Pedestrians distracted by their smartphone: are in-ground flashing lights catching their attention? A laboratory study

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Abstract

Pedestrian distraction is a growing road safety concern worldwide. While there are currently no studies linking distraction and pedestrian crash risk, distraction has been shown to increase risky behaviours in pedestrians, for example, through reducing visual scanning before traversing an intersection. Illuminated in-ground Light Emitting Diodes (LEDs) embedded into pathways are an emerging solution to address the growing distraction problem associated with mobile use while walking. The current study sought to determine if such an intervention was effective in attracting the attention of distracted pedestrians. We conducted a controlled laboratory study (N=24) to evaluate whether pedestrians detected the activation of LEDs when distracted by a smartphone more accurately and efficiently when the lights were on the floor compared to a control position on the wall. Eye gaze movements via an eye tracker and behavioural responses via response times assessed the detection of these LEDs. Distracted participants were able to detect the activation of the floor and wall-mounted LEDs with accuracies above 90%. The visual and auditory distraction tasks increased reaction times by 143 and 124 ms, respectively. This performance decrement was compensated for floor LEDs close to participants, with reaction time improvements by 43 and 159 ms for the LEDs 2 and 1 metres away from the participant respectively, resulting in a performance similar to the one observed for wall-mounted LEDs in the non-distracted condition. Moreover, participants did not necessarily need to fixate on these LEDs to detect their activation, thus were likely to have detected them via their peripheral vision. The findings suggest that LEDs embedded in pathways are likely to be effective at attracting the attention of distracted pedestrians. Further research needs to be conducted in the field to confirm these findings, and to evaluate the actual effects on behaviour at road intersections.

1. Introduction

1.1 Prevalence of distraction

Distraction is a growing road safety concern worldwide. The widespread use of personal mobile devices can increase distraction for all types of road users, including drivers, pedestrians and cyclists. The majority of research in this area has focused on driver distraction, demonstrating that a third of drivers engage in distracted driving (Huisingh, Griffin, & McGwin, 2015), with little research into distraction of other road users.

There are however recent concerns regarding the safety impacts of distracted walking, particularly related to the use of smartphones. Large numbers of pedestrians are distracted at intersections when crossing roads (Mwakalonge, Siuhi, & White, 2015) and at rail crossings (Goodman, 2018). For example, approximately a quarter of all pedestrians observed at 10 Manhattan intersections were engaged in distracted walking behaviour such as talking on a mobile phone, looking at a mobile phone screen, or wearing headphones (Basch, Ethan, Rajan, & Basch, 2016). The use of headphones was the most frequently recorded distracted walking behaviour (approximately 16%) (Basch et al., 2016). Of those engaged in distracted walking, a small proportion (less than 3%) were observed engaging in more than one distracted behaviour (Basch et al., 2016). A similar proportion of distracted pedestrians were observed in a cross-sectional study in Kuala Lumpur that examined pedestrian distraction at non-signalised and signalised pedestrian crossings (Solah et al., 2016). Mobile phone use was again the most common distraction observed (84.8%) (Solah et al., 2016).

1.2 Impact of distraction on safety

As defined by the National Highway Traffic Safety Administration (2010), distraction is a specific type of inattention that occurs when drivers or pedestrians divert their attention from the driving or walking task to focus on some other activity instead. Distracting tasks can affect road users in different ways: visual distraction, when the road user looks away from the road environment; cognitive distraction through the additional mental workload when thinking about something not related to the driving or walking task ;and manual distraction for drivers, when a task requires the driver to take a hand off the steering wheel to manipulate a device for instance.

There has been no research to examine the link between pedestrian distraction and crashes (Coleman & Scopatz, 2016). A meta-analysis by Mwakalonge et al. (2015) suggests that further research is required to quantify how much of a problem distracted walking is, with more accurate and complete pedestrian crash data required to determine the impact of distracted walking on crash risk. While distraction, regardless of its source, is poorly recorded and documented in Australian crash databases (e.g. Bureau of Infrastructure Transport and Regional Economics, 2019), 236 crashes involving pedestrians in New South Wales between 2010 to 2014 identified the use of hand-held mobile phones as a contributing factor (Centre for Road Safety, 2018).

While there has been no research examining the association between distracted walking and crash risk, several studies have examined the impact of distraction on the task of walking itself. Distraction negatively affects the road crossing behaviours of pedestrians, increasing time to cross the road, is associated with inattentional blindness and poor decision making such as crossing at non-designated areas, as well as affecting gait and stride parameters (Coleman &

Scopatz, 2016; Solah et al., 2016). At unsignalised intersections, pedestrians distracted by mobile phones while crossing the street were found to exhibit less safe crossing behaviours than those who were not using a mobile phone (Lin & Huang, 2017; Pešić, Antić, Glavic, & Milenković, 2016), and the use of a smartphone also resulted in altered gaze-scanning patterns including a reduction in the chance of looking for traffic at crossings (Lin & Huang, 2017).

The type of smartphone task has also been found to differentially affect walking and situational awareness depending on the task. Talking on a mobile phone while crossing the street was shown to have the greatest effect on walking behaviour, followed by texting/viewing content (Pešić et al., 2016). That is, pedestrians who were talking on a mobile phone less frequently looked for traffic prior to crossing, less frequently waited for traffic to stop, and were less likely to complete the crossing at a marked pedestrian crossing compared with those who were texting/viewing content, listening to music, or using a phone when crossing the road (Pešić et al., 2016). Those who were texting or viewing content on their phone were less likely to look at traffic while crossing, were more reliant on their central vision to guide safe walking, and those using phone apps were less likely to scan for traffic prior to crossing and were the slowest to cross compared to pedestrians using a hands-free or handheld phone (Lin & Huang, 2017). Individuals using a handheld phone or using phone apps are also more likely to walk following a path with more lateral variability while crossing the road (Sammy, Robynne, Miranda, & Conrad, 2015; Solah et al., 2016).

