Acceptance of visual and audio interventions for distracted pedestrians

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Abstract

Distraction from mobile devices increases pedestrian risks at intersections. Innovative interventions are currently installed at road and rail intersections to alert pedestrians. These interventions will be effective only if pedestrians modify their behaviour. The Technology Acceptance Model (TAM) posits that behaviour changes as a result of behavioural intention, which is affected by perceived usefulness and perceived ease of use. However, the link between intention and actual behaviour is often overlooked. The current study aims to investigate this link and apply this theoretical framework to interventions for distracted pedestrians. We conducted a day-time field study at three railway level crossings in New Zealand with such interventions reminding pedestrians to look for trains: in-ground flashing lights located at footpath level, an audio warning message, and in-ground flashing lights combined with the audio warning message. Participants (N=34, Mean age 33.6, SD=8.6 years) walked through level crossings while performing a distractor task (visual and auditory distraction) or when not distracted. Actively checking for trains from both sides of the crossing was used as a measure of actual behaviour. All three interventions were perceived as useful (5.1±0.4) and easy to use (5.6±0.2) and resulted in positive intention to use the technology (5.8±0.3). Statistical analyses confirmed that the TAM constructs - particularly perceived usefulness - affected intention, and intentions lead to behavioural change with improved crossing behaviours. This study highlights the importance of perceived usefulness and intentions to use the interventions with reducing distracted pedestrian behaviours.

Keywords

Pedestrians; Distraction; Interventions; Railway level crossings; User acceptance; Intentions

1. Introduction

1.1 Pedestrian distraction

Smartphones are an embedded part of daily life (Rush, 2011). Pedestrian distractions, such as talking on a mobile phone, looking at a mobile phone screen, or wearing headphones (C. H. Basch, Ethan, Rajan, & Basch, 2016), have therefore become more prevalent. Observational studies at road intersections have found that up to 30% of pedestrians are distracted by mobile devices and headsets (Barin et al., 2018; Violano, Roney, & Bechtel, 2015). It has been suggested that distraction from mobile devices plays a role in increasing pedestrian fatalities and injuries by its effects on both pedestrians and drivers (Schwebel & Griffin, 2020). Currently, over 6,400 pedestrians are fatally injured in the US per year, a currently growing number (Centers for Disease Control and Prevention, 2019). Recent analysis tends to support this view, with 24% of fatal collisions between pedestrians and road vehicles involving a distracted pedestrian (Das et al., 2019). It is also corroborated by hospitalisation records, where 1,506 pedestrians injuries were recorded in the US in 2010 an related to the use of a mobile phone while walking (Nasar & Troyer, 2013).

Being distracted by mobile phone use while walking can lead to unsafe behaviour such as reduced scanning of the environment (Lin & Huang, 2017; Tapiro, Oron-Gilad, & Parmet, 2016), accepting smaller gaps (Tapiro et al., 2016), and sometimes the inability to follow a straight path (Sammy, Robynne, Miranda, & Conrad, 2015; Solah et al., 2016). Distraction from a mobile device can also result in non-compliance with road rules, such as failing to stop (Lin & Huang, 2017; Pešić, Antić, Glavic, & Milenković, 2016; Russo, James, Aguilar, & Smaglik, 2018). It is also not uncommon for pedestrians distracted by their mobile device to bump into other pedestrians or obstacles: more than half of all adults owning a smartphone having experienced such a situation (Barin et al., 2018). Such effects on pedestrians are of concern at intersections, which are safety-critical areas where pedestrians need to negotiate the environment with other road users, including vehicles.

Railway level crossings are an example of intersections where pedestrian distraction has become more prevalent with the increased use of mobile phones and headsets (Goodman, 2018). While collisions with trains have reduced by 49% for road vehicles, the number of pedestrian and bicycle fatalities have increased by 48% during the last decade (Metaxatos & Sriraj, 2015). As a consequence of these trends, pedestrians are soon expected to overtake vehicle occupants as the road users with the most fatalities at railway crossings. This highlights the need for further investigations of pedestrians behaviour at such crossings (Russo, James, Erdmann, & Smaglik, 2020), particularly distraction as limited research has focused on it despite its growing prevalence. This is further supported by the fact that pedestrian non-compliance at railway crossings is a known and common issue (Larue, Naweed, & Rodwell, 2018; Mulvihill et al., 2016): for instance, 57% of pedestrians in one study, entered closed crossings before or after the train had crossed, representing a rate of non-compliance of 2.58 per train (Metaxatos & Sriraj, 2013). It was also shown that 15% of younger pedestrians using a level crossing were not checking for trains while wearing headphones (Baric, Pilko, & Starcevic, 2018). Pedestrian distraction was found to be more prevalent during afternoon peak hours, for pedestrians on their own, particularly men younger than 30, and after a train passed (Russo et al., 2020).The potentially fatal consequences are evidenced by several recent rail incident investigations which identified pedestrian distraction as a contributing factor (Rail Accident Investigation Branch, 2009, 2010, 2013; Transport Accident Investigation Commission, 2016).

1.2 Existing Interventions

The current signage for pedestrians consists of warning signs and signals positioned at eye level and in some instances some static marking on the ground. The effectiveness of such signage is likely to be reduced when pedestrians divert their attention towards their mobile devices and when they use headphones. Studies highlight up to 29.8-43.2% of pedestrians use or are engaged in using a portable electronic device (i.e., mobile phone or portable music device) while crossing at intersections (C. Basch, Ethan, Zybert, & Basch, 2015; Nasar, Hecht,

& Wener, 2008; Thompson, Rivara, Ayyagari, & Ebel, 2013). However, with limited budgets, safety upgrades are spent with priority on railway crossings for road vehicles, leaving pedestrian crossings to their existing level of protection (Larue & Naweed, 2018; Metaxatos & Sriraj, 2015; Wullems, 2011). Thus, cost-effective interventions are needed to improve pedestrians' awareness when approaching railway crossings.

