Improving the safety of distracted pedestrians with in-ground flashing lights. A railway crossing field study

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Abstract

Current signage at intersections is designed for attentive pedestrians who are looking ahead. Such signage may not be sufficient when distracted by smartphones. Illuminated in-ground LED lights at crossings are an innovative solution to alert distracted pedestrians. We conducted a field study at a railway crossing equipped with in-ground lights to assess whether distracted pedestrians (N=34, Mean age 33.6±8.6 years) could detect these lights and how this impacted on their visual scanning and crossing behaviour. This involved a 2 x 3 repeated measures design exploring the impact of the presence (treatment) or absence (control) of in-ground lights (treatment) at a crossing, and a distractor task presented through a mobile device (none, visual, and audio) on eye movements recorded using an eye tracker, and verbal reporting of when participants detected the lights. Participants engaged in the distraction tasks as evidenced by their accuracy and reaction times in all conditions. With both the audio and visual distraction tasks, participants looked at the in-ground LEDs and detected their activation as accurately as when not distracted (95%). While most participants detected the lights at their activation, visual distraction resulted in 10% of the detections occurring as participants entered the rail corridor, suggesting effectiveness in gaining pedestrians' attention. Further, participants were significantly less likely to check for trains when visually distracted (70%), a 10% reduction compared to the no or audio distractor conditions (80% and 78% respectively). The introduction of the in- ground lights resulted in appropriate scanning of the rail tracks (77% and 78% for the visual and auditory distractor tasks respectively) similar to that of non-distracted participants for the crossing without lights (80%). Our findings indicate that illuminated in-ground lights could be useful in attracting the attention of distracted pedestrians at railway level crossings, and possibly at other road intersections.

1. Introduction

1.1 Pedestrian distraction at intersections

Distraction is a growing road safety concern worldwide for all road users. Extending the definition of driver distraction (National Highway Traffic Safety Administration, 2010) to pedestrians, suggests a specific type of inattention that occurs when pedestrians divert some of their attention from the walking task to focus on an alternative activity. Distracted walking has become more prevalent as the use of smartphones has become more widespread in everyday-life (Basch, Ethan, Rajan, & Basch, 2016; Solah et al., 2016).

Pedestrian distraction has, however, not been widely researched, despite numerous observational studies and anecdotal reports that report large numbers of pedestrians being distracted, especially while crossing roads, as shown by Mwakalonge, Siuhi, and White (2015)'s review of the literature. Distractions include talking on a mobile phone, looking at a mobile phone screen, or wearing headphones (Basch et al., 2016).

Pedestrian distraction is associated with poor decision-making such as crossing at non-designated areas (Pešić, Antić, Glavic, & Milenković, 2016), as well as inattentional blindness (Coleman & Scopatz, 2016; Solah et al., 2016). At intersections, pedestrians distracted by their smartphones are less likely to scan their environment while approaching and entering the intersection (Lin & Huang, 2017). They also exhibit increased levels of unsafe behaviours while crossing, such as failing to stop (Lin & Huang, 2017; Pešić et al., 2016) and being unable to follow a straight path (Sammy, Robynne, Miranda, & Conrad, 2015; Solah et al., 2016).

1.2 The case of railway crossings

Railway level crossings are an example of intersections where pedestrian distraction can result in catastrophic consequences. One major contributor to the risk of pedestrians being involved in collisions with trains at railway level crossings is when pedestrians are complacent, distracted or inattentive (Edquist, Stephan, & Wigglesworth, 2009; Larue, Naweed, & Rodwell, 2018). Distraction and inattention also become more prevalent at this type of intersection with increased use of mobile phones and headsets (Goodman, 2018; Larue, Naweed, et al., 2018).

The current form of pedestrian protection at railway level crossings comprises a warning sign when passively protected, or warning sign signals, sometimes associated with bells and gates, when the crossing is actively protected. The effectiveness of such warning devices is likely to be reduced by pedestrians diverting their attention towards their mobile devices or by using their headphones. Despite the rarity of train collisions with pedestrians at railway crossings, the contribution of pedestrian distraction to these collisions has been highlighted by the number of rail incident investigations of collisions involving pedestrians (and even cyclists) which report distraction as being a contributing factor. This has been identified in the United Kingdom and in New Zealand for pedestrians using a mobile phone (Transport Accident Investigation Commission, 2016), when wearing earphones which reduce the ability to hear warning sounds (e.g. train horn, Rail Accident Investigation Branch, 2009; Rail Accident Investigation Branch, 2013), or more general distraction in the rail environment (Rail Accident Investigation Branch, 2010), and at railway stations (Transport Accident Investigation Commission, 2011).

1.3 Advanced warnings

An innovative solution to address the issue of distracted pedestrians is the use of visual warning lights installed in the ground. Such devices have been trialled in some locations around the world at road intersections (Potts, 2016; Sulleyman, 2017; Timson, 2016). These warning lights can be used at signalised or unsignalised intersections. At signalised intersections, the lights are activated concurrently with the standard crossing signals provided to pedestrians and inform pedestrians that they should not proceed through the crossing. At unsignalised intersections, the lights are activated when a motion sensor detects the approach of pedestrians. At such intersections, the aim of the lights is to remind pedestrians that they are approaching an intersection.

Railway level crossings represent one type of intersection where such interventions could be useful, given their design leads to complex interactions between road and rail users and that the consequences of a collision are significant and often fatal. Railway crossing design often leads to human errors, deliberate non-compliance with signals and road rules (Larue, Blackman, & Freeman, 2020; Larue & Naweed, 2018), and inaccurate perceptions of risks by road users (Larue, Filtness, et al., 2018). In-ground lights have been installed to try and circumvent these problems and have been tested in New Zealand at selected railway level crossings, first for road vehicles (Larue, Watling, Black, & Wood, 2019) and more recently for pedestrians (Hirsch, Mackie, & Cook, 2017).

In a laboratory study conducted by Larue, Watling, Black, Wood, and Khakzar (2020), lights placed at ground level were effective in attracting the attention of distracted pedestrians, regardless of whether they were engaging visually or auditorily with their mobile device. Pedestrians are likely to have detected the activation of the lights through the use of their peripheral vision while performing the distractor task on a smartphone (Larue, Watling, et al., 2020). While showing promising effects in laboratory conditions, there have currently been no field-based evaluations regarding the potential safety benefits obtained from such interventions.