In addition to visual distractions, auditory distractions can also negatively impact on safe street crossing as shown by Schwebel et al. (2012), in a study conducted in a semi-immersive virtual environment. This study showed that distraction by music or texting was more likely to lead to being struck by a vehicle during a crossing manoeuver than undistracted participants, and that all distractions (talking on the phone, texting, and listening to music) resulted in pedestrians being more likely to look away from the road environment than non-distracted participants. While listening to music might not necessarily mean that a road user is distracted, this study shows that listening to music leads to increased likelihood to look away from the road environment, which has been identified as a consequence of distracted walking (National Highway Traffic Safety Administration, 2010).

Another factor that can influence attentional demands and task performance is the locomotion task being performed. Standing requires less cognitive resources than walking (Woollacott & Shumway-Cook, 2002). When a secondary task, such as a reaction time task is included with the locomotion task, reaction times are slower when walking compared to standing (Abernethy, Hanna, & Plooy, 2002; Lajoie, Teasdale, Bard, & Fleury, 1996; Mazaheri et al., 2014). These findings have relevance to pedestrian safety. At signalised intersections, pedestrians are known to stop while waiting to cross, but checking for traffic prior to crossing is not performed by all pedestrians and is less likely when distracted by a mobile device (Hatfield & Murphy, 2007). As such, understanding an individual's ability to detect any warning device when distracted when walking or standing is an important consideration for improving pedestrian safety.

1.3 Risk perception

It is well known that while drivers acknowledge the increased crash risk associated with using a mobile phone (e.g., Prat, Gras, Planes, Font-Mayolas, & Sullman, 2017), this does not necessarily align with some of their behaviours. That is, several studies suggest road users routinely use their mobiles while driving (Hill et al., 2015; Huisingh et al., 2015; Pope, Bell, & Stavrinos, 2017; Rupp, Gentzler, & Smither, 2016) and that risk perceptions for specific behaviours, such as texting or talking on a handsfree device, may be erronous (Prat et al., 2017). These findings suggest a mismatch between an individuals perceptions and their behaviours.

While not as well studied, similar trends are likely to be present for pedestrian risk perceptions. For instance, one study showed that teenagers did not consider distracted walking as risky, but the majority of these teenagers (78%) perceived it as a risky activity for younger children (Ferguson, Xu, Green, & Rosenthal, 2013). Distracted walking, as a result of reading at phone screen (which included answering questions on the phone), was also found to have a higher level of perceived workload and a greater reduction in environmental awareness than texting. Both were found to elicit a higher workload than picture-dragging apps (Lin & Huang, 2017).

1.4 Advanced warnings

Given the increased prevalence of pedestrian distraction and its likely negative effects on safety, a number of jurisdictions are attempting to mitigate this issue by proactively installing footpath warning lights for pedestrians at various crossing locations. Such interventions have been trialled in Bodegravenin the Netherlands (Sulleyman, 2017), in Augsburg, Germany (Timson, 2016), in Singapore, and in Sydney (Figure 1) and Melbourne in Australia (Potts, 2016) at various road intersections. A similar approach is also being trialled in New Zealand (Figure 1) for railway level crossings (Mackie Research & Consulting, 2016). Mobile phone lanes have also been installed on wide footpaths in Antwerp, Belgium, Chingqing, China, and Kasestsart University in Thailand (Timson, 2016) in an attempt to separate mobile phone walkers from other pedestrians.

Such warning lights aim to attract the attention of distracted pedestrians who are using their mobile phones, who tend to look down rather than ahead, as well as aiming to improve pedestrian behaviour as a whole. They may operate in various ways: they can be continuously lit (Figure 1-left), or alternatively flashing (Figure 1-right); they can be triggered by the signal at the crossing when it is red for pedestrians (Figure 1-left), or by the approach of the pedestrian for crossings with no signals (Figure 1-right).

While these jurisdictions may have evaluated the effects of introducing such warning devices on footpaths, outcomes of the trials have not been publicised, and there has been no systematic and scientific evaluation of the effects of such lights on distracted pedestrians, limiting the ability to understand whether these lights should be installed. Further, there is wide variability in how such lights are implemented in the field. There is therefore a need for an evaluation of these under controlled conditions, where a range of factors can be controlled and manipulated, such as the type of distracting activity performed on the mobile device (e.g. visual or auditory).

Figure 1: Examples of in-ground LEDs installed at a signalised road intersections in Sydney, Australia (left) and at a railway level crossing in New Plymouth, New Zealand (right).

1.5 Study aim

This research aimed to evaluate whether the addition of LEDs located at footpath level is likely to be effective at attracting the attention of pedestrians when performing a visual or auditory distraction task on a smartphone under controlled laboratory conditions.

2. Method

2.1 Study design

A repeated measures design was used to evaluate the effect of distraction on the detection of LED flashing lights positioned at various floor locations in two walking conditions: (1) standing and (2) walking. The LED flashing lights tested aligned with the design presented in Figure 1-right (flashing and activated by the approach of the pedestrian). The LED position factor had four conditions: (1) on the wall (control); on the floor (2) 1 metre, (3) 2 metres and (4) 4 metres away from the participant. The distraction factor had three conditions: (1) no distraction (control); (2) visual distraction; and (3) auditory distraction. Wall-mounted lights were used as a control as the current information provided to pedestrians through signs or signals is as eye level. In the no distraction condition, only the flashing light detection was performed (no dual-task) and participants did not use a mobile device. The order of conditions was counterbalanced between participants.

A sample of 24 participants completed the study. A sample size of 22 was required to detect small to medium effects size effects (f=0.15) on the reaction times during the detection task at a level $\alpha = 0.05$, power 0.9, and a correlation of 0.6 between repeated measurements.

2.1.1 Detection task

The detection task involved detection of randomly activated LEDs located either on the floor (test targets), or at eye level (control). The position of the floor-mounted LEDs was informed by the authors piloting the detection of lights at various distances while looking at a smartphone. This pilot demonstrated that in a laboratory-setting and for these particular LEDs, those located more than 4 meters away from the participant were outside the field of view and very unlikely to be detected while looking down at a mobile phone.

