking at the road	229	85
	Looking at the lighting	0	0
	Looking elsewhere	17	7
Safety related behaviours	Stop before crossing	25	9
	Did not stop before crossing	244	90
	Talking on the phone	7	1

Table 3
Types of crossing behaviour by group.

Group	Straight on crossing		Looking before crossing		Looking during crossing		Stopping before crossing	
	Count [Expected]	% of total	Count [Expected]	% of total	Count [Expected]	% of total	Count [Expected]	% of total
Carrying objects	69 [68.4]	25.7	68 [62.7]	25.3	13 [9.7]	4.8	9 [7.2]	3.3
Not carrying object	170 [170.6]	63.2	151 [156.3]	56.1	21 [24.3]	7.8	16 [17.8]	5.9
Talking on phone	6 [6.2]	2.2	6 [5.7]	2.2	2 [0.9]	0.7	0 [0.7]	0
Not talking on phone	233 [232.8]	86.6	213 [213.3]	79.2	32 [33.1]	11.9	25 [24.3]	9.3
Crossing alone	197 [196.4]	73.2	181 [179.9]	67.3	29 [27.9]	10.8	21 [20.5]	7.8
Crossing as part of a group	42 [42.6]	15.6	38 [39.1]	14.1	5 [6.1]	1.9	4 [4.5]	1.5
Car in sight	108 [111.9]	40.1	105 [102.6]	39.0	16 [15.9]	5.9	16 [11.7]	5.9
No car in sight	131 [127.1]	48.7	114 [116.4]	42.4	18 [18.1]	6.7	9 [13.3]	3.3
Cloudy	114 [117.3]	42.4	106 [107.5]	39.4	16 [16.7]	5.9	9 [12.3]	3.3
Sunny	125 [121.7]	46.1	113 [111.5]	41.6	18 [17.3]	6.7	15 [12.7]	5.6

Table 4
Description of survey participants.

Category	Sub-category	Count	%
Did you notice the lights on the crossing?	No	15	25
	Not sure	4	7
	Yes	40	68
Do you think the lights have influenced the way you crossed? (n = 63 as some participants gave multiple responses)	Didn't notice the lights	2	3
	Yes	17	29
	No	36	61
	Maybe	4	7
	No response	4	7
Do you think the lights would improve safety at this crossing?	Don't know	12	20
	No	4	7
	Yes	43	73
How visible are these lights? (5 being very visible: 1 being not visible at all)	1	7	12
	2	7	12
	3	17	29
	4	15	25
	5	11	19
	No response	2	3
How helpful are the lights in improving safety at this crossing (5 being very helpful: 1 being no help at all)	1	10	17
	2	10	17
	3	16	27
	4	7	12
	5	15	25
	No response	1	2
How helpful are the lights in drawing your attention to the crossing (5 being very helpful: 1 being no help at all)	1	14	24
	2	8	14
	3	9	15
	4	12	20
	5	15	25
	No response	1	2
Overall, how do you feel about the lights? (5 being you really like it: 1 being you really dislike it)	1	5	9
	2	5	9
	3	17	29
	4	6	10
	5	25	42
	No response	1	2

Participants were asked to explain what they thought was the purpose of the lights in the ground. 76 statements were identified and coded, identifying 14 suggested purposes of the lighting that were indicative of positive attributes of the lighting (as described in Table 5). In a smaller number of statements, the participants were more neutral and unable to identify a positive purpose of the lighting (Table 6).

Almost a third (29 %) reported that the lights had had some influence on crossing behaviour, with 61 % suggesting that the lights had not influenced crossing behaviour. Reasons for no influence of the lighting were largely oriented around the lights not being visible in daylight. For example: *"No, but maybe I couldn't see them as it was still light outside"*, and "*No, maybe because I have been there during daytime*". Other reasons were that they already use a preferred route across the road, or that they make use of other crossing features,

Table 5
Description of coding for participant suggestions of the purpose of the lights.