1.4 Study aim

This research aimed to evaluate whether the addition of in-ground LEDs located at ground level at railway level crossings is useful in attracting the attention of pedestrians when performing a visual or auditory distractor task on a smartphone. We focused on evaluating pedestrians' accuracy in detecting the illuminated in-ground LEDs and in their scanning behaviour toward railway crossings, while performing a distractor task (visual or auditory) compared to when not distracted.

2. Method

2.1 Study design

In this field-based study, a 2 x 3 repeated measures design was used to evaluate the safety effects of in-ground LEDs during the daytime. Two within-subject factors were considered:

1) Level crossing protection type: standard passive pedestrian crossing (control), and passive pedestrian level crossing with the illuminated in-ground LEDs (treatment); and
2) Distraction condition: no distraction (control); visual distraction; and auditory distraction.

The order of conditions was counterbalanced between participants to mitigate order effects.

For each testing condition (in-ground LED lights present or absent (2), for each given distraction condition(3)), participants walked toward the level crossing (from 30 metres before the crossing), traversed the crossing and continued walking for another 30 metres after the crossing. They then walked back to their original position. They repeated this walking task three times for each of the six conditions, resulting in the participants crossing the level crossing a total of eighteen times. The key outcome measures were the participants' ability to detect the activation of the illuminated in-ground LEDs, the gaze behaviour of participants, and their crossing behaviours.

2.1.1 Trial site and signage

The trial site was one of the passive pedestrian level crossings in New Plymouth where KiwiRail had installed in-ground LEDs. Level crossings in the vicinity were investigated to find a comparison site. This required comparable characteristics in terms of protection (passive), standard signage (‘Look for Trains’), and enclosed maze (enclosure forcing pedestrians to make at least one 180 degrees turn when approaching the rail tracks, to elicit alternative scanning toward both the left and right rail tracks, see Figure 1), as well as similar low traffic both in terms of trains (~4 per day) and pedestrians (~130 per day). No other level crossings in the vicinity matched the characteristics of the site selected for treatment, so the selected crossing was used as its own control.

Figure 1: View of the Cutfield level crossing (Left: Control configuration; Right: Treatment configuration (LEDs) with the protection officer in position for monitoring the rail tracks).

The illuminated pedestrian warning devices (treatment) consisted of in-ground LEDs, and the reiteration of the standard ‘Look for Trains’ signage which is displayed vertically on the fence positioned in the middle of the maze at passive pedestrians level crossings in New Zealand. This combination of in-ground LEDs and warning sign was installed on both sides of the rail corridor, after the maze when travelling towards the rail tracks (see Figure 2) and had been installed two months prior to commencement of the study.

The in-ground LEDs comprised yellow flashing lights, which were activated on both sides of the crossing simultaneously by the movement of pedestrians just before their entrance into the maze of the level crossing (around a metre and a half away from the maze). Once activated, the lights flashed for 10 seconds, alternating every second. LEDs were only activated on movement of the pedestrian towards the level crossing. The activation of the LEDs was independent of the presence of trains and aimed to alert pedestrians regarding the presence of the crossing and the need to look for trains when crossing.

For the control configuration, mats were placed over the in-ground lights and hid their activation, as it was not possible to control whether the lights were activated or not at the site (see Figure 1-Left).

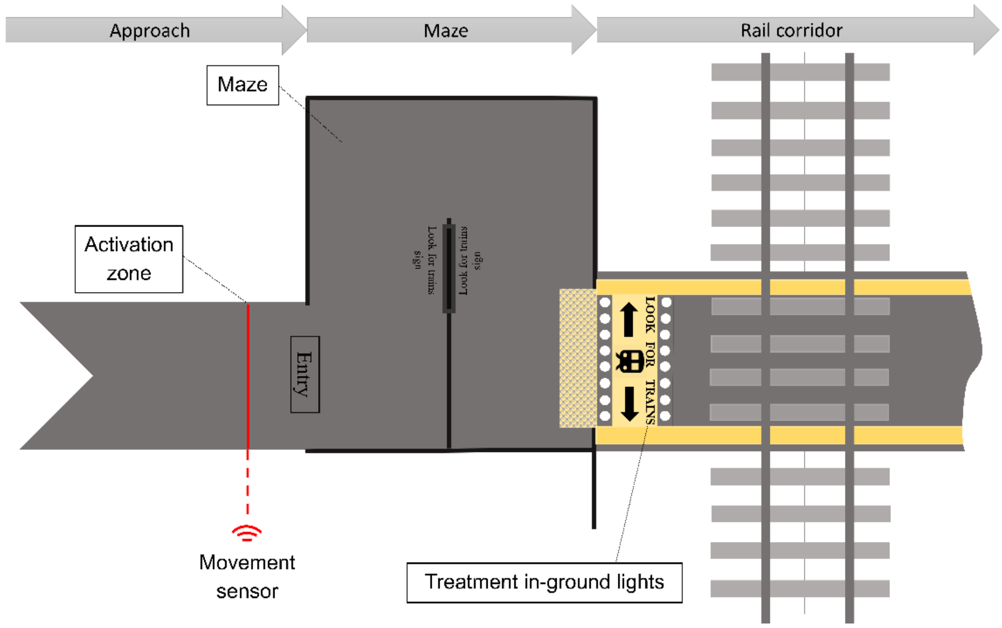

Figure 2: Signage and its placement (showing only one side of the level crossing; grey area: pedestrian footpath; black lines: fence).

2.1.2 Distractor tasks

A simple reaction time task was developed to create a distractor task that sufficiently engaged the participants, provided an analogue for either texting on a phone or engaging in an active listening task using a headset, and increasing their cognitive workload without overloading them and jeopardising their safety while walking. The distractor tasks were similar to those used by Larue, Watling, et al. (2020).

The visual distractor task was performed on a smartphone. Every 1.5 seconds, a word was randomly selected from a list of 6 words (cat, box, pen, desk, note, switch), and displayed on the screen for 1.0 second. One of these words (cat) was the target word and appeared 25% of the time, while the other five words were equally likely to appear. Participants were instructed to touch the screen as quickly as possible only when the target word appeared. The 'Screen' text changed to red when the screen was touched, independent of the word (or lack of) displayed on the screen, to provide feedback to participants.