Therefore, four sets of flashing yellow LEDs were used, yellow LEDs being the most commonly used colour in real-world in-ground LEDs devices. Each set consisted of two LED arrays, to the left and right of the participant. These two arrays were 1.2 meters apart, allowing participants to move between the LED arrays without the risk of falling. The first set was placed on a wall, 1.2 metres high and 4 metres from the participant. It was the baseline condition, replicating a scenario where information is provided to pedestrians when looking ahead. The three other sets were placed on the floor, 1, 2 and 4 metres away from the participant respectively (Figure 2).

Participants conducted the detection task six times, each time being a different combination of the distraction condition and the walking condition. For each task, each set of flashing LED lights was randomly activated for five seconds four times, the order being randomised between participants (random permutation), and resulting in a total of 16 activations per test. The left and right LEDs in each a set were activated alternately for one second. When standing, the time-lapse between activations was randomly selected between 10 and 20 seconds (uniform distribution). When walking, a photoelectric sensor activated the lights (random permutation) when the participant was 1 meter away from the first set of LEDs. LEDs were randomly activated on average two times out of three movement detections.

A handheld press button was used for the participant to report detection of the activation of the LEDs.

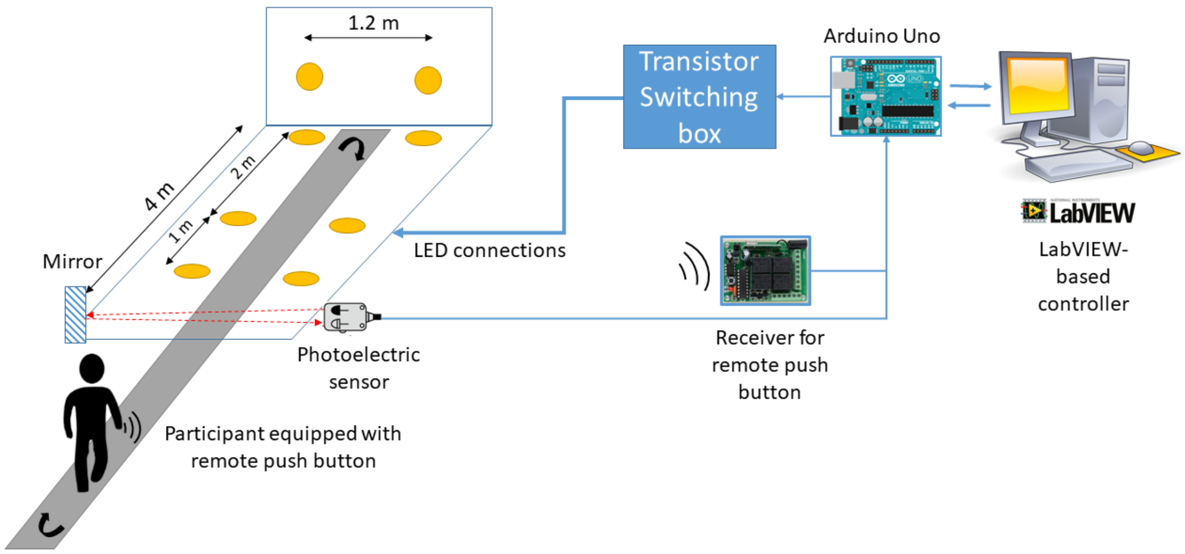


Figure 2: Experimental setup

2.1.2 Distraction tasks

A simple reaction time task was adapted to suit the needs of the current study. Simple reaction time tasks are relatively straightforward in their conception and performance. The current study required a task that sufficiently engaged the participants, providing an analogue for texting on a phone and listening to a headset, while not increasing their cognitive workload to the extent that it might jeopardise their safety while walking.

The visual distraction task was performed on a smartphone (Figure 3) and involved presentation of one of six words (cat, box, pen, desk, note, switch), of which one was designated the target word (cat). Participants were required to touch the screen only when the target word was presented. One of these words was presented randomly every 1.5 seconds and displayed on the screen for 1.0 second. The target word was presented 20% of the time, whereas the other five words were equally likely to appear (16% of the time each).

The auditory task was similar to the visual task, except that the words – the same as those used in the visual distraction task - were not displayed on the screen, but played as a sound by the smartphone equipped with earphones. The sound level was set by the participant to their preferred volume.

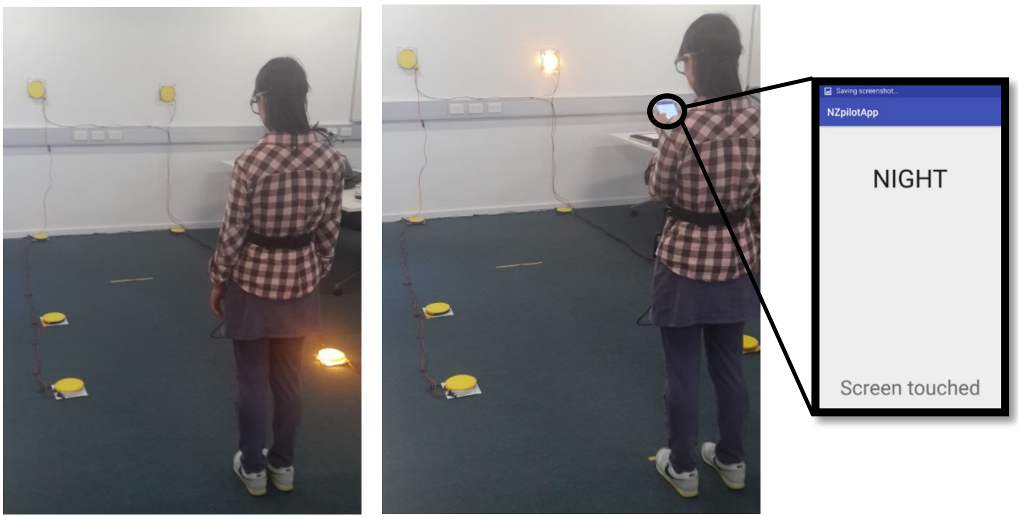


Figure 3: Illuminated ground LEDs; participant equipped with eye tracking glasses. Left: no distraction task. Right: Visual distraction task

2.1.3 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

Participants were healthy adults who were required to be regular users of mobile devices while walking (i.e., three times or more per week). Participants were also required to have no physical impairment with walking and to pass a vision test (i.e., visual acuity and contrast sensitivity test) to ensure the obtained results are affected by poor vision.