Initial attempts have focused on pedestrian safety messaging campaigns, but there is currently no evidence that such an approach has been effective (Violano et al., 2015). As such, innovative interventions targeted at distracted pedestrians focused on pavement markings with messages such as 'Heads Up, Phones Down' (Barin et al., 2018), the use of auditory and verbal warning (Dreßler et al., 2020), visual warning lights installed in the ground, and more recently prototypes using Bluetooth beacon technology as a means to alert and warn pedestrians (Schwebel & Griffin, 2020) have been proposed. Such interventions have been installed at some road intersections (Potts, 2016; Sulleyman, 2017; Timson, 2016) and railway crossings (Hirsch, Mackie, & Cook, 2017). In general, there are limited evaluations of these interventions (Barin et al., 2018; Metaxatos & Sriraj, 2015) regarding their effectiveness and pedestrian perceptions of acceptability. Pavement markings tend to have limited effects which are not sustained over time (Barin et al., 2018). In-ground lights are likely to be useful as they can be detected by pedestrians through the use of peripheral vision while performing a distractor task on a smartphone (Larue, Watling, Black, Wood, & Khakzar, 2020). Audible tones, verbal messages and vibrating surfaces have also been installed at level crossings to assist pedestrians with limited visual acuity, but the effects of such interventions have not been evaluated (Metaxatos & Sriraj, 2015). Vibrotactile warning systems (wristbands) have also been trialled and were found to improve hazard awareness of distracted pedestrians (Marsalia, Ferris, Benden, & Zheng, 2016).

While showing promising short-term effects, interventions may require further reinforcement over time (Barin et al., 2018), and attention should be put to acceptance of these interventions by the targeted users. Indeed, prior research has shown when pedestrians hold positive perceptions regarding the efficacy of safety countermeasures, behavioural change is more likely to persist (Emo, Funke, & Matthews, 2011). Also, pedestrians who perceive their level of safety as high have a lower chance to see value in interventions designed to reduce their risks, as measured through the willingness to pay for such interventions (Puttawong & Chaturabong, 2020). Moreover, interventions associated with low levels of acceptance may be more detrimental than beneficial (Roberts, Ghazizadeh, & Lee, 2012). Road users generally accept technology interventions in critical situations, primarily when it includes additional information increasing their awareness of the situation (Joshi, Bellet, Bodard, & Amditis, 2009; Van Driel & can Arem, 2005; Varhelyi & Makinen, 2001). However, safety interventions may also be perceived as distracting, irritating or unnecessary (Buckley, Larue, Haworth, & Rakotonirainy, 2013), or unreliable when experiencing failure of the system (Chugh & Caird, 2016; Larue & Wullems, 2015), potentially reducing the use of the technology.

While road safety authorities embrace systems-based thinking, advocating efforts to change public policy and supporting legislative reform to prevent injuries, most strategies, however, are *in fine* designed to change road user behaviour (Dellinger & Sleet, 2010). It is, therefore, critical to ensure individuals accept technologies aimed at improving safety outcomes. This has currently not been investigated for the interventions implemented for distracted pedestrians.

1.3 User acceptance

An important factor determining technology usage concerns individuals' motivation or intention to use the device (Ajzen, 1991; Chau & Hu, 2001). The Technology Acceptance Model (TAM) provides a sound theoretical framework for investigating users' adoption of new technologies (Chen, Fan, & Farn, 2007). It explains why users accept or reject particular technologies based on two types of user beliefs. These two factors, namely perceived ease of use and perceived usefulness (see Figure 1), are important factors determining usage (Dybå, Moe, & Arisholm, 2005; Legris, Ingham, & Collerette, 2003) through their effect on intention (Turner, Kitchenham, Brereton, Charters, & Budgen, 2010; Wu, Cheng, Yen, & Huang, 2011).

Acceptance models have been successfully applied to driver acceptance of advanced driver systems (Rahman, Lesch, Horrey, & Strawderman, 2017; Roberts et al., 2012) but also for pedestrians (Emo et al., 2011). They have also been used for assessing acceptance of vibrotactile warning systems for pedestrians (Coeugnet et al., 2017) and new technologies for railway level crossings (Larue, Rakotonirainy, Haworth, & Darvell, 2015; Rail Safety and Standards Board, 2011). Thus, acceptance have proved useful with evaluations of safety interventions.

Technology usage is also influenced by other factors (Legris et al., 2003), and the literature shows that additional constructs can be incorporated into acceptance models (Turner et al., 2010). For example, pedestrians who are more likely to perform unsafe behaviours may also be more likely to walk distracted (Deb et al., 2017a). Pedestrians unsafe behaviours can be accessed via self-report questionnaires such as the Pedestrian Behaviour Scale (PBS: Granié, Pannetier, & Guého, 2013). The PBS assess different pedestrian behaviours such as lapses, errors, violations, and aggressive behaviours – these different behaviours are associated with risky pedestrian behaviours and incidents (Deb et al., 2017b). An individual's usage of a mobile phone, particularly problematic usage levels, is related to engaging in distracted walking (Tao et al., 2016). Problematic mobile phone use can be quantified using the Mobile Phone Problem Use Scale (MPPUS: Bianchi & Phillips, 2005) which assess several dimensions of problematic phone use such as time spent using, attachment to, and preoccupation with a mobile phone amongst others aspects. Understanding how pedestrian behaviours and problematic phone use are related to acceptance of technology aimed at reducing distracted walking behaviours is important and could regulate actual use of such technology and lessen distracted walking behaviours. Such constructs should, therefore, be considered when evaluating innovative countermeasures for distracted pedestrians.

Phone usage can differ on factors such as gender and age, both in terms of frequency, duration and type of usage (Andone et al., 2016; Vanden Abeele, Beullens, & Roe, 2013). Younger people tend to engage with their smartphone more than other age groups (Lu et al., 2011; van Deursen, Bolle, Hegner, & Kommers, 2015), and females more frequently than males (Jeong, Kim, Yum, & Hwang, 2016; Wang, Wang, Gaskin, & Wang, 2015). Indeed, older people are less likely than younger people to embrace new technologies (Charness & Bosman, 1992). Types of use also vary with younger users engaging in communication apps and social media more often, while older users use it more as a regular phone or for reading the news (Andone et al., 2016). Furthermore, problematic internet use has also been found to be affected by age and gender (Billieux & Van der Linden, 2012) and it is suggested to be similar for mobile devices (van Deursen et al., 2015). Gender and age should, therefore, be accounted for when assessing acceptance of interventions for distracted pedestrians who use their mobile device while walking.

A limitation of the Technology Acceptance Model is its focus on behavioural intention rather than actual usage of the technology (Straub & Limayen, 1995; Turner et al., 2010). It has been noted, that positive intentions are more likely to translate into actual use when the user experienced the technology before evaluating it (Wu et al., 2011). Further, when users do not have prior experience with the technology, their intentions are primarily predicted by ease of use, unlike experienced users (Szajna, 1996). In addition, intentions predicted usage in the case of experienced users but not for users with no experience of the technology. It appears, therefore, critical that acceptance of the interventions targeted at distracted pedestrians is evaluated objectively with participants who have experienced these interventions while walking and using a mobile device. Turner et al. (2010) reviewed the literature systematically; they showed that most studies using the TAM fails to consider objective effects on actual behaviour, despite a difference in the relationship between behavioural intention and usage, when measured subjectively or objectively. Indeed, behavioural intention can be closely related to subjective use and much less to objective use (Szajna, 1996). More robust knowledge would be gathered on the models if the link between intentions and actual behaviour was considered.