The auditory task was similar to the visual task, where rather than displaying the words on the screen, it was played as a sound by the smartphone equipped with earphones. Participants were provided with the same red 'Screen' feedback when they touched the screen. This approach ensured that only the task modality was investigated, rather than a combination of modality and task difficulty.

2.1.3 Detection task

A detection task was also performed when the level crossing was in its treatment configuration (with the in-ground LEDs illuminated, see Figure 3). Participants were instructed to verbally report the word 'LIGHT' as soon as they noticed that the in-ground LEDs were illuminated as they approached the level crossing.

Figure 3: Illuminated in-ground LEDs; participant equipped with eye-tracking glasses and performing the visual distractor task.

2.1.4 Questionnaires

A demographic questionnaire was administered. Self-reported pedestrian behaviour was also assessed, using the Pedestrian Behaviour Scale (PBS: Granié, Pannetier, & Guého, 2013). Problematic mobile phone use was quantified via self-report on the Mobile Phone Problem Use Scale (MPPUS: Bianchi & Phillips, 2005).

2.2 Participants

A sample of 34 participants completed the study. Participants were healthy adults between the ages of 18 and 45 years who identified as regular users of mobile devices while they are walking (three times or more per week). Participants were screened to ensure that their visual acuity would not affect the results of the study: all participants were required to meet the visual requirements (with or without correction) for holding a private driving licence. Participants were also required to have normal hearing, and no physical impairments which affected walking (which were derived through self-report).

Participants were recruited from the general public in the New Plymouth area. Recruitment strategies included local flyer distributions, as well as through local community or volunteer groups who circulated email or paper flyers. A snowballing approach was also used with participants who completed the study. Ethical clearance was obtained from the university's Ethics Committee (clearance number 1800000417).

2.3 Materials

2.3.1 Eye-tracking system

The SensoMotoric Instruments (SMI Instruments, Teltow, Germany) eye-tracking system was used to record scanning patterns and is specifically designed for active users in the field. It is fully wireless, compact, and allows the use of unconstrained eye, head and hand movements under variable lighting conditions. The system comprises lightweight eyeglasses with high-resolution cameras and records natural gaze behaviour in real-time at a 60 Hz sampling rate.

It provides point of gaze with audio capability to record what participants are saying as they are walking.

2.3.2 Smartphone

A Samsung S6 smartphone was used to run the visual and auditory distractor tasks. An app was developed to implement the distractor task and record participants performance on the task, using AndroidStudio version 3.2.1.

2.4 Procedure

Participants attended a pre-testing screening session at a local library. During this initial session, each participant signed the consent form. They had their vision tested under photopic conditions to ensure that they met normal limits for visual acuity using a high contrast letter chart (logMAR) and contrast sensitivity using a Pelli-Robson chart and met the visual acuity requirements for driving. They also familiarised themselves with the eye-tracking equipment, and completed the demographic survey, as well as the questionnaires including the Pedestrian Behaviour Scale and the Mobile Phone Problem Use Scale.

At the start of each testing session, researchers met participants near the level crossing used in the study. Each testing session took up to 2 hours, and started at either 9am, 11am, 1pm or 3pm. Participants were then equipped with the eye tracker, which recorded their scanning behaviour and their oral comments. After the eye tracker was calibrated, the rail protection officer provided a safety briefing to each participant. The protection officer then positioned himself in a strategic and unobtrusive position in the maze (see Figure 1 right image), in order to detect any approaching trains and inform participants of the need to stop walking in a safe location if a train was approaching.

Participants were instructed to walk to the other side of the rail crossing and continue until they reached a given location and then turn and walk back three times consecutively under each distraction condition. Each walking task took up to five minutes. Participants were requested to complete these tasks to the best of their ability. Participants were informed that the mobile phone task was a reaction time task and involved tapping on the phone screen (using their thumb) as quickly and accurately as possible. They then practised walking with and without completing the mobile phone task, until they felt confident to proceed with the experiment. Prior to the walking tasks, participants were instructed to say the word “LIGHT” whenever they perceived the in-ground lights flashing on approach to the level crossing (note that the in-ground LEDs were covered for the walking tasks using large mats for the control configuration). Participants were also told to maintain their safety at all times during the study, to be aware of their surroundings and other pedestrians or cyclists and to be aware that trains did run from time to time through the rail crossings that they were approaching. After each testing conditions, participants completed a quick questionnaire (outside the scope of this study) and were given the opportunity to take a rest. At the end of their session, participants were thanked and provided with their incentive payment.

2.5 Data Analysis

2.5.1 Coding of eye tracker videos

Videos recorded with the eye tracker provided information on where participants fixated their gaze while completing the study. Participants’ gaze during their approach to the crossing (10 seconds before entering the maze) to the exit of the rail corridor were coded with the software Interact (version 9). The following coding scheme was used to record gaze position:

- Forward: Gazes that were directed straight ahead or towards the ‘Look for trains’ sign;
- Down: Gazes towards the ground, looking at the phone or looking at the in-ground LEDs; and
- Rail tracks: Gazes towards rail tracks, to both the left or right of the participant.

The video recordings were further coded in order to record the times when participants:

- Approached the crossing (10 seconds prior to the entrance of the maze);
- Entered the maze;
- Arrived at the entrance of the rail corridor;
- Entered the rail corridor;
- Exited the rail corridor; and, in the case of the level crossing with flashing lights
- Reported “LIGHT” To indicate that they had detected an in-ground LED light at the crossing.

These times were also used to estimate participants’ walking duration (as a proxy for speed), in conjunction with measurements of the level crossing and their position (‘Approach’, ‘Maze’, and ‘Rail corridor’ as in Figure 2) as they progressed through their tasks.