They were recruited from the general public in the Brisbane area, using advertising (flyers) in Brisbane and through the university environment, as well as online forums, posting on notices boards, and snowballing effects. Recruitment was stratified to obtain a cohort with approximately equal gender split. Participants were screened to ensure that their visual acuity was at normal levels, and the minimum visual requirements for driving were used as a threshold. Visual acuity was assessed binocularly with participants wearing the spectacles/contact lenses that they normally wore for driving using a standard logMAR chart at a working distance of 3 metres. Participants were required to read the letters as far down the chart as possible, guessing was encouraged and scoring was on a letter by letter basis, with each letter being worth 0.02 long units. Contrast sensitivity was measured in the same testing room using a Pelli-Robson chart at a working distance of 1 metre with a +1.00D lens used to correct for the working distance; scoring was on a letter by letter basis as recommended, with each letter being 0.05 log units. Participants received a $40 incentive at study completion.

Ethical clearance was obtained from the QUT Ethics Committee (clearance number 1700001100).

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 (Figure 3). 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 up to a 60 Hz sampling rate. It provides point of gaze with audio capability to record what respondents are saying as they observe their environments, such as when walking.

2.3.2 Flashing lights

Each set of flashing lights comprised 46 high bright LEDs with a warm colour (12Volt SMD-Light-Dimmer) placed in a 10cm diameter circle. The LEDs were covered by yellow plexiglass. A LabVIEW-based interface was developed to trigger the relevant set of LEDs at the appropriate time, and was run on a PC. The interface controlled an Arduino Uno-based controller, which controlled the switching box (including BD139 transistor) as an I/O module to trigger the selected set of LEDs. For the walking condition, the activation was triggered by a photoelectric sensor. A radio remote push button and a receiver were also used to record responses from the participant (Figure 2).

2.3.3 Smartphone

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

2.4 Procedure

Each laboratory testing session took 1.5 to 2 hours. Before performing the task, participants completed the questionnaires. They then completed the vision assessment binocularly, using their usual optical correction when walking (visual acuity and contrast sensitivity); participants who usually wore corrective lenses or spectacles were asked to wear them during the study.

The eye tracker was then fitted onto each participant and a 3 point calibration procedure completed to ensure both vertical and horizontal accuracy for the recorded point of gaze. Participants were then provided with instructions on the detection task. They were told to report the activation of the lights by pressing as rapidly and as accurately as possible the push-button that they holding in their hand. They practised this task until they felt comfortable with it. They were then introduced to the visual and auditory mobile phone distraction tasks. They were instructed to perform the phone reaction time task as quickly and as accurately as possible, to the best of their ability. In the walking condition, participants were also told to be mindful of their safety. Participants practised this task while performing the detection task until they felt comfortable with it.

Participants were then directed to perform one of the six tasks. For the standing tasks, they stood a meter away from the first set of lights and the sequence of activations was initiated from the computer. For the walking condition, participants walked towards the wall at their normal walking pace – from 5 meters away from the first set of lights (four meters to the photoelectric sensor) to a meter away from the wall (an indication was placed on the floor, see Figure 3). Participants returned to the starting position for the next run, walking forward towards the wall, repeating this sequence until all light activations were complete. In the distracted conditions, they also either performed a visual or audio task with a mobile device. Participants were required to press a push-button when they detected the activation of a set of lights.

2.5 Data Analyses

The following participants' measures were recorded and analysed in this laboratory study:

The analysis of data aimed at evaluating the effect of (1) the walking task, (2) the LED position and (3) the distraction factor (no, visual or audio distraction) on the following dependent variables:

- Engagement with the distraction task, evaluated through the percentage of correct detections of the target word, reaction times (time taken by the participant to tap the screen of the smartphone after the word is displayed or played by the smartphone) and percentage of incorrect detections (non-target words);
- Percentage of correctly detected illuminated LED;
- Reaction time once the lights were activated (where slower reaction times are indicative of poorer performance); and
- Gaze behaviour toward the LEDs, recording whether participants fixated their gaze on the lights when performing the detection task.

Statistical tests were run using Generalised Linear Mixed Models in order to take into consideration the repeated measures design of this study. Software R version 3.4.1 was used. Specifically, the following outcome measures were modelled using Generalised Linear Mixed Models (GLMMs) from a Gaussian (for continuous variables) or Binomial (dichotomous variables) families, while considering the effects of the walking condition (2 levels: walking or standing), location of the LEDs (4 levels: wall, or floor at 3 distances), distractor task (3 levels: no distractor, auditory or visual), as well as all interactions. Given the safety critical nature of the detection of the activation of the lights for the intended application, the distribution of the reaction times was also investigated through the 90^{th} and 95^{th} percentiles. Cronbach's alpha was calculated to assess the internal consistency of the self-report surveys.

3. Results

3.1 Demographics

In total, twenty-four participants completed the study. The mean age of participants was 30.4 years (SD=6.9; range=20-43, 11 male and 13 female, Table 1). The Pedestrian Behaviour Scale of positive behaviours (Table 1) suggests participants reporting several positive pedestrian behaviours as well as performing frequent pedestrian violations and errors. The Mobile Phone Problematic Use Scale mean score (Table 1) was below the mid-point of 121.5 and well below the 160 cut-off mark indicating dependent mobile phone use (Kalhori et al., 2015).