Theme	Count	Description
Highlight crossing to drivers	12	Referring to the lights as a means of drawing drivers' attention to the fact that there is a crossing *"Personally I've used the crossing more as a car driver and it's really useful to have that extra bit of light to draw your attention to it especially as the crossing is on a hill"*
Warning for distracted pedestrians	12	Referring to a purpose in which the lights catch the attention of people who are otherwise distracted before they attempt to cross the road *"Perhaps to try and prevent pedestrians (who are probably engrossed in their mobile phone screen) from stepping blindly out into the road"*
Assistance for visual impairment	7	Referring to a purpose in which the lights provide extra salience to those with low vision: *"To make the crossing more conspicuous to visually impaired people"*
Safety	7	Participants referred to the lights being a safety measure or simply wrote the word *"safety"*
Highlight position of crossing to pedestrians	6	Referring to the function of the light as a signpost to the crossing for pedestrians: *"To notify pedestrians of the crossing's whereabouts in the dark"*.
Influence crossing behaviour	6	Referring to the lights as a means of guiding pedestrians into a particular way of using the crossing: *"Attract pedestrians to use the crossing"*
Aesthetics	4	Referring to the decorative nature of the lights: *"I vaguely remember light is [on] the ground which I thought were decoration"*
Highlight features of crossing	4	Referring to the lights drawing attention to specific parts of the crossing: *"Seems to be there to indicate the edge of the pavement or the start and finish of the tactile surface"*
Illumination	4	Referring specifically to the illumination afforded by the lights, for example *"to light up the crossing"* (rather than referring to visibility of the crossing)
Influence driver behaviour	2	Referring to the purpose of the lights as a means of guiding drivers to adhere to the crossing: *"To ensure cars stop for pedestrians"*
Assistance for people	1	One person simply wrote the following: *"Help disable people"*
Highlight crossing	1	Making the crossing more salient in general e.g. *"To see the crossing clearly"*.
Highlight crossing to cyclists	1	One person specified that the lights highlight the crossing to drivers and cyclists: *"To alert drivers and cyclists to the crossing when it's dark"*
Improve visibility of pedestrians	1	One person suggested that the lights make pedestrians visible: *"To make pedestrians waiting to cross more visible"*
Total count	68	

Table 6
Coding of neutral responses by participants to the question of the purpose of the light.

Theme	Count	Description
Don't know	3	Participants simply wrote *"unsure"* or *"no idea"*
No response	3	Participants did not enter any description here
Didn't notice the lights	2	Participants noted they had not seen the lights: *"didn't see any lights"*
Total count	8	

such as the beacons. Those who suggested that the lights had influenced how they crossed the road referred to how the lights encouraged them to use the official crossing rather than crossing elsewhere in the road: "*I cross at that specific point now, whereas I didn't before*", and "*Yes, I used to cut through but after the lights were put in place cars have stopped more frequently and crossing feels safer*", or "*colour lights are a useful way to define the purpose*". Others noted that the lights had improved their awareness of their surroundings.

Participants were asked several rating questions about the lights (see Table 4). More participants felt positive about the lights than felt negative about them in questions on the visibility of the lights, helpfulness of the lights in improving safety and in drawing attention to the crossing. Higher ratings were evident for the question about overall feelings about the lights, with more than half of sample liking the lights, and 73 % of participants thought that the lights would improve safety at the crossing. Several of the responses to open questions indicated that participants liked the aesthetics of the lights, ("*I love the lights, although the odd angle of them makes it look more like public art*", or *"I love them though, they're a bit bonkers"*, and *"they add to the overall look and feel of the campus"*).

5. Discussion

In-ground lighting interventions are promising for influencing the safety behaviours of pedestrians at crossings (Kim et al., 2020; Larue et al., 2021), though there is a lack of naturalistic observations of behaviours relating to these interventions in use. The current study aimed to develop and apply a field-based approach to observe behaviours and responses to a ground-mounted lighting intervention at a crossing at a university campus. The study used video observation of pedestrians at the road crossing to identify observable behaviours (e.g. looking and crossing behaviours) and determine how these were influenced by the lighting intervention, also taking account of various additional situational factors (e.g. weather conditions, whether people were alone or part of a group, and potential distractions, carrying objects, Madigan et al., 2021). The study also used a small consultation exercise to collect user experiences of the crossing. Findings from this field observation on the outcomes and impacts of implementation of the lights at the crossing are discussed below, in conjunction with findings from the extant literature.

Fig. 5. Example of the variability of visibility in different light conditions.

5.1. Findings on questions in the evaluation framework

Are the lights functioning as intended (Question 1 in the evaluation framework)?

The lights were observed to be functioning as intended (i.e., consistently flashing on and off), however, there was some variability in visibility in different lighting conditions, as highlighted in Fig. 5 (i.e. areas in sunlight are less vibrant than in the area in shade). There were no sensors used in this implementation of the lighting (i.e. the lights are not activated in response to the presence of people approaching the crossing), so the lights were continuously flashing.