2.5.2 Statistical analyses

Data analysis evaluated the effect of (1) the level crossing type (2 levels: control or treatment including in-ground LEDs), and (2) the distraction condition (3 levels: no, visual or auditory distraction) on the following dependent variables:

- Engagement with the distractor task, evaluated through the percentage of target words correctly detected, reaction times (time taken by the participant to tap the screen of the smartphone after the word was displayed or played by the smartphone), effects on gaze directions (looking down), and effect on walking speed when navigating the maze and traversing the rail tracks (measured as time);
- Ability to detect the activation of the flashing in-ground LEDs, evaluated through the percentage of correct detections, and the location where the lights were detected (approach, maze or once in the rail corridor);
- Gaze behaviour while navigating the level crossing, evaluated as whether participants looked for trains before entering the crossing (three categories: cases when participants looked for trains in both direction, cases when participants only looked one way, and cases when participants did not look at all for trains) and the total time spent looking for trains.

Variables related to engagement with the distractor task were obtained from the data log of the app, as well as the coding of the eye tracker videos. Variables relating to the detection of the LEDs were obtained from the audio recording of the eye tracker, and gaze behaviour were obtained from the coding of the eye tracker videos.

Statistical tests were run using Generalised Linear Mixed Models (GLMMs) to take into consideration the repeated measures design of this study. Software R version 3.4.2 was used with the MCMCglmm library. The level of significance chosen for the study was set at α=0.05. The participant sample size was chosen to reach a 0.9 power for medium to large effect sizes.

Specifically, the outcome measures were modelled using GLMMs from a Gaussian (for continuous variables) or Binomial (dichotomous variables) families, while considering the effects of the level crossing configuration (control or treatment including in-ground LEDs), distractor task (no, visual or auditory distraction), as well as their interactions.

3. Results

3.1 Demographics

Thirty-four participants completed the study protocol; however, visual acuity measures were not available for one of the participants (the participant was not able to attend the visual acuity testing session). The mean age of participants was 33.6 years (SD=8.6; range=18-51; 65% female). A summary of the demographic details is presented in Table 1.

The Pedestrian Behaviour Scale (Table 2) indicated that participants performed several positive pedestrian behaviours as well as frequent pedestrian violations and errors. The Mobile Phone Problematic Use Scale (Table 2) mean score was below the mid-point of 121.5 and well below the 160 cut-off mark indicating that participants were dependent on mobile phone use (Kalhori et al., 2015).

Table 1: Participants' demographics

Demographic variable and Proportion/Frequency[a] (%)			
Gender		Highest education	
Male	12 (35.3)	High school	10 (29.4)
Female	22 (64.7)	Diploma	9 (26.5)
		Undergraduate	9 (26.5)
		Post-graduate	4 (11.8)
		Other	2 (5.9)
Activities mobile phone used for			
Phone calls	34 (100.0)	Navigation	29 (85.3)
Texting	33 (97.1)	Banking	29 (85.3)
Emailing	30 (88.2)	Shopping	19 (55.9)
Social networking/Facebook	33 (97.1)	Exercising	9 (26.5)
Entertaining	29 (85.3)		
Yes, had a 'close call' meaning you were almost hit, by a vehicle while walking and using your mobile phone[b]			27 (79.4)
Yes, hit by a vehicle while walking and using your mobile phone			1 (2.9)
[a] Gender, Highest education are proportions (add to 100%), while Activities mobile phone used for is reported as frequency (adds up to more than 100% given the multiple usages of the phone one participant can have)			

Table 2: Self-reported measures of pedestrian behaviour, and mobile phone problematic use.

Construct	Mean	SD	Actual range	Number of items	Cronbach's alpha
Pedestrian Behaviour Scale (PBS)[a]					
PBS Violation Subscale	3.20	1.02	1.00-6.00	4	.69
PBS Error Subscale	3.39	0.89	1.75-5.50	4	.61
PBS Lapse Subscale	1.70	0.76	1.00-5.00	4	.80
PBS Aggressive Subscale	1.55	0.64	1.00-4.67	4	.26
PBS Positive Subscale	3.41	1.07	1.75-6.00	4	.66
Mobile Phone Problematic Use Scale[b]	107.06	33.74	46.00-191.00	27	.91

[a]Possible range: 1 – 6
[b]Possible range: 27 - 270

3.2 Visual acuity

Participants who usually wore corrective lenses or spectacles were asked to wear them for the vision testing and during the study. The mean visual acuity for participants was -0.08

(SD=0.07) logMAR for their better eye, -0.02 (SD=0.11) logMAR for their worse eye and -0.11 (SD=0.07) logMAR with both eyes (better than 6/6 Snellen equivalent). Contrast sensitivity was also assessed and was shown to be normal for all participants, with a mean score of 1.96 (SD=0.12) logCS.

3.3 Engagement with the distractor tasks

3.3.1 Performance

While navigating the control level crossing, participants correctly detected 94.4% of the target words in the visual and 95.3% in the auditory distractor condition. Statistical analyses (see Table 3) showed that accuracy on the distractor task was significantly reduced when walking through the crossing in the presence of the in-ground LEDs ($t=-3.47$, d.f.=147, $p<.001$), independent of the modality of the distractor task (91.0% for the visual and 90.2% for the auditory condition). This decrement was on average 3.4%, which is likely to be due to participants attending more to navigation of the level crossing in the presence of the in-ground LEDs, resulting in reduced performance on the secondary task. However, the magnitude of this reduction was relatively small and is not the primary outcome of interest which was scanning of and navigation of the crossing.

The reaction time to the distractor tasks was not significantly affected by the presence or absence of the flashing in-ground LED lights for either the visual (639 vs 644; $p=0.962$) or auditory distractor tasks (992 vs 969 ms; $p=0.525$).Participants were, however, 350 ms slower when performing the auditory distractor task compared to the visual distractor task ($t=42.3$, d.f.=3,780, $p<.001$; see Table 3).

Table 3: Statistically significant effects of factors considered on the variables of interest in this study.