Table 1: Participants' demographics (N=24)

Demographic variable and Proportion/Frequency[a] (%)			
Gender		Highest education	
Male	11 (45.8)	High school	3 (13.0)
Female	13 (54.2)	Undergraduate	4 (17.4)
		Post graduate	16 (69.6)
Activities mobile phone used for			
Phone calls	24 (100.0)	Navigation	21 (87.5)
Texting	23 (95.8)	Banking	17 (70.8)
Emailing	21 (87.5)	Shopping	12 (50.0)
Social networking/Facebook	20 (83.3)	Exercising	5 (20.8)
Entertaining	23 (95.8)		
Yes, had a 'close call' meaning you were almost hit, by a vehicle while walking and using your mobile phone[b]	8 (34.8)		
Yes, hit by a vehicle while walking and using your mobile phone	0 (-)		

[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)
[b] *n* =23 (one participant omitted to respond to that particular question)

Table 2: Self-report measures of pedestrian behaviour, mobile phone problematic use, and technology acceptance of the new pedestrian alerting system. (N=24)

Construct	Mean	SD	Range	Number of items	Cronbach's alpha
Pedestrian Behaviour Scale (PBS)[a]					
PBS Violation Subscale	3.51	1.26	1.00-6.00	4	.82
PBS Error Subscale	3.68	1.12	1.75-5.50	4	.69
PBS Lapse Subscale	1.96	1.18	1.00-5.00	4	.91
PBS Aggressive Subscale	1.53	0.99	1.00-4.67	4	.78
PBS Positive Subscale	3.81	1.07	1.75-6.00	4	.68
Mobile Phone Problematic Use Scale[b]	109.83	40.39	46.00-191.00	27	.94

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

3.2 Visual acuity

All participants had visual acuity above the level required to hold an Australia driver licence, with a mean score of -0.17 logMAR (SD=0.09, range: -0.30 – 0.00). Contrast sensitivity was also assessed and was shown to be normal for all participants, with a mean score of 2.01 LogCS (SD=0.08, range: 1.85 – 2.15).

3.3 Engagement with the distraction tasks

When visually distracted, participants detected 96.4% of the target words, with a mean reaction time of 639 ms (SD=141, Table 3). Participants incorrectly reacted to non-target words only 0.2% of the time. When distracted with the auditory distractor task, participants detected 96.7% of the target words, with a mean reaction time of 1,016 ms (SD=238). Participants incorrectly reacted to non-target words only 0.5% of the time. These differences in reaction times were significant, with the auditory distraction task, being 377 ms longer (t=27.90, d.f.=2242, p<.001), reflecting the difference in modality of the distraction, while detection performance was not affected by the type of distraction (visual / auditory).

Overall, participants engaged with both the visual and auditory distractor tasks in all conditions during the trial and thus were distracted as intended.

3.4 Detection of flashing lights

3.4.1 Accuracy

Almost all flashing lights were detected by participants, regardless of the location of the flashing light, the primary task (standing or walking), or the distraction task, with detection accuracies above 90% (Table 3). Detection accuracy was significantly higher when participants were walking (t=3.97, d.f.=2266, p=.011), and when the LEDs activated were closer to the participant (t=2.38, d.f.= 2266, p=.018). Analyses also showed that visual distraction had a negative effect on accuracy (t=-2.58, d.f.= 2266, p=.010), and that the interaction between walking and visual distraction was also significant resulting in reduced accuracy (t=-2.14, d.f.= 2266, p=.032). There were no significant effects of the auditory distraction task on accuracy.

Table 3. Effects of the walking and distraction conditions and LEDs position on the performance on the distraction task and detection of the activation of the lights

Walking condition	Distraction condition	LED	LED detection task			Distractor task		
			Detection accuracy	Reaction Times (ms) Mean (SD)	Gaze directed at LEDs	Accuracy Target	Accuracy Non target	Reaction Times (ms) Mean (SD)
Standing	None	wall	94.8%	977 (212)	51.0%			
		floor, 4m	94.8%	973 (356)	49.0%			
		floor, 2m	94.8%	993 (359)	27.1%			
		floor, 1m	97.9%	861 (288)	11.5%			
	Audio	wall	95.8%	1170 (402)	34.4%	96.9%	99.6%	1014 (233)
		floor, 4m	95.8%	1057 (226)	40.6%			
		floor, 2m	94.8%	1153 (411)	24.0%			
		floor, 1m	98.9%	1013 (362)	5.2%			
	Visual	wall	92.7%	1242 (530)	24.0%	97.0%	99.8%	632 (133)
		floor, 4m	93.8%	1149 (443)	26.0%			
		floor, 2m	93.8%	1134 (418)	12.5%			
		floor, 1m	94.7%	1016 (377)	1.0%			
Walking	None	wall	96.9%	942 (264)	43.8%			
		floor, 4m	99.0%	910 (421)	47.9%			
		floor, 2m	97.9%	909 (235)	22.9%			
		floor, 1m	99.0%	770 (194)	11.5%			
	Audio	wall	96.8%	1010 (313)	34.4%	94.7%	99.3%	1012 (234)
		floor, 4m	95.8%	1035 (570)	36.5%			
		floor, 2m	97.9%	961 (264)	13.5%			
		floor, 1m	96.8%	876 (226)	6.3%			
	Visual	wall	92.7%	1045 (270)	22.9%	97.3%	99.8%	667 (207)
		floor, 4m	91.6%	1043 (671)	32.3%			
		floor, 2m	93.8%	964 (288)	13.5%			
		floor, 1m	93.7%	876 (346)	4.2%			

3.4.2 Reaction times

Reaction times for all conditions are also summarised in Table 3 and visually presented in Figure 4. Participants detected the activation of the LEDs 107 ms faster when they were walking compared to standing (t=-7.41, d.f.=2163, p<.001).

The introduction of both the visual and auditory distraction tasks resulted in an increase of the reaction time. The increase was more pronounced for the visual task (143 ms; t=7.96, d.f.=2163, p<.001) than for the auditory task (124 ms; t=7.01, d.f.=2163, p<.001).

For the floor LEDs, reaction times decreased for the LED positions closest to the participant (1 and 2 meters away), regardless of the task. Across all conditions, no significant difference was observed for the furthest floor LED compared to the wall LED. Compared to the wall LEDs, a limited improvement was found for the floor LEDs 2 metres away from the participant

(43 ms; t=-2.11, d.f.=2163, p=.035). The improvement was more pronounced for the LEDs 1m away, reaching 159 ms (t=-7.84, d.f.=2163, p<.001); distracted reaction times were at a similar level for the floor LED 1m away as the non-distracted reaction times for the wall LEDs.