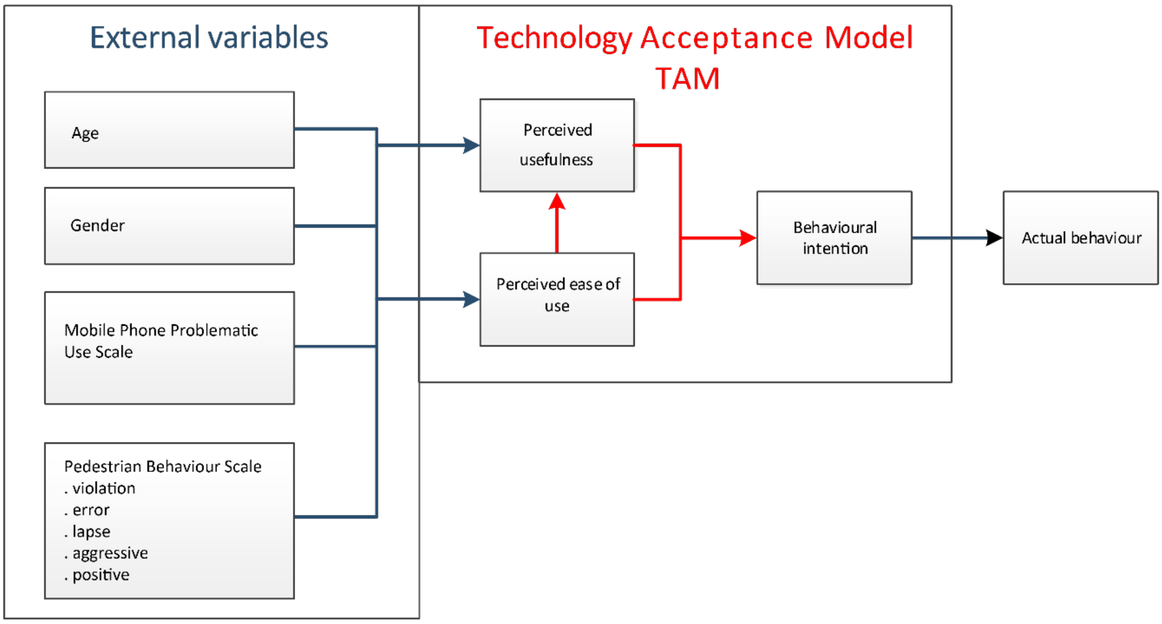

Figure 1: Technology Acceptance Model as implemented in the current study.

1.4 The current study

This study aimed to evaluate the acceptance and intention to use new interventions designed to attract the attention of distracted pedestrians in the context of railway level crossings. The link between intention and actual behaviour was also investigated in an objective manner, addressing the main limitation of studies using the TAM in the current literature. This study represents part of a broader investigation which aimed at understanding whether such interventions are effective at attracting the attention of pedestrian distracted through a visual or auditory distractor task on their smartphone. The current study used the Technology Acceptance Model to evaluate user acceptance of three interventions installed at passive level crossings in New Zealand for pedestrians distracted by their smartphone: in-ground flashing lights located at footpath level, an audio warning message, and in-ground flashing lights combined with the audio warning message.

2. Method

2.1 Study design

2.1.1 Trial sites

The trial sites were three passive pedestrian level crossings in New Plymouth, New Zealand. The region's rail provider, KiwiRail, installed three different interventions to alert pedestrians distracted by their mobile device. The three selected level crossings were located on the New Plymouth Coastal Walkway. They were similar in terms of protection (passive), enclosure (maze to force pedestrians to make at least one 180 degrees turn when approaching the rail tracks), signage ('Look for Trains' positioned in advance of the level crossing within the maze), as well as similar low traffic flow in terms of trains (~4 per day) and pedestrians (~130 per day).

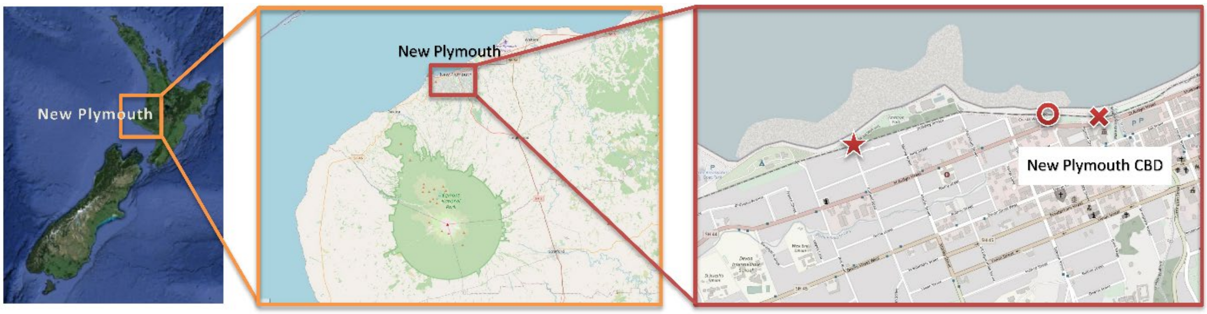

Figure 2: Site locations: crossing with illuminated in-ground LEDs (highlighted by a red star), crossings with the audio message (red circle), and crossing with both LEDs and audio message LEDs (red cross).