Do pedestrians take notice of the lighting (Question 2)?

There were no obvious, observable reactions as people approached the lighting, though the survey suggested that the majority (68 %) of respondents had noticed the lighting. In an earlier study (Ryan et al., 2021), five levels of response and interaction were classified from observable, behavioural responses to projected lights at in a railway station environment. However, those involved gross body postures and movements and were observable in camera recordings of behavioural responses to the lights. It is possible that some of the observed pedestrians in the current road study had detected and made a response to the lights, but this did not involve any observable head or body movements in relation to the lights.

There are various plausible reasons why observations in this field study have not been able to identify overt responses of people to the lighting. Larue et al., (2020, 2021) suggest that people do not need to fixate directly on the in-ground LEDs and even distracted pedestrians (those looking at a phone) accurately detected flashing LED ground mounted lights with their peripheral vision, though their reaction times were slower than those who were not participating in distraction tasks. Similarly, Kim at al. (2021) found that participants detected their visual crossing cues at rates between 93.5 % and 74.1 % during upright walking, browsing while walking, and texting while walking tasks. It is also possible that glances towards the lighting, potentially involving head movements, occurred at an earlier point before entering the field of view of the camera. Familiarity with the intervention over time might also result in limited explicit, observable, interaction with the lighting. Many pedestrians (e.g. university students and staff/Health Centre staff) can be assumed to be regular visitors to the area, and so may have been exposed to the lights during repeated visits. There was also limited contrast and visibility of the lighting, as reported by several participants, who said that the lights were not visible, especially during daylight hours.

Do pedestrians understand the purpose of the lighting (Question 3)?

Most participants felt positively about the lights, with favourable ratings for visibility, helpfulness in improving safety and drawing attention to the crossing. They also liked the lights, though some participants gave lower ratings for the question on visibility. An earlier study by Larue and Watling (2021) found that their in-ground lighting intervention at a rail crossing was perceived to be useful by a modest sample of pedestrians.

Do pedestrians respond appropriately to the crossing? Do pedestrians progress when safe to do so? (Questions 4 and 5).

Safe crossing behaviours constitute those such as looking into the road, stopping before crossing and crossing within the boundary features of the road crossing (in a straight line from one side to the other) (Papadimitriou et al., 2016). Various activities or environmental conditions were also identified which could potentially influence crossing behaviour (Escobar et al., 2021; Madigan et al., 2021), such as distraction whilst crossing in groups of people, looking at or using phones/electronic devices or carrying an object. Similarly, crossing use was observed in different background lighting conditions (sunny or cloudy).

Pedestrians' responses to the crossing were generally appropriate, with most looking at the road for traffic (85 %) and walking within marked features (89 %). Havard and Willis (2012) previously compared the use of a refuge style crossing and a zebra crossing, observing behaviours on approach to, and across, the crossings. They found that the zebra crossing induced more crossing within the defined crossing location (compared to more variation in the entry and exit points and not-straight crossing).

A small proportion in the current study stopped before the crossing (9 %), though this action will be influenced by whether cars are present. Few were distracted, with only 8 % looking at or using their phones whilst crossing the road. Earlier studies have estimated 13.5 % of pedestrians were distracted looking at a phone when crossing roads (Russo et al., 2018) or as many as 28 % of pedestrians engaged in risky/distracting behaviours (Thompson et al., 2013).

Whilst less than one third (29 %) in the current study reported that the lights had influenced their crossing behaviour, positive features of the lights at the crossing were reported, such as providing a visible indication of a safe place to cross. Responses to the survey indicated that the lights might also influence driving behaviours, such that crossing in the location feels safer. A previous study by Patella et al. (2020) considered how ground-mounted lights influenced how drivers approached a crossing more slowly after similar lighting had been installed. Boyce and Van Derlofske (2002) observed an initial decrease in speed, followed by an increase in speeds over time, approaching a crossing with in-pavement flashing lighting. The reaction of drivers to the lighting intervention was not observed directly in the current study and measuring approach speeds and other driver-related behaviour would be useful for future evaluations.