In all conditions, 90% of the detections occurred within 1.5 seconds, and 95% of the detections within 2 seconds. However, a few outliers were found, with detection reaching up to 5 seconds from activation. Interestingly, the floor LEDs 1m away were those with the least variability in detection, all of which were detected within 2.5 seconds of activation.

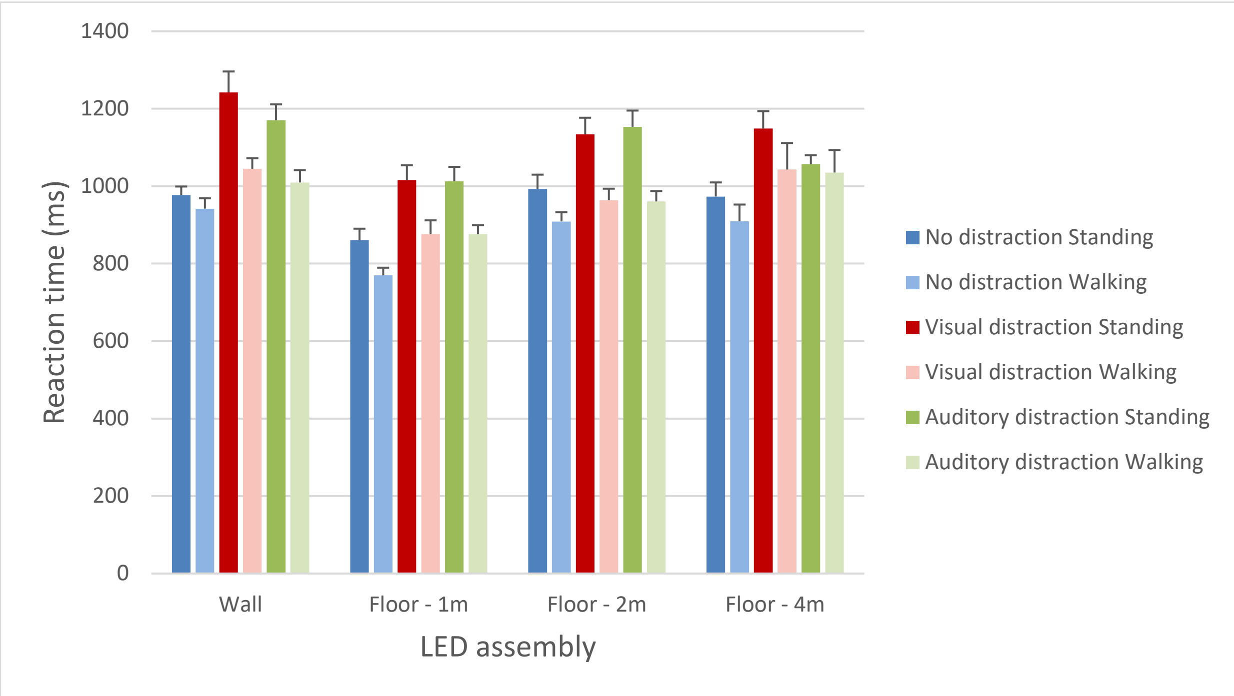


Figure 4: Reaction times for the different tasks and the different LEDs' locations (Standard Error of the Mean (SEM) reported as a vertical bar).

3.5 Eye gaze behaviour

Participants gaze behaviour was recorded during the detection task. Example screenshots from the eye tracker are presented in Figure 5 for each distraction task condition (none, visual, and audio) and LED light condition (activated or not). The red circle indicates the location (i.e., fixation point) of the participants eye gaze.

The gaze analysis showed that without any distraction task, or with auditory distraction, participants predominantly looked straight ahead, directing their gaze towards the LEDs on the wall or to the furthest LEDs on the floor (Figure 5-a). With the visual distraction task, the participants' heads were tilted downwards, as their gaze was directed onto the screen of the mobile phone. A large degree of variability was observed with respect to the ways in which participants held the mobile device, particularly in terms of the vertical position of their head. Some had the device higher and tilted their head down less (Figure 5-c), while others tilted their head down more using the device at a lower level (Figure 5-d). When using the mobile device, either the wall LED (around half of the time) or the floor LED 1m to the participant (the other half of the time) were outside the field of view recorded by the eye tracker. The other two sets of lights were always visible.

Gaze analysis also revealed that while some participants were looking at the flashing lights directly when activated (as in Figure 5-b), most were able to detect the activation of the lights (as demonstrated by them pressing the button), without directly looking at the LED array (as in Figure 5-d and Figure 5-f). In all conditions, more than half of the detections were completed without directly looking at the LEDs (Table 3). This indicates that participants used their peripheral vision to detect the activation of the lights.

There was no significant difference in detection performance regardless of whether participants looked at the LEDs when walking or standing. There was also no significant difference in scanning behaviour (i.e. looking at the LEDs) when performing the auditory distraction task, compared to no distraction task. In these conditions, participants looked at the LED arrays on average 40.9% of the time when detecting the activation of the wall LEDs. The introduction of the visual distraction resulted in a much lower proportion of participants directly gazing at the LED arrays to detect their activation, reducing to 23.4% ($t=-6.39$, $d.f.=549$, $p<.001$).

In terms of location of the LED arrays, no significant difference in gazes towards LEDs for detecting their activation was found between the wall LEDs and the furthest floor LEDs (four meters away from the participant). However, direct gaze at the LEDs was significantly less frequent for the floor LED at 2 meters from the participant ($t=-2.25$, $d.f.=549$, $p<.001$), reaching 21.9% and 13.0% for the no / audio distraction and visual distraction conditions respectively. The effect was even more pronounced with the floor LED 1 metre from the participant ($t=-3.80$, $d.f.=549$, $p<.001$), reaching 8.6% and 2.6% for the no / audio distraction and visual distraction conditions respectively.