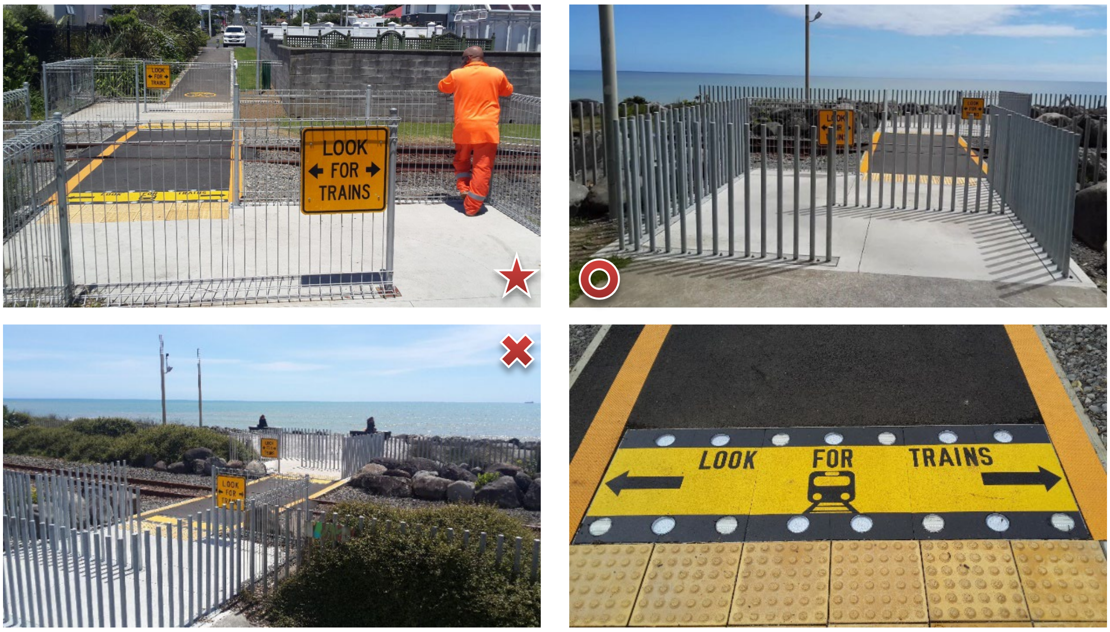

Figure 3: View of the selected level crossings (Top left: crossing with in-ground LEDs and the protection officer his observation position (red star); Top right: crossing with audio message (red circle); Bottom left: crossing with in-ground LEDs and audio message (red cross)) and the in-ground LED intervention (Bottom right).

2.1.2 Interventions

The first intervention consisted in an illuminated pedestrian warning device using in-ground Light-Emitting Diodes (LEDs) and reiterating the 'Look for Trains' signage displayed vertically on the approach of 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. 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 (around a metre and a half away from the maze). Every second yellow flashing light was reflected with a 45 degrees angle (both toward and away from the level crossing), so the that lights could be detected by pedestrians both during the approach and while directly above the lights. 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.

The second intervention was an audio message. The message was '*Whakarongo* [Maori for Listen]*. Caution. Railway crossing ahead. Look for trains both ways before crossing'.* It was played by speakers at the crossing when a pedestrian approached the crossing. The location where the message was activated was the same as for the previous intervention.

The third intervention was a combination of the two interventions presented above.

2.1.3 Experimental design

The study used a repeated measures design with all participants experiencing the in-ground LEDs intervention, and forty per cent of participants experiencing all three interventions (due to technical issues at the two crossings including audio messages). The level crossing with in-ground LEDs was also used as a control site. In that case, mats were installed on the ground to hide the LEDs. Participants experienced the different level crossing configurations in a counterbalanced order.

At each level crossing type, participants, equipped with an eye tracker, walked through each crossing six times under three different distraction conditions: (i) no distraction; (ii) visual distraction; and (iii) auditory distraction. The order of the tasks was counterbalanced between participants. The visual and auditory distraction task was performed on a smartphone and was a simple time task developed to ensure participants were sufficiently engaged when completing the tasks. The tasks were analogues for either texting on the 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 et al. (2020). The task consisted of pressing the screen (as soon and as accurately as possible) when a target word was displayed on the screen or heard in the headset.

2.2 Participants

Participants were healthy adults who identified as regular users of mobile devices while walking (i.e., three times or more per week). Participants were required to have normal visual acuity, 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. Written consent was obtained from all participants. At completion of the study, participants received a $100 incentive for taking part in the study. Ethical clearance was obtained from the Queensland University of Technology Ethics Committee (clearance number 1800000417).

Thirty-four participants completed the study. Of these, 64.7% (n=22) were female. The mean age was 33.6 years (SD=8.6; range=18-51). In terms of highest education completed, 29.4% (n=10) of participants completed high school, 26.5% (n=9) obtained a diploma, 26.5% (n=9) an undergraduate degree, 11.8% (n=4) a postgraduate degree, and 5.9% (n=2) reported completing other education (i.e., trade or technical college).

2.3 Instruments

2.3.1 Questionnaires

The survey consisted of demographic questions and an acceptance questionnaire based on the Technology Acceptance Model. Most items were positively worded, and all were scored on 7-point Likert scales ranging from strongly disagree to strongly agree. Each question was asked with reference to the interventions each participant experienced. Three items assessed participants' perceived usefulness of the technology (e.g., 'I believe the use of flashing lights would improve my awareness at the crossing') and two assessed their perceived ease of use of the technology (e.g., 'Learning to use the flashing lights was easy for me'). Items were averaged to obtain an overall measure of the construct. Perceived usefulness exhibited high scale reliability ($\alpha = .92$), while the perceived ease reliability was $r = .67$. Behavioural intention was measured using two items (e.g., 'When walking through a rail crossing, I would prefer these flashing lights were installed and in use.'). Items were averaged to yield an overall measure of intention, which was reliable ($r = .85$). Responses to the TAM scales were used as the dependent variables in the analyses.

The study also included two independent variable scales measuring injury risk behaviour among pedestrians and psychological factors predicting problematic use of mobile phones. Pedestrian risky behaviour was measured using the 20-item Pedestrian Behaviour Scale (PBS: Granié et al., 2013). The PBS consists in subscales, each with four items, which differentiate between five types of pedestrian behaviours: Violations, Errors, Lapses, Aggressive and Positive behaviours. Higher scores on a six-point Likert scale (1 never to 6 very often) indicate that the pedestrian reports engaging in this behaviour more frequently. Violations consist in intentional deviation from the legal rules of pedestrian behaviour. Errors are defined as decisions that put the pedestrian in danger despite not being illegal. Lapses are ill-suited behaviours related to a lack of concentration on the walking task. Positive behaviours are those appeasing social interactions, while aggressive ones lead to conflicting interactions with other road users. The Cronbach's alphas indicated strong levels of internal consistency for the Lapse subscale (.80) and was quite reliable for the Violation, Error and Positive subscales (.69, .61 and .66 respectively). The level of consistency was low for the Aggressive subscale (.26), and that scale was not used in the analysis.

Problematic mobile phone use was quantified via self-report on the Mobile Phone Problem Use Scale (MPPUS: Bianchi & Phillips, 2005). Each question of this 27-item questionnaire is scored on a 10-point Likert scale (1 not true at all to 10 extremely true agree), and higher scores indicated higher use of the phone. The Cronbach's alpha for the scale used in this study was .91.

2.3.2 Eye-tracking system

Actual behaviour was quantified as the eye scanning behaviours of the participants. The SensoMotoric Instruments (SMI Instruments, Teltow, Germany) eye-tracking system was used to record scanning patterns. 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 gaze behaviour in real-time at a 60 Hz sampling rate.

2.4 Procedure

Participants first attended a screening session at a local library. During this initial session, each participant signed the consent form. During that session, they completed the demographic survey, as well as the Pedestrian Behaviour Scale and the Mobile Phone Problem Use Scale questionnaires.