Crossing behaviours did not seem to be influenced by the environmental conditions. Sunny or cloudy conditions could influence the visibility of the ground-mounted lights (Fig. 5), but these different background lighting conditions were not associated with crossing behaviours. Similarly, other potential influencing factors or observed activities (e.g. carrying objects or phone use) were not associated with crossing behaviours in the current study. Previous research has indicated that carrying an object was associated with greater frequency of looking left and right behaviours (Aghabayk et al., 2021). Earlier studies have also explored how activities such as looking at phones results in less safe behaviours, such as not stopping before crossing (Simmons, Caird, Ta, Sterzer and Hagel (2020). The current study was conducted on a road with a 20mph speed limit and good visibility of the road to either side of the crossing. Pedestrians who have looked at the road prior to arriving at the crossing, or before entering the area covered by the cameras, may have been confident that this would remain clear for the duration of their crossing. The absence of observable behaviour of looking for traffic in the current study may not be indicative of unsafe behaviour at this crossing. This situation may be different on roads with higher speeds, or those with poorer visibility on approach to the crossing.

Potential improvements in safety at the crossing (Points 6–8 in the evaluation framework).

It was only possible to collect data over a short period of time, so the potential for medium- and longer-term impacts is considered using the theory-based approach to evaluation (Hills and Junge, 2010), taking account of how the lights function, and whether they are noticed, understood, and promote appropriate responses. When considering whether there could be positive effects of the lighting over a longer period for pedestrians and drivers, it should be recognised that the lights were operational for over 6 months prior to this study and largely positive responses were observed or reported by pedestrians after this extended period of operation.

In response to an overall objective of examining pedestrian responses to an in-ground lighting intervention for crossing safety, this investigation has collected extensive observational data on how people use this crossing, along with subjective responses to the new lighting intervention. Predominantly safe behaviours have been observed from a large sample of pedestrians interacting with the crossing and no adverse or ultimately dangerous situations have occurred. Overall, the observation enabled the study of general crossing behaviours at this location, providing valuable descriptive information about how a substantial number of people approach and pass over this crossing, and the types of local and environmental circumstances and distractors that people encounter in doing so.

Those using the crossing considered it to be a safe crossing. A large majority of people who participated in the questionnaire had noticed the lights and many had understood the safety-related warning within the design of the lighting product. It is promising that of the third of respondents who reported being influenced by the lights, the explanations given suggest that they were more likely to cross safely (using the official crossing) and felt safer with the intervention in place. Increasing the visibility/noticeability of the crossing was highlighted as a major reason why the lighting might improve safety through the positive effect of attention to the lights (Larue et al., 2020), as well as improving the visibility of the crossing for people with visual impairments, indicative of the perception of the usefulness of the lights (Larue and Watling, 2021). Those who stated that the lights had not influenced their crossing behaviour might not have been aware of the influence of the lights on their behaviour (Berry and Broadbent, 1984).

These initial findings suggest that it is possible that the lights will have lasting positive effects, particularly in highlighting the crossing to pedestrians and drivers. A longer-term evaluation of perceptions, behaviours and continued monitoring of any safety related incidents would be valuable.

5.2. Methodological and practical challenges in developing and applying the approach to evaluation in field studies

Researchers need to be able to develop and apply their evaluation approach with some flexibility. The study has highlighted how researchers can be faced with having a lack of control over all aspects of the design of the intervention, and in a situation where they are not always able to implement and test what they would prefer to test. The lighting intervention had many positive features, but there are opportunities to improve the ability to attract attention and maintain these over a longer period, such as with the use of sensors to make this intervention responsive to the approach of people. Boyce and Van Derlofske (2002) argued that their identified effect of reduced driver response to their lighting intervention over time resulted from the lights flashing constantly, rather than responding solely to pedestrians in the area. Consequently, drivers began to lose confidence in the intervention. They recommended that the intervention reliably activates only to the presence of people, rather than being constantly activated. Implementation of a more interactive lighting intervention (e.g., sensor activated) may reveal further insights into the ability to encourage safe responses to this type of lighting cue. It would also be advisable to enable variability in the lighting cue (e.g. different colours, flash rates and patterns) which could encourage appropriate behavioural responses to the lighting over a longer time (Hallewell et al., 2023; Hughes et al., 2020).