4. Discussion

4.1 Detection of activations of lights when distracted

This study investigated the use of in-ground flashing LED lights to attract the attention of pedestrians using mobile devices while walking. It was observed that the use of floor LEDs significantly improved reaction times when detecting the activation of the lights. Importantly, the findings are based on participants who are regular users of their mobile device while walking, and hence who are at risk of engaging in distracted walking. Furthermore, the distractor tasks are representative of the tasks that pedestrians engage in the most when walking (Basch et al., 2016; Ferguson et al., 2013; Safe Kids Worldwide, 2014), namely visual interaction through texting or using apps, and listening to music using headsets.

The participants' accuracy in the distraction task was very high and suggests they were engaged in the distraction task. Consequently, the visual and auditory distraction tasks resulted in significant but various and expected effects. While performing the visual distraction task, participants tended to look for a significant amount of time at the smartphone screen and had their head tilted downwards. Such behaviours are similar to those observed for pedestrians using a smartphone in the field (Basch et al., 2016; Lin & Huang, 2017). In both the visual and auditory distractions, participants tended to not look directly at the LEDs. While able to detect the activation of the lights peripherally for some of the trials, their reaction times increased for the visual and auditory distraction conditions. This reduction in performance on the primary task aligns with those observed during street crossing (Lin & Huang, 2017) or research on virtual environments which included visual and auditory use of smartphones (Schwebel et al., 2012).

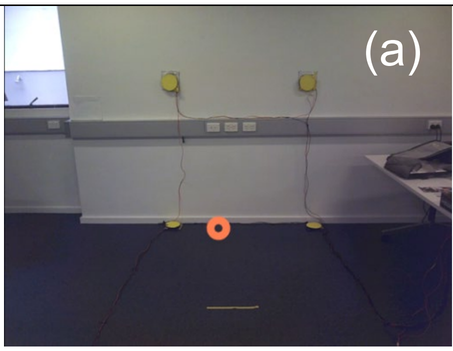
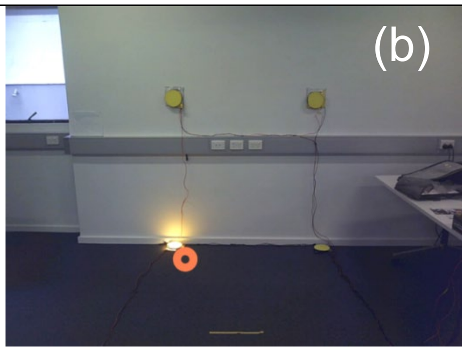
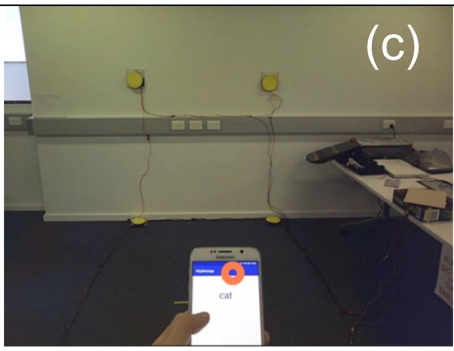
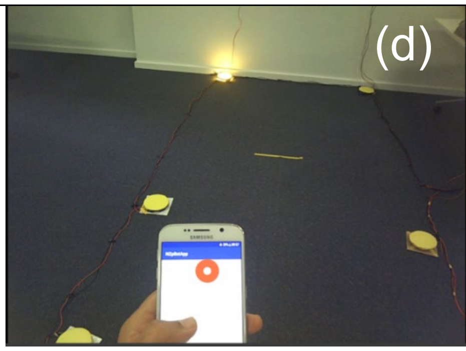
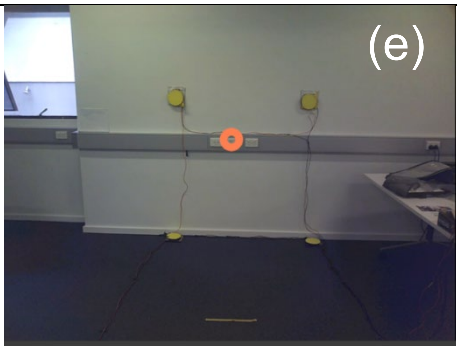
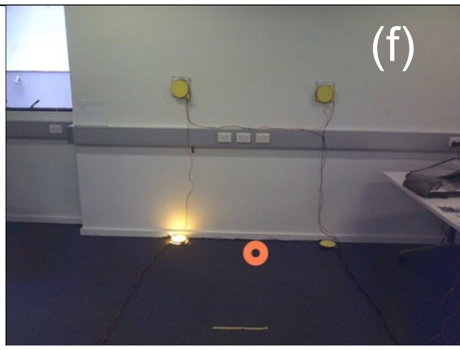
Distraction task	**Light not activated**	**Light activated**
None		
Visual		
Audio		

Figure 5: Screenshots from the eye tracker recording for each distraction condition, with and without LED flashing lights activated

Collectively, these findings provide confidence that the results on the detection of the activation of LEDs reflect those of distracted pedestrians. When distracted, participants almost always detected the flashing LED lights, regardless of whether the distraction was visual or auditory even when there was an associated reduction in scanning of the environment (particularly towards the LEDs). However, participants took significantly longer to detect the activation of lights. Further, eye tracker data revealed that most participants did not need to fixate on the lights to detect their activation, and thus must have relied on their peripheral vision for detection. This suggests that using flashing lights is a way to effectively and rapidly attract attention even when pedestrians are focusing on their mobile device or on their central vision, as reported previously for distracted pedestrians (Lin & Huang, 2017). Importantly, such results were found even when not intentionally looking toward the lights, which is crucial to the effectiveness of such interventions in the field for pedestrians absorbed in a distraction task.

Reaction times were reduced (faster response times) by placing LEDs on the floor as compared to wall mounted LEDs. This improvement was most pronounced similar to the participant (1 metre away), and resulted in a performance while distracted being close to that obtained for wall mounted LEDs when not distracted. It is likely that these findings reflect the relationship between gaze behaviour and stepping while walking, with research showing that walkers tend to fixate the ground around one to two steps ahead (Patla & Vickers, 1997).This suggests that placing lights in-ground could be very effective in mitigating the decrement in performance on the primary task due to the engagement in a visual or auditory task on a smartphone. These laboratory-based findings also provide a useful basis for determining the optimum position of in-ground LEDs in the field in the case of lights indicating the presence of the crossing rather than its state. They could be placed a few meters away to the entrance of an intersection, in order to provide sufficient time for pedestrians to detect the flashing lights and then decide how to react to the warning before they enter the intersection. For lights indicating that the intersection is closed to pedestrians (active signal), lights should be placed at the intersection for them to be targeted at the pedestrians in the most dangerous area. This study also highlighted that such an intervention is likely to be the most effective if activated when the pedestrian is within two meters of the LEDs, as the reaction times were significantly lower for these compared to LEDs placed further away or at eye level.