At the start of each testing session, researchers met the participant near one of the level crossing used in the study. Each testing session took up to 2 hours, and started at either 9am, 11am, 1pm or 3pm. A protection officer was positioned in a strategic and unobtrusive position in the maze (see Figure 3), 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 equipped with the eye tracker, and their gaze calibrated. They were then 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. No information was provided to participants about the meaning of the intervention. For participants trialling the three different interventions, they were then accompanied to their next level crossing to complete the same tasks in a counterbalanced order. At the end of their session, participants completed the questionnaire assessing their experience of each intervention they experienced in accordance with the Technology Acceptance Model framework. They were finally thanked and provided with their incentive payment.

2.5 Data Analysis

Statistical analyses were performed using R statistical software version 3.4.2 and the level of significance was set at $p < 0.05$. The MCMCglmm library was used to obtain confidence intervals. Participants' demographic and responses to the different scales were presented using descriptive statistics. Effects of demographics (gender and age, age is categorised into two groups using 30 years as a cut-off), PBS and MPPUS constructs and interventions on the TAM constructs (Perceived Ease of Use, Perceived Usefulness and Behavioural Intention) were examined using repeated measures regression analysis using Generalised Linear Mixed Models (GLMMs). All models included random intercepts for participants, to take into consideration the repeated measures design, and used maximum likelihood estimation. This enabled an assessment of whether TAM constructs predicted behavioural intention over and above socio-demographic and the other psychological variables considered.

The effect of intention to change behaviour due to intervention (also referred to as Behavioural Intention in this paper) on the Actual Behaviour participants engaged in while navigating the railway crossing was then evaluated. The interventions were designed to attract the attention of distracted pedestrians and remind them to look for trains. Actual behaviour was therefore defined in this study as eye scanning behaviours of actively looking toward rail tracks (both directions) before proceeding through the crossing. Eye tracker videos were coded for gazes toward rail tracks and participant's actual behaviour extracted for each traversal of the level crossings.

3. Results

3.1 Descriptive statistics

All participants reported using their mobile phone for phone calls, and the majority also used it for texting (97.1%; n=33), emailing (88.2%; n=30), social networks (97.1%; n=33), entertainment (85.3%; n=29), navigation (85.3%; n=29) and banking (85.3%; n=29). Half of then also used it for shopping (55.9%; n=19) while a quarter used it for exercising (26.5%; n=9). The majority of participants (79.4%; n=27) reported having experienced a 'close call' with a vehicle while walking, and one having been hit by a vehicle while walking and using their mobile phone.

Table 1 presents the means, standard deviations and range for the independent and dependent variables. The Pedestrian Behaviour Scale indicated that participants performed several positive pedestrian behaviours as well as frequent pedestrian violations and errors. Some significant but moderate correlations were found between some subscales of the PBS: Violation and Error (r=.432, p=.010), Error and Aggressive (r=.408, p=.015), and Lapse and Aggressive (r=.406, p=.015). The Mobile Phone Problematic Use Scale mean score was below the mid-point of 121.5. All of the scores for the Technology Acceptance Model were well above the mid-point of 3.5, indicating, on average, that participants reported favourable perceptions and behavioural intentions towards the three interventions.

Table 1: Self-reported measures of pedestrian behaviour, mobile phone problematic use, and trialled technology acceptance.

Construct	Mean	SD	Actual Range
Pedestrian Behaviour Scale (PBS)[a]			
PBS Violation Subscale	3.20	1.02	1.00-6.00
PBS Error Subscale	3.39	0.89	1.75-5.50
PBS Lapse Subscale	1.70	0.76	1.00-5.00
PBS Aggressive Subscale	1.55	0.64	1.00-4.67
PBS Positive Subscale	3.41	1.07	1.75-6.00
Mobile Phone Problematic Use Scale (MPPUS)[b]	107.06	33.74	46.00-191.00
Technology Acceptance Model (TAM)[c]			
Perceived Ease of Use			
In-ground LEDs	5.31	1.06	3.00-7.00
Audio warning	6.04	0.66	4.50-7.00
In-ground LEDs + Audio warning	6.00	0.65	4.50-7.00
Perceived Usefulness			
In-ground LEDs	4.44	1.58	1.00-6.33
Audio warning	6.21	0.53	5.33-7.00
In-ground LEDs + Audio warning	5.79	1.38	0.33-7.00
Behavioural Intention			
In-ground LEDs	5.57	1.13	1.50-7.00
Audio warning	6.29	1.07	3.50-7.00
In-ground LEDs + Audio warning	6.04	1.51	1.50-7.00
Actual behaviour (looking for train when distracted; reported as a percentage)	Mean	Standard Error	Actual Range
Control	79.6	1.0	0-100

In-ground LEDs	82.4	3.6	0-100
Audio warning	82.1	6.1	0-100
In-ground LEDs + Audio warning	78.8	6.4	0-100

[a]Possible range: 1 – 6
[b]Possible range: 27 – 270
[c]Possible range: 1 – 7

3.2 Technology Acceptance Model

3.2.1 Perceived ease of use

Results indicate that all systems were perceived to be easy to use, even though participants experienced it while being visually or auditorily distracted (Table 1). Participants exposed to the audio warning message perceived that this intervention, with or without in-ground LEDs, was easier to use (6.04 and 6.00, respectively) than the in-ground LEDs' approach (5.31).

The statistical analysis confirmed that perceived ease of use differed depending on the type of technology that was trialled at the level crossing. No significant differences were found between the audio warning messages provided alone or in conjunction of in-ground LEDs (B=-0.04; t = -.12, df = 26, p = .90). In comparison to these two systems, the in-ground LEDs yielded a significantly lower level of perceived ease of use (B=-.73; t = -3.50, df = 27, p = .002). The 95% confidence interval for this decrement was -1.22 to -0.19. The statistical analysis did not find any significant effect of gender, age, PBS and MPPUS constructs on the perceived ease of use of the interventions. The model explained 14% of the variance in perceived ease of use, as measured by marginal R^2.

3.2.2 Perceived usefulness

Results indicate that all systems were perceived to be useful (Table 1). As for perceived ease of use, participants exposed to the audio warning message perceived that this intervention, with or without in-ground LEDs (6.21 and 5.79, respectively), was more useful than the in-ground LEDs' approach (4.44).