Researchers also need the ability to respond with flexibility to unexpected circumstances for implementation of field trials. In this study, this involved responding to circumstances around the Covid19 pandemic, where the timescales for the evaluation study were compressed. There were no opportunities to collect pre-intervention data and there were limitations in the times of day when data could be collected from natural users of the crossing, as well as potential limitations in diversity of the sample of crossing users, and need to change preferred methods of consulting with users to avoid face-to-face contact for reasons of social distancing. Future studies should expand to other times of day, such as when users approach the crossing outside daylight hours (Uttley and Fotios, 2017). Expanding the participant groups would be beneficial, including children who may be engaged in more risky crossing behaviours (Escobar et al., 2021) and have difficulties in identification of hazards when crossing (Meir, Oron-Gilad and Parmet, 2015), and older age groups who may display slower walking speeds or use mobility aids (Avineri, Shinar, and Susilo, 2012; Russo, James, Aguilar, and Smaglik, 2018).

An observational method has been a central part of the approach to this evaluation. This study has highlighted limitations in the observational method that should be considered in future studies. The inability to observe small head movements towards the lighting was an important limitation. There was a limited range of vantage points from which to record pedestrians on the crossing, whilst remaining relatively inconspicuous. This resulted in a need to trade-off views of facial and other finer details of behaviour with wider views of the behaviours and trajectories of pedestrians in the vicinity of the crossing. Identifying optimal camera locations to cover both a wide field of view for the study of the approach to the crossing and the ability to focus on small head movements, glances and scanning behaviours in relation to the lighting (Larue et al., 2021) would be recommended for future studies. This could include use of more sensitive measurement techniques to understand the behavioural responses of people to the lighting cue (e.g. using eye tracking and cameras enabling more detailed views of head movements). Better positioning of cameras may need appropriate supporting infrastructure and ground-mounted tripods may be insufficient to obtain the necessary field of view to examine the trajectories and behaviours on the approach to the crossing area and exit points from the crossing. These observational methods could be supplemented with methods to explore the intentions and decision processes that people employ as they move around the crossing area. This will enable understanding of how technology such as lighting can be used to support people as they navigate the built environment and encounter a variety of contextual factors that will influence their behavioural responses. Such examinations might explain the motivations for some of the observable findings (e.g. phone use may be for the purpose of wayfinding, or in this context, looking at health centre appointment details).

Despite this observational limitation, the study has been valuable in clarifying what data can and should be collected, and how to do this effectively in this type of real-world evaluation context. It has also been successful in collecting data on many existing naturalistic crossing behaviours, such as trajectories of crossing users, stopping behaviours, gross looking movements rather than minor movements for peripheral vision, carrying objects and phone use. This has been supplemented by various types of subjective data on identification and understanding of lighting cues, reported responses, and opinions (liking / disliking, reasons for opinions).

6. Conclusions

A real world, naturalistic study has been used to collect observations of 269 crossing events at a pedestrian crossing that has been equipped with a ground-mounted lighting intervention, also collecting experiential data from a modest sample of crossing users. The analysis of the observational data used a coding strategy devised from previous literature to explore potential influences on crossing behaviours. The analysis focused on crossing behaviours of people in various circumstances (e.g. alone or in groups, carrying objects, in different weather conditions), and their behavioural responses did not seem to be affected by these activities or environmental factors. The questionnaire survey results are from a smaller sample but collected useful insight from users. Many people liked the lighting at the crossing and understood its safety-related purpose, though different background lighting conditions may have affected experience of the lighting. It is concluded that the lighting intervention has the potential to improve and maintain safety behaviours at crossings. However, further testing is needed to establish efficacy.

The study also contributes to the wider discourse surrounding pedestrian observation methodology. There were limitations in terms of what could be observed in this study, many of which were beyond researcher control. In a low-cost, short-timescale study, there is a trade-off in terms of what can be collected on the detail (e.g. gross head movements and more subtle gaze, head position) and the wider field of view (e.g. for the movement trajectories in the crossing area). Suggestions have been made for the use of technology in resolving these limitations in future work. There are also opportunities to improve the ground-mounted lighting intervention. Most importantly, there is a need for the testing of a design with reactivity to the presence of people in the area.

Funding

This work was supported by the Rail Safety and Standards Board (RSSB) and the Department for Transport under the Train Operator Competition - TOC17 Minimising disruption from antisocial behaviour using behavioural insights and new technology. RSSB/2754. The funders had no involvement in the conduct of the research and preparation of this paper.

CRediT authorship contribution statement

Madeline Hallewell: . **Nastaran Dadashi:** Data curation, Formal analysis, Investigation, Methodology, Writing – original draft. **Brendan Ryan:** Conceptualization, Funding acquisition, Project administration, Supervision, Writing – original draft, Writing – review & editing.

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.

Data availability

Data will be made available on request.

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