	B	SE B	β	t	df	p
Distractor tasks						
Target word detection accuracy						
Intercept	3.14	0.22	2.89	14.60	147	<.001
LEDs	-0.64	0.18	-0.61	-3.47	147	<.001
Reaction times (ms)						
Intercept	655	14.30	0.56	69.19	3780	<.001
Visual task	-350	8.30	-1.10	-42.28	3780	<.001
Walking duration (s)						
Intercept	8.96	0.20	-0.13	47.19	1049	<.001
Visual distractor	0.79	0.06	0.36	7.94	1049	<.001
Audio distractor	0.28	0.06	0.20	4.37	1049	<.001
LEDs	0.18	0.05	0.13	3.34	1049	<.001
Down gazes (s)						
Intercept	2.71	0.32	-0.66	8.57	945	<.001
Visual distractor	6.13	0.22	1.46	28.38	945	<.001
LEDs	0.63	0.18	0.15	3.53	945	<.001
Detection of flashing lights						
Accuracy						
Intercept	3.51	0.30	3.51	11.67	513	<.001
Location where detected						

During approach						
Visual distractor	-0.58	0.19	-0.24	-3.00	488	0.003
In maze						
Intercept	3.65	0.42	3.08	8.80	275	<.001
Visual distractor	-1.53	0.39	-0.74	-3.96	275	<.001
Checking for train behaviour						
Appropriately checked						
Intercept	4.12	0.74	3.90	5.60	1188	<.001
Visual distractor	-1.08	0.22	-0.60	-4.96	1188	<.001
LEDs:Visual distractor	0.56	0.27	0.44	2.07	1188	0.038
Duration (s)						
Intercept	2.92	0.13	0.15	21.92	923	<.001
Visual distractor	-1.24	0.12	-0.37	-9.90	923	<.001
LEDs	-0.62	0.10	-0.35	-6.50	923	<.001
LEDs:Visual distractor	0.36	0.18	0.11	2.03	923	0.042

3.3.2 Walking duration

Participants took an average of 8.9 seconds (SD=1.2) to navigate through the control crossing and traverse the rail corridor while not distracted. Participants reduced their walking pace while performing the distractor task, as highlighted by the longer time taken to navigate the maze and the crossing (see Table 3). This increase in duration was more pronounced for the visual distractor task (0.79 s; $t=7.94$, d.f.=1,049, $p<.001$) than the auditory distractor task (0.28 s; $t=4.37$, d.f.=1,049, $p<.001$). Participants also walked more slowly to perform the task when the crossing was equipped with LEDs, with an increase in time of 0.18 s ($t=3.34$, d.f.=1,049, $p<.001$) compared to when traversing the crossing in its control condition (without in-ground lights).

3.3.2 "Down" gaze behaviours

The gaze analysis revealed that participants spent on average 2.9 s (SD=2.0) looking down when approaching the control crossing while not distracted. Performing the auditory task did not significantly affect the "down" gaze behaviour (p=), given that participants did not need to look at the mobile device to perform the task. In the presence of the visual distractor task, participants increased their "down" gazes to view the mobile phone screen (see Table 3). Under this visual distractor condition, participants spent on average 6.13 s longer looking down ($t=28.38$, d.f.=945, $p<.001$). The presence of the in-ground LEDs further increased the duration of "down" gazes by 0.63 s ($t=3.53$, d.f.=945, $p<.001$), most probably due to the need to look down at the LEDs. There were no significant first-order interactions.

3.4 Detection of flashing lights

3.4.1 Accuracy

Participants detected almost all in-ground LED light activations. On average, they detected the activation of the LEDs 95.2% of the time. There were no significant differences in LED detection as a function of distractor task.

3.4.2 Position where light activation is detected

For each detection of the activation of the in-ground lights, the relative position of the participant (approach, maze, or rail corridor) was determined (Table 4). There were no significant differences in detection position between the auditory task and the non-distraction condition (p=0.764), showing that the auditory task did not have any effect on the location away from the crossing where participants' detected the LEDs. Participants were less likely to detect the activation of the LEDs in the 'Approach' section when visually distracted (t=-3.00, d.f.=488, p=.003; see Table 3). Detection of the in-ground lights reduced from 45.5% (no and auditory distractor tasks combined) to 36.1% during the approach when performing the visual distractor task. This suggests that they detected the activation of the lights later in their approach to the level crossing compared to the no distractor or auditory distractor tasks. Participants were also more likely to detect the LED activation after they entered the rail corridor when they were visually distracted, as compared to the two other conditions (t=-3.96, d.f.=275, p<.001).

Table 4: Count and frequency of when the activation of the LEDs was first detected by condition and location.

Distractor task	Location where in-ground LED activation detected		
	Approach	Maze	In the rail corridor
None	75 (45.2%)	85 (51.2%)	6 (3.6%)
Auditory	76 (45.8%)	87 (52.4%)	3 (1.8%)
Visual	61 (36.1%)	92 (54.4%)	16 (9.5%)

Further analysis was conducted to determine more precisely when the in-ground LEDs were first detected within the participant's navigation path. Heat maps of the location where participants reported detecting the LEDs are presented in Figure 4 for each distractor condition. The heat maps revealed that participants detected the activation of the LEDs either during the approach or at the start of the maze, with most participants detecting the in-ground lights as soon as they activated. When completing the visual distractor task, a second peak in the probability distribution was observed in the vicinity of the in-ground LEDs. This suggests that participants who did not detect the LEDs when first activated (because of looking down at the visual distractor task), detected them as they got closer to them. Importantly, detections of the LEDs reported while in the rail corridor (i.e. while traversing the crossing) occurred as they reached the entry to the rail corridor, before reaching the danger zone, thus well in time for acting on such detection.