Statistical analyses confirmed that usefulness differed depending on the type of technology that was trialled at the level crossing (Table 2). Again, no significant differences were found between the audio warning messages provided alone or in conjunction of in-ground LEDs (B=-0.41; t = -1.05, df = 25, p = .30). In comparison to these two systems, the perception of the usefulness of the in-ground LEDs was significantly lower (B=-1.23; t = -3.97, df = 26, p < .001). Higher scores on the Lapse subscale of the PBS were found to be associated with lower perceived usefulness of the technology (B=-0.62; t = -2.96, df = 26, p = .011). The analysis did not find any significant effect of gender, age, and MPPUS constructs on the perceived usefulness of the interventions. The model explained 46% of the variance in perceived usefulness, as measured by marginal R^2.

To illustrate the substantial effect of perceived ease of use on perceived usefulness, perceived usefulness increases by 1.88 when perceived ease of use increased from the minimum observed value (3) to the maximum one (7). This effect is larger than the effect of the intervention itself. However, there is a cumulative component for the LEDs intervention since this intervention also has lower perceived ease of use, and this explains the larger perceived usefulness gap with the other two interventions.

The effect of the lapse subscale of the PBS is even higher, decreasing by 2.48 when lapses change from 1 to 5 (observed range). Importantly, participants with a higher chance of experiencing increased risks when distracted at intersections are also the ones perceiving the interventions as less useful.

Table 2: Effects of perceived ease of use and the considered external factors on perceived usefulness of the interventions.

Variable	B	SE B	95% CI B	β	t	df	p
Intercept	4.24	1.14	2.16 – 6.92	<.01	3.71	33	<.001
Pedestrian Behaviour Scale							
Lapse	-0.62	.21	-1.08 – -.18	-.33	-2.96	33	.006
Perceived Ease of Use	0.47	.17	.07 – .77	.29	2.75	26	.011
In-ground LEDs	-1.23	.31	-1.86 – -.67	-.39	-3.97	26	<.001

3.2.3 Behavioural intention

This study was interested in determining whether, and to what extent, intention to change behaviour due to intervention differed for the three interventions targeted at distracted pedestrians. Means and standard deviations of participants' self-reported intention to change behaviour with the different systems are reported in Table 1, according to the type of intervention. Results indicate that participants formed stronger intentions to change behaviour for the intervention that would be based on an audio message alone (6.29). Intention was slightly lower when LEDs were used in conjunction with the audio message (6.04), and substantially lower for the in-ground LEDs (5.57).

Statistical analyses revealed, however, no direct effect of the technology on behavioural intention. Rather, in line with the Technology Acceptance Model, behavioural intention was found to be related to perceived usefulness, and, to some extent, to perceived ease of use (Table 3). The differences between the interventions are indirect, through their respective effects on perceived usefulness and perceived ease of use. Specifically, higher intention to use the technology was found when participants found the technology more useful (B=.41; t = 4.83, df = 26, p < .001). To some extent, a similar effect was found for perceived ease of use. However, this effect only approached significance (B=.27; t = 1.94, df = 26, p = .064). No significant effects were found for gender, age, PBS and MPPUS constructs on the behavioural intention to use of the interventions. Without considering the effect of perceived ease of use, the model explained 40% of the variance; while adding perceived ease of use resulted in 44% of the variance explained.

The effects are not only statistically significant but also large enough to affect intentions measures. To illustrate this effect, intention increases by 2.73 when perceived usefulness changes from 0.33 to 7 (observed range). The direct effect of perceived ease of use on intention is smaller, with an increase of 1.08 for the observed range of values for that construct. The overall effect on intention suggests that perceived usefulness is a crucial construct to consider for interventions targeted at distracted pedestrians.

Table 3: Effects of perceived usefulness and perceived ease of use on behavioural intention toward the interventions.

Variable	B	SE B	95% CI B	β	t	df	p
Intercept	2.17	.69	.60 – 3.75	.02	3.30	34	.002
Perceived Ease of Use	.27	.14	-.04 – .17	.21	1.94	26	.064
Perceived Usefulness	.41	.08	.22 – .61	.52	4.83	26	<.001

3.3 Behavioural Intention and Actual Behaviour

The relationships between behavioural intention and actual behaviour were explored. Means and standard errors of participants' probability to actively look for trains when distracted with the three interventions are reported in Table 1. Results indicate that participants largely looked for trains when approaching the crossing when distracted. Still, approximately 20% of the time, they entered the crossing without checking at least one side of the tracks.

Statistical analysis showed that behavioural intention has an effect on actual behaviour (Table 4; Model 1): more positive intentions were related to a higher chance of appropriately checking for trains before entering the crossing (B=.44; t = 5.05, df = 87, p < .001). However, the model only explained 4% of the variance.

Further analysis of the data revealed that the link between behavioural intention and actual behaviour was different for two groups of participants: *(i)* participants who always complied during the control trial, and *(ii)* participants who were not always checking for trains during the control (Table 4; Model 2). Unsurprisingly, participants who were always compliant during the control were found to have a high likelihood to look for trains appropriately when they trialled the interventions (B=11.19; t = 3.07, df = 33, p = .004). Higher levels of behavioural intention were found to result in higher proportions of looking for trains (B=1.29; t = 2.55, df = 85, p = .013). This finding was independent of the intervention. For participants who complied during the control, an additional effect was found for behavioural intention (B=-1.29; t = -2.09, df = 33, p = .040), which nullified the overall effect of behavioural intention for that group. This can be explained by the fact that this group has no opportunity for behavioural improvement, being already compliant. When the subgroups are considered, the statistical analysis explains 39% of the variance.

While statistically significant, the effects of intention on participants who were already compliant during the control do not affect actual behaviour much. Independent of their intentions toward the technology, their behaviour remained the same with the intervention, almost always complying. On the other hand, intention has an important effect on actual behaviour for participants who were not always complying during their control. The higher the intention, the higher the chance the pedestrian would look for trains. For the mid-point of intention (3.5) and lower, participants checked for trains less than 10% of the time when distracted. From that point, behaviour improved continuously, reaching 82% when intention was at the maximum (7). These findings support the link between intention and actual behaviour, and this was found for the group that is targeted by the intervention.

Table 4: Effects of behavioural intention toward the interventions on actual behaviour (looking for trains).

Variable	*B*	SE B	*95% CI B*	*β*	t	df	p	R^2
Model 1								.04
Behavioural Intention	.44	.09	.27 – .62	.15	5.05	87	<.001	
Model 2								.39
Intercept	-7.49	2.94	-13.3 – -1.8	.00	-2.55	85	.013	
Behavioural Intention	1.29	.51	.30 – 1.29	1.59	2.55	85	.013	
Compliant during control	11.19	3.65	3.89 – 18.49	11.19	3.07	33	.004	

Compliant during control * Behavioural Intention	-1.29	.62	-2.50 – -.08	-1.29	-2.09	33	.040

4. Discussion

In this field-based study, the acceptance of in-ground LEDs, an audio message and their combination at a passively protected level crossing was evaluated with participants who regularly used their mobile phones while walking. These interventions were trialled by participants while distracted with a smartphone, both visually and auditorily. The interventions were activated by the approach of the pedestrian and alert participants to look for trains.

4.1 Engagement with mobile devices while walking

Participants self-reported engaging with their phone regularly when walking, as evidenced by the Mobile Phone Problematic Use Scale scores. The mid-point was 121.5 and was well below the 160 dependence cut-off mark (Kalhori et al., 2015), indicating that participants were unlikely to have problematic mobile phone use. Importantly, the vast majority of participants (79.4%) reported having experienced a near-miss (close call) while using their phone while walking, suggesting that they represent a group of pedestrians that could benefit from the interventions.

4.2 Acceptance of the interventions

The results of the study indicated that participants reported favourable perceptions toward the three interventions and intended to use all three, with all of the scores well above the mid-point of 3.5 (range: 5.6 to 6.3). This behavioural intention is higher than similar studies conducted on road interventions, whether in the field or through simulations. Field evaluations of Advanced Driver Assistance Systems were reached an average score of 4.7 (Rahman et al., 2017), while simulations of vibrotactile warning systems for pedestrians were slightly negatively rated (Coeugnet et al., 2017). In-vehicle advanced warning for railway level crossings were seen almost as positively, reaching a 5.5 score (Larue et al., 2015). Overall, the model explained 44% of the variance in intention to use the interventions, which is comparable to the 39% average amount of variance explained by models of acceptance such as the Technology Acceptance Model (Armitage & Conner, 2001). The model indicated that behavioural intention to use the technology was primarily predicted by the constructs of the Technology Acceptance Model, namely perceived usefulness and less so, perceived ease of use. Such findings align with research conducted in the IT domain, and tend to suggest that the acceptance of these technologies could last beyond short-term effects as they are perceived as useful (Szajna, 1996; Wu et al., 2011). In our sample of participants, no effects of gender, age or MPPUS were found.

Behavioural intention to use the technology was found to be positively related to the perceived usefulness of that technology. On the other hand, perceived ease of use only weakly affected behavioural intention, suggesting that perceived usefulness is the primary driver to consider for acceptance of interventions for distracted pedestrians. It may be attributable to the fact that participants generally perceived these interventions to be very easy to use, making the construct of perceived ease of use less variable. However, perceived ease of use has an indirect positive effect on acceptance through its positive effect on perceived usefulness, as found in multiple studies in the literature (Keil, Beranek, & Konsynski, 1995; Szajna, 1996;

Venkatesh & Davis, 2000). Therefore, even though the direct impact of perceived ease of use is limited, it is a factor to consider through its indirect effect on perceived usefulness. These findings align with previous findings with in-vehicle distraction mitigation systems (Roberts et al., 2012), or for drivers approaching railway crossings, where perceive ease of use of in-vehicle and on-road interventions were not found to directly affect behavioural intention (Larue et al., 2015). Some studies have found a stronger effect of perceived ease of use, but they either reflected participants who were obliged or mandated to use a particular system (Brown, Massey, Montoya-Weiss, & Burkman, 2002) or applications that were not safety-critical, such as in-vehicle navigation and multimedia entertainment systems (Chen & Chen, 2009; 2011). Both types differ from the interventions studied here, as they are designed to improve safety, and will be effective only if pedestrians decide to act upon detection of their message.

Importantly, this study showed a link between behavioural intention to use the interventions and actual behaviour. For participants complying during the control, there was no meaningful link between intention and actual behaviour. This can be explained by the fact that individuals who perceive their behaviour as safe are less willing to perceive intervention for safety as beneficial (Puttawong & Chaturabong, 2020). This is also a result of the fact that the relationship is trivial and no importance to pedestrian safety as no change in behaviour is necessary for such participants. Such participants are, therefore, not the target of these interventions. More importantly, this study found a positive association between intention and actual behaviour for participants who are likely to fail to check for trains when distracted. Behaviour, when distracted, was significantly safer when participants expressed positive intentions toward the interventions. Such findings highlight the importance of acceptance by the target users for such interventions to be successfully implemented. It also provides needed evidence in favour of the Technology Acceptance Model and the link between behavioural intention and actual behaviour, at least in the case of participants who have experienced the technology.

The three different interventions trialled in this study were found to differ in terms of behavioural intention through their respective effects on perceived usefulness and perceived ease of use. The in-ground LEDs were considered less useful and less easy to use compared to the interventions containing the audio message.

While the different interventions provided similar information to pedestrians, there may have been some confusion around the in-ground LEDs' message. The perceived ease of use results suggest that participants found the audio message clearer in describing the behaviour expected while entering the crossing (i.e. looking for trains). On the other hand, the lights may have been interpreted as meaning that a train was approaching, while they were designed to inform of the presence of the crossing and the need to look for trains. On that matter, the audio message may have provided clear and direct instructions to the participants (Wogalter, 2006). Participant may not have paid sufficient attention to the static part of the intervention, which reminded to look for trains, aligning with previous outcomes showing that static sign performance is related to their conspicuity and comprehensibility (Charlton, 2006). Similar confusion has been observed with drivers when encountering advanced flashing lights (Larue, Watling, Black, & Wood, 2019; Noyce & Fambro, 1998) whereby it was incorrectly assumed that a train was at or approaching the crossing when a flashing light was observed. This misperception is, however, greater for lights that continuously flash compared to vehicle-activated lights (Noyce & Fambro, 1998). Overall, the lack of difference between the audio interventions with or without LEDs, and the lower perceptions of LEDs suggest that combining the two modalities may not be necessary to convey a clear message to distracted pedestrians.

The better outcomes for the audio warning suggest that improving the design of in-ground LEDs may improve the perception of the usefulness of this intervention, and align it their actual effectiveness in attracting the attention of distracted pedestrians (Larue et al., 2020). This is crucial as presenting the required information the way drivers expect it results in quick and less errors, while poor or unexpected information results in inappropriate and slow reactions (Rudin-Brown, George, & Stuart, 2014).

It is also possible that the lower scores for the LEDs on the Technology Acceptance Model constructs may be due to the trial being performed in day-time conditions. The particular implementation of the system trialled at the crossing used a single brightness level, which was a compromise between the brightness needs for day and night conditions. The lights may have been not sufficiently bright during sunny conditions for participants to find them as useful as the audio message. Using a timer with two different settings for day and night conditions, or a system measuring lighting conditions and adapting to them may also help in increasing the perception of in-ground LEDs. On the other hand, the audio warnings were provided in a quiet environment, which represent ideal conditions for that intervention. Perceptions of the audio interventions may have been less favourable in noisier environments.