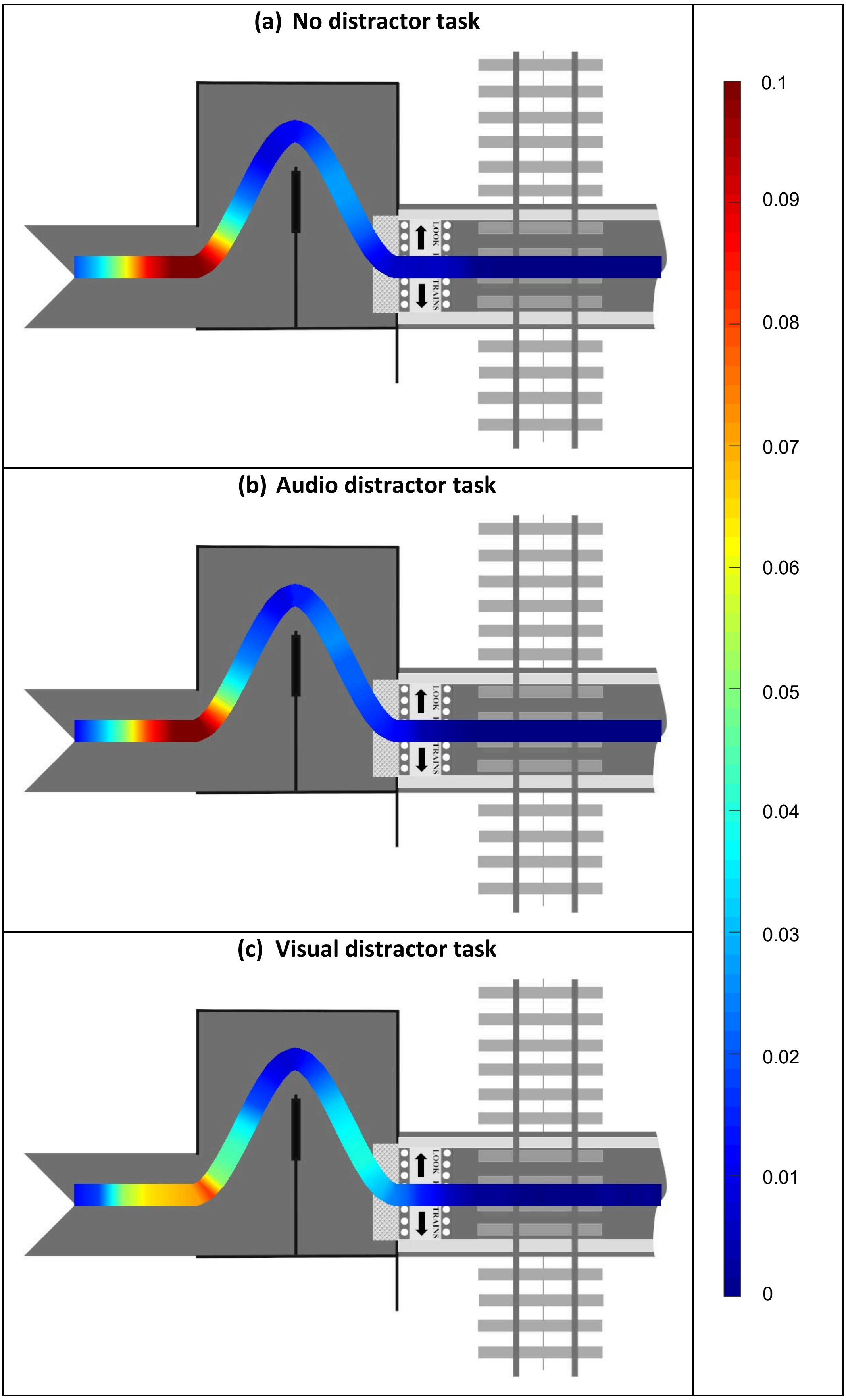

Figure 4: Probability density function (displayed as a heat map) of the location where the activation of the LEDs was detected by participants.

3.5 Eye gaze behaviour at the crossing

3.4.2 Checking for presence of trains

Figure 5 reports the proportion of participants who searched for trains or not. Analyses revealed that for most traversals (79.9%) of the control crossing, participants looked at least once in both directions when not distracted, and this was statistically similar when performing the auditory task (77.9%). However, participants were less likely to check for trains when performing the visual distractor task (see Table 3), with a reduction to 70.1% (t=-4.96, d.f.=1,188, p<.001). For the treatment condition, participants performing the visual distractor task checked both sides of the crossing 77.0% of the time, which was a significant increase compared to visual distraction when navigating the control crossing (t=2.07, d.f.=1,188, p=.038). This level of performance was close to that found when not distracted at the control crossing.

Furthermore, the detection of the in-ground lights was followed by gazes toward the rail tracks 42.9% of the time. This suggests that the in-ground LEDs were effective at reminding participants to look for trains, and may explain the improvement in checking behaviour when visually distracted relative to the visual distractor condition when crossing the control site.

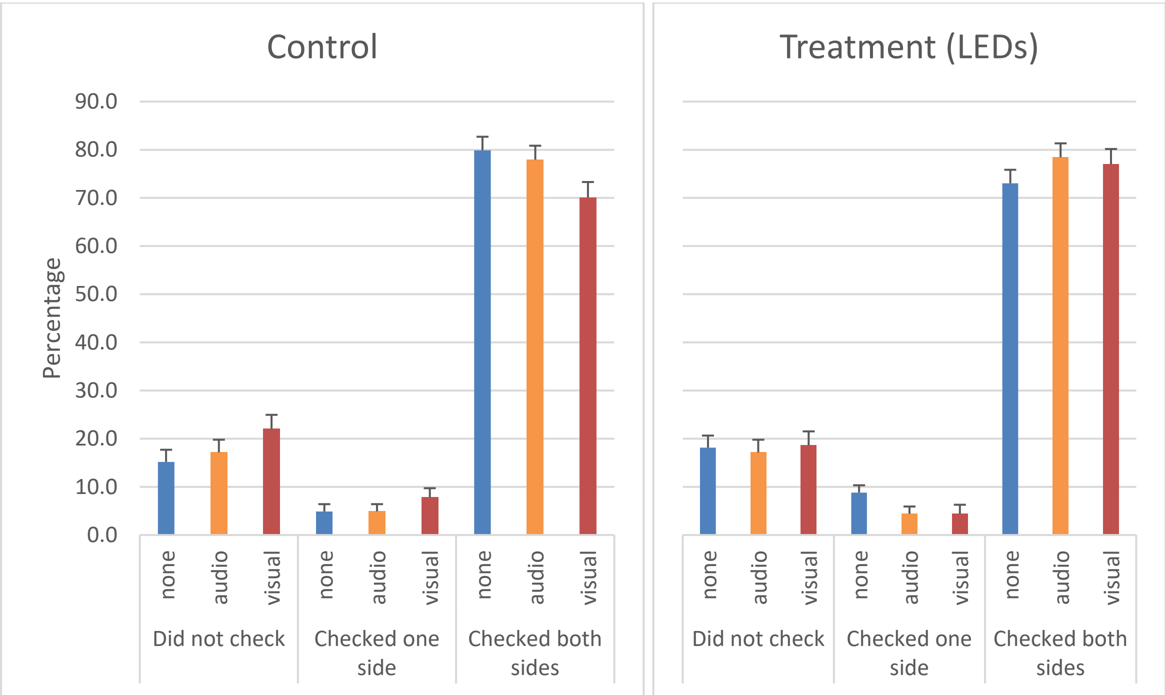

Figure 5: Gazes at the rail tracks when looking for trains.