Currently, interventions based on in-ground LEDs are more widespread worldwide than audio messages. This can be explained by the fact that visual signage is the primary format for information provided to pedestrians, as well as the fact that audio interventions may only be used at locations with limited traffic. Indeed, it is difficult to target the audio message for each pedestrian approaching, especially when multiple pedestrians are moving through the crossing and the message could be unintelligible if background environmental is excessive (Edworthy & Hellier, 2000). This suggests, however, a need to further educate users on the way they operate and their usefulness, to ensure that users better accept them. Indeed, this study provides evidence that other alerting mediums may be better accepted. Improving perceptions by users may then result in higher chances in modifying pedestrian behaviour (through checking for trains) and better safety outcomes for pedestrians walking while using their mobile device.

The audio warning intervention was found to be resulting in higher behavioural intention, as it was perceived as more useful and easier to use. Adding in-ground LEDs to that intervention was not found to result in any statistical improvements on any of the constructs. It suggests that combining both types of modalities may not be necessary for pedestrians engaged with their mobile device while walking. This is despite the fact that mobile devices can lead to both auditory and visual distraction. Participants experienced these interventions while visually and auditorily distracted, and they, therefore, provided an evaluation that considered both types of distractions. This suggests that participants found an audio message as an effective way of reminding them of the approach of the crossing, independently of the modality of the distraction caused by the smartphone. While some studies have evaluated the effectiveness of in-ground LEDs in attracting the attention of pedestrians visually or auditorily distracted by their mobile device (Larue et al., 2020), no research has currently been conducted to evaluate whether an audio warning would provide similar benefits. It is therefore important to evaluate its effects on behaviour to understand whether the positive perceptions toward such interventions are warranted.

Higher scores on the lapse subscale of the Pedestrian Behaviour Scale – which is indicative of engaging in frequent pedestrian behaviours lacking in concentration – were associated with reduced perception of usefulness of the intervention. This highlights that participants who may be best suited to this intervention through their higher chance of being distracted while approaching a crossing may also be the ones that perceive it as less useful, and may, as a result, not change their behaviour with such intervention. This study also showed that the different modalities of the intervention had different levels of acceptance and, individuals who are inclined to performing lapses might also be more accepting of different modalities. Overall, this suggests a need for education about the need for these interventions for the most at-risk groups.

4.3 Strengths, limitations and future directions

This study is the first to assess recent interventions targeted at attracting the attention of pedestrians distracted by a mobile device when they approach an intersection in terms of acceptance. However, there are some limitations that need to be acknowledged when interpreting the results. The primary limitation of this study concerns the small number of participants involved in trialling the three interventions, particularly the two with an audio message. However, the study employed the widely used Technology Acceptance Model and provided effects that were large enough to be detected with such a sample. Also, the comparison between the three interventions was possible with the use of a within-subject design. Future research should, nevertheless, aim to recruit larger samples through survey methods.

Another limitation is that participants engaged in tasks requested by the researchers, which may not fully represent their actual behaviour in the field. However, this approach allowed to ensure that participants experienced the intervention while distracted, which would be difficult to ensure in observations. For safety reasons, a protection officer was present and wearing a high-visibility uniform. This may have modified the behaviour of participants, but the officer was positioned in a way that was the least disruptive, and he only had to intervene a couple of times when trains were approaching. It is therefore not expected that the presence of the protection officer would modify behaviour significantly.

Only one type of crossing was evaluated, namely a passive pedestrian crossing with a maze. Further research could, therefore, be conducted to confirm whether the reported positive intentions toward this technology also apply to other level crossing configurations (e.g. active crossings) and for road intersections, where similar interventions are also used. Given the worldwide use of mobile devices by pedestrians, studies in other jurisdictions would also be necessary to understand whether such findings apply outside the New Zealand context. Further, the selected sites were in rather quiet environments. This may have rendered the audio messages more conspicuous, and further research would be necessary to ensure that participants' positive intentions would remain in louder environments.

Another limitation is that participants reported an overall evaluation of the intervention, independent of the distractor task that they performed. It would be beneficial to better understand how the modality of the distractor task affects the perception of the different interventions, and this could be done by asking participants to provide their perceptions of the interventions for each distractor condition. However, the results from this study suggest a clear preference for the warning to be provided as an audio message, given that participants experienced both visual and audio distractor tasks.

No evaluation was conducted during the night-time. The interventions based on LEDs are likely to be more conspicuous at night and participants' perceptions may improve under such conditions. However, the approach taken ensures that perceptions were not over-estimated.

It also ensured that a good understanding of perceptions was obtained for day-time conditions, when trains run with greater frequency, pedestrian distraction is more prevalent (peak hours) and the interventions potentially less effective. An interesting finding from this study is that pedestrians who perform more lapses when walking tended to perceive the interventions as less useful. Given that these interventions are particularly targeted at such pedestrians, future research should investigate the perceptions of pedestrians with frequent lapses further to identify ways to increase their perceptions towards such interventions. Finally, this study concerned with three interventions with different modalities (visual, audio, and combined). Future research might examine the acceptance of different flashing light combinations, warning sounds, or message content; preferable beginning with the laboratory conditions but also expanding to include low light, night-time or noisy-quiet conditions.

5. Conclusion

This study has used the Technology Acceptance Model as a framework to gather insight into the acceptance of interventions designed to attract the attention of pedestrians distracted by their mobile device. Unlike most studies using this model, we also investigated whether behavioural intention led to actual behavioural change, providing strong support for the model. Three different interventions were trialled on the approach of passive railway crossings to remind pedestrians to look for trains. The interventions, triggered by the approach of the pedestrian, were in-ground illuminated lights installed in the footpath, an audio message and the combination of both. This study showed that positive behavioural intentions toward the interventions were positively related to changes toward safer behaviour when distracted. This effect was observed for participants who were not always compliant. These participants are the target of these interventions, and these findings show the importance of acceptance by their end-users for safety interventions to translate to improved road safety. Participants exposed to these interventions held positive intentions to use the technology, suggesting that these interventions can potentially be effective in attracting the attention of distracted pedestrians. While the systems trialled in the current study were generally perceived to be useful and easy to use, the in-ground lights obtained lower perception scores compared to the audio message. It is possibly due to the audio warning being a less confusing message provided in a quiet environment. Given that interventions based on in-ground LEDs are more prominent, this study suggests that design improvements may be necessary to improve how they are perceived, which is necessary for this intervention to attain its full potential. Future research should therefore be conducted to identify ways to improve their design. Education of users is also an avenue to increase acceptance and ensure perceptions align with the actual effectiveness of these interventions.

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