3.4.2 Amount of time spent looking for trains

On average, participants spent 2.92 s searching for trains when they navigated through the maze and traversed the control level crossing. The auditory distractor task did not significantly affect this duration, however the visual task resulted in a reduction of this checking behaviour by 1.24 s (t=-9.90, d.f.=923, p<.001, see Table 3). In the presence of the in-ground LEDs, this duration decreased by 0.62 s (t=-6.50, d.f.=923, p<.001) when participant were not distracted, which may be related to the fact that participant spent some time looking at the LEDs when in the maze, which is often the location where most participants looked for trains. This reduction in the treatment condition was not as pronounced for the visual distraction condition. Indeed, the reduction was 0.36 s less than what would have been expected when combining the reduction from the visual distractor and the presence of LEDs (t=2.03, d.f.=923, p=.042). However, this checking duration remained the shortest of all conditions (1.42 s) and is likely to be due to participants checking for trains just as they entered the crossing (see Section 3.4.1).

4. Discussion

In this field-based study, the effects of in-ground LEDs at a passively protected level crossing equipped with a maze were evaluated, with the LEDs being activated by the approach of the pedestrian just prior to them entering the maze. Participants were regular users of mobile devices when walking, as confirmed by the Mobile Phone Problematic Use questionnaire.

4.1 Engagement with distractor tasks

The findings showed that the participants were actively engaged in the visual and auditory distractor tasks. Both tasks were performed at a high level of accuracy, with rapid response times. Participants' performance was similar to the performance levels reported in a laboratory study using a similar task (Larue, Watling, et al., 2020). We can therefore be confident that participants were allocating a sufficient attention towards the distractor tasks. Participants compensated for performing the distractor tasks while walking through the crossing (a dual task) by reducing their walking pace. Such behaviour has also been observed in other research concerning distracted drivers reducing their vehicle's speed (Alsaleh, Sayed, & Zaki, 2018) as well as pedestrian behaviours (Kim, Park, Cha, & Song, 2014). Reducing walking speed was more pronounced for the visual distraction condition, suggesting that the visual task was more difficult to perform while walking through the crossing and undertaking the other tasks. This is also supported by the fact that pedestrians looked down three times longer when performing the visual task, potentially to look at the phone, or at the path just in front of them. This behaviour was different in the absence of the visual distractor task, where participants were looking ahead most of the time during the no distractor and auditory distractor conditions. This suggests that the audio distractor task was less distracting compared to the visual task, likely due to participants being able to perform the audio secondary task while looking ahead. Overall, this highlights that participants were distracted while navigating the crossing, and that we can be confident that our findings reflect the effects of in-ground LEDs at passive level crossings while distracted. However, the effects of the audio distractor task were less pronounced than the visual distractor task.

4.2 Behaviour at the control pedestrian level crossing

The observed behaviour of pedestrians navigating through the crossing in the absence of in-ground lights (control) was to enter the maze and to look for trains while going through the maze. The mazes are designed to make pedestrians look for trains in both directions prior to entering the rail corridor without stopping. In the current study, participants did check for trains in both directions of the rail corridor 79% of the time, collapsed across distractor conditions. Searching for trains took, on average, 4.5 seconds to complete in the absence of any distractors.

Performing the auditory distractor task did not result in any significant change in behaviour while navigating through the crossing. On the other hand, the visual distractor task was found to reduced performance: checking for trains in both directions was reduced by 10%. Participants also spent less time looking for trains, when visually distracted as the results showed they had to keep looking down at their phone while performing the task, even though they reduced their walking pace (a compensatory behaviour). These outcomes are consistent with several studies examining the effect of distracted pedestrians when crossing roadways and their fail to check their surroundings for danger (e.g., Pharo, 2019; Simmons, Caird, Ta, Sterzer, & Hagel, 2020). In the current study, participants' compensation (slower walking) was sufficient to maintain similar performance when performing the auditory task relative to the no-distractor condition and the audio distractor may have not been sufficiently distractive to be representative of a realistic listening task. Yet, slower walking was not sufficient to maintain performance when visually distracted, and this resulted in more risky crossing behaviours occurring such as not checking for trains before crossing when visually distracted.

4.3 Detection of activations of LED lights

The activation of in-ground LEDs with the approach of a pedestrian was found to be an effective way to attract their attention. Indeed, participants almost always detected the activation of the flashing lights, even when distracted. However, distraction affected the location at which the flashing LEDs were first detected. The auditory distraction resulted in the activation of the LEDs being detected slightly later than when not distracted, as pedestrians entered the maze. This highlights that the audio distractor task, while simpler, had nonetheless a distractive effect on participants, slowing their response to the activation of the lights. When participants were visually distracted, the typical pattern of detection of the LEDs consisted in either detection at the entrance of the maze (similar to the non-distraction and auditory distraction conditions), or when they were almost walking on top of the LEDs, as they approached and entered the rail corridor. This suggests that while participants were looking down at the phone, they were less likely to detect the activation of the LEDs when they approached or entered the maze, which would likely have been out of their field of view.

As the participants traversed through the maze, they were able to detect the LEDs as they looked down at the phone and were almost on top or next to the LEDs. The current findings are consistent with outcomes reported from a laboratory study, where visually distracted participants were effective at detecting the activation of lights only when they were close to them (Larue, Watling, et al., 2020). It should also be noted that in the present study when traversing the crossing with in-ground LEDs, participants spent more time (0.7s) looking down, which suggests that they were looking down at the activated LEDs. Gazes toward the in-ground LEDs may increase the chance for pedestrians to notice the "Look for Trains" signage. This is a positive finding, given participants tended not to look at the 'Look for Trains' sign placed vertically in the middle of the maze. But more thorough investigations are necessary to confirm this and ensure that this is not due to a novelty effect (e.g., Schomaker & Meeter, 2012). Together, these findings support the efficacy of in-ground LEDs for attracting distracted pedestrians' attention and facilitating safer crossing behaviours. Moreover, this also suggests that the placement (at the entrance of the rail corridor, on both sides of the crossing, and around 2 metres away from the rail tracks) and time of activation of the LEDs (around the entrance of the maze) are important and appropriate for their intended use, being effective at attracting pedestrians' attention, even when visually distracted.

4.4 Effects of the lights on behaviour

In addition to attracting the participants' attention, in-ground LEDs resulted in safer environment scanning behaviours at the crossing, particularly when visually distracted, compared to the control condition. Participants who were visually distracted by the phone task but detected the activation of the LEDs, were found to check for trains on both sides of the crossing 77% of the time. This behaviour is similar to that observed in the absence of distraction. It should be noted that 43% of the time, the first gaze following the detection of the LEDs when visually distracted was on the rail tracks, suggesting that participants made the link between detecting the lights and the need to look for trains. This suggests that in-ground LEDs can act to remind distracted participants to perform checking behaviours when approaching rail tracks, in a similar manner to when they are not distracted. Previous research has determined that road signage and road perceptual treatments can lead to safer driving behaviours, despite signage not being explicitly comprehended but rather at an implicit awareness level (Auberlet et al., 2012; Charlton, 2004; Montella et al., 2011). However, it did not appear to induce an increase in the time checking for trains in this study, which could be due to participants perceiving that their visual scanning of the tracks was sufficient and no further checking was required, however, the motivation for these behaviours needs to be explored further. Alternatively, given the sample was generally effective at checking for trains in the control condition, the LEDs may act as a reminder for them to perform visual checking they would have performed anyway if they were not distracted. Further investigations should be conducted to better understand the positive effects found here, especially since the installation of in-ground lights at road intersections has been reported to heighten pedestrians' level of caution (Transport for New South Wales, 2014).

When visually distracted, pedestrians not only tended to check for trains less often, but they also checked for trains for a shorter duration. Importantly, this reduction was less pronounced in the presence of the in-ground LEDs. While no literature is available to provide a minimum duration for checking for trains appropriately, it is likely that such time (2.8s) is sufficient to safely assess the situation on both sides of the crossing.

Finally, participants were found to spend less time looking for trains when the LEDs were installed. The duration reduced by 0.7s, such that they spent 3.8s looking for trains. This is linked to the 0.7s increase in looking down behaviour, which is the time participants spent looking at the in-ground LEDs.

4.5 Strengths, limitations and future directions

This study is the first to evaluate in the field the potential benefits of in-ground LEDs for attracting the attention of pedestrians distracted while using mobile devices. However, there are a number of limitations that need to be acknowledged when interpreting the results. Only one site was evaluated, and only one type of pedestrian level crossing: passive level crossings with a maze. The sample size also does not allow generalisation of the findings outside the current circumstances and tasks performed. Further research is therefore necessary to confirm whether the observed effects of in-ground flashing LEDs are also observed at other level crossing configurations, (such as active crossings, or crossing without mazes), and also for road intersections and other populations.

The distractor tasks were designed to increase cognitive workload without being overly challenging. This approach was selected to ensure the safety of participants at a site where trains could traverse the crossing, due to the current lack of evidence around the effectiveness of the treatment. In particular, the auditory distractor task focussed solely on listening and had a limited effect on participant's performance while navigating through the level crossing. The distractor task difficulty level, while sufficient for the visual modality, may have been not sufficient as a distractor in the audio modality. Further research should investigate whether the positive effects found in this study remain for other types of distractions (e.g. phone discussion) and for more challenging and realistic distractor tasks, particularly when presented in an auditory mode.

The observed behaviour may also not be fully representative of participants' habitual behaviour at level crossings. Indeed, participation while wearing an eye tracker and the presence of the safety officer are likely to have increased people's awareness of looking for trains. However, the safety officer tried to be as inconspicuous as possible and intervene on only limited occasions.

Effects over longer periods of time were not investigated in this study. The positive changes in behaviour at the crossing may reduce with habituation, and further research should aim at assessing whether behaviour changes remain after pedestrians get used to this warning, and when not involved in a study. Indeed, longer exposure to such added warning could lead to complacency, which is a known issue at railway crossings for road vehicles (Landry, Jeon, & Lautala, 2016), particularly at passive level crossings with low train traffic volumes (Larue, Wullems, Sheldrake, & Rakotonirainy, 2018; Rudin-Brown, George, & Stuart, 2014).

The effects of the in-ground flashing lights were not investigated at night. However, their conspicuity at night is likely to be higher and effects on attracting pedestrians' attention are likely to be even stronger than during daytime. It would be useful to determine if this were the case by conducting further research at night.

While the results suggest that the behaviour of participants improved with the LEDs, with increased attention towards the rail tracks when distracted, further research should aim to understand whether such an intervention is likely to be effective for all types of users of level crossings, or whether it will attract pedestrians' attention without resulting in a change in behaviour. This understanding is critical in determining whether it would be beneficial to install in-ground LEDs more generally at level crossings. If the presence of LEDs changes behaviour, they would be effective generally, however, if they are only effective at attracting attention, they may only be effective with pedestrians who are generally compliant with signage and fail to realise they were approaching a crossing when distracted. Such information would be useful for conducting cost-benefit analyses, which are critical to ensure the viability of the approach as an intervention. Future research should also investigate the effects of in-ground LEDs at other types of intersections, such as road intersections.

5. Conclusion

The use of in-ground illuminated lights installed in the footpath demonstrate a range of positive effects at passive rail crossings with a maze, in terms of attracting attention and checking for trains. Performance at the control level crossing decreased when distracted, particularly with the visual distractor task. With these flashing in-ground LEDs, performance at the level crossing while distracted was similar to that when not distracted. These benefits were found for a cohort of pedestrians who regularly use their mobile device while walking and are largely compliant with level crossings. Further research could focus on whether such signage is effective for pedestrians who would not normally comply with the crossing (due to habituation to low train traffic which can lead to complacency, for instance through not looking for trains) and for other types of intersections, such as road intersections. Evaluation over longer periods would also be valuable to ensure that any positive effects are sustained following pedestrians becoming familiar with these warning devices.

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