The outcomes regarding the differences between the walking and standing task suggest that the walking task was not overly taxing in terms of the participants' attentional demands when identifying the wall mounted LED. In fact, a main effect was found for the walking-standing factor; such that participants performed more accurately and had faster reaction times with the detection of the LEDs when walking (i.e., when approaching the LEDs) compared to when standing. However, the participants' accuracy was poorer when walking and completing the visual distraction task. This finding is consistent with several previous studies (Abernethy et al., 2002; Lajoie et al., 1996; Mazaheri et al., 2014) that have demonstrated the combination of movement/activity and the performance of a dual-task, in this case being the visual distraction task, leads to poorer performance outcomes. Importantly for safety outcomes, the floor-based LEDs, regardless of the walking and standing task, when perceived, resulted in quicker reaction times and demonstrated the utility of the ground LEDs for obtaining the participant's attention.

Importantly, engagement in distraction tasks when walking is also likely to result in restricted peripheral attentional awareness. Studies show that increased attentional load for a central task can lead to reduced attention to peripheral stimuli, creating a constricted attentional field of view (Künstler et al., 2018; Lavie, 2006), with both auditory and visual distractors restricting attentional fields, particularly in the inferior or lower field (Wood et al., 2006). In the case of this experiment, the visual distractor task generated a sufficiently demanding load to reduce peripheral awareness for the wall-mounted lights, with faster reaction times for the closer lights. These findings highlight the benefits of having conspicuous warning signals situated on the ground, which is closer to the downgaze fixation that is used for distracting tasks such as when viewing a mobile phone while walking.

4.2 Strengths, limitations and future directions

This study is the first to evaluate 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 which need to be acknowledged when interpreting the results.

First, the study was conducted in a laboratory environment. Lighting conditions in such an environment are likely to result in the LEDs being easier to detect than in the real world. Indeed, external lighting conditions may result in the brightness of the LEDs being insufficient, particularly under bright daylight conditions. Further, no other pedestrians were present to mask the LEDs in this study, which differs from the dynamic environment where they are likely to be installed, being in urban areas with dense traffic on pedestrian paths and roads. Also, the tasks completed in this study may be limited and relatively artificial compared to navigating amongst other pedestrians (e.g. walking towards a wall). It has to be noted that while different light positions were investigated, no consideration was made on the inter-individual variability in field of view, which may affect effects of the position reported here, particularly for young children given their narrow field of view. More broadly, the sample used in this study focused on the demographics known to be the most exposed to distracted walking with mobile phones, but they most likely are not fully representative given the non-inclusion of disadvantaged or impaired participants for instance. Therefore, given the promising findings reported here, further studies need to be conducted in the field and with a broader range of participants in order to confirm that the findings of this study translate to the real world.

The distraction tasks developed for the mobile device in this study have been shown to elicit some degree of distraction as demonstrated by the high level of accuracy and short reaction times, despite their low level of cognitive demand. Importantly, this study has shown that participants were able to perform the task while walking and wearing the eye tracker, suggesting that it can be deployed to the field. This provides confidence that the methodology proposed in this study can be applied in the field in future investigations. However, further investigations should also confirm whether the findings also translate to tasks conducted on mobile phones which would be more cognitively demanding. This could include the interaction between auditory and visual components. Combined with an investigation of the cognitive demands of the tasks that pedestrians engage in when walking with their mobile phones, such research would provide valuable information on how effective flashing lights on the ground would be for different types of phone distractions.

The finding that most participants do not need to look at the lights directly to detect them, the fact that the LEDs 1m to the participants are often outside the field of view of the eye-tracking camera, and the potential obstructions from other pedestrians in a real-world setting suggest collectively that it is not viable to only rely on the eye tracker to measure the detection of flashing lights on the floor during field-based testing. Therefore, other measures should be considered when evaluating whether pedestrians detect the activation of the lights in the field. Such measures could be obtained from pedestrians' verbal feedback, through pushing a button (as in this lab study), or through performance-based measures that focus more on changes in the behaviour of interest as a result of the presence of distractions, such as a reduction in the frequency of risky behaviours observed at road intersections (Lin & Huang, 2017; Pešić et al., 2016).

This study only investigated whether distracted pedestrians were able to detect the activation of lights. Furthermore, unlike real world walking, participants were primed of the activation of the lights, which may have improved their performance while distracted. This study also provided no information on how pedestrians would actually react to the warning provided through activation of the LEDs. Future studies should therefore investigate whether providing such warning in the field effectively attracts their attention and results in safer behaviours from pedestrians after they detect the activation of the lights.

5. Conclusion

Given the increase in use of mobile devices, pedestrian distraction and the potential for injury with crossing roadways the use of embedded illuminated lights installed in the footpath shows potential for effectively attracting the attention of distracted pedestrians within their attentional field of view, whether engaging visually or auditory with their mobile device. This study has shown that pedestrians can detect the activation of such lights while performing a distraction task on their smartphone, and that the LEDs can be detected without the need to look directly at them, through the use of peripheral vision. Detection was most effective close to the pedestrian (i.e. closer to where their attentional field of view is located), with performance at this location similar to that obtained without distraction for warnings placed vertically at eye level. Further research should be conducted to evaluate whether such findings transfer to the field, and whether the level of other distractions within the environment is more varied than in the controlled conditions of laboratory-based experiments. Field-based studies will be important to determine whether this countermeasure is effective in reminding distracted pedestrians of the presence of intersections, and in eliciting safer behaviour, potentially reducing the risk of fatalities and major injuries at road intersections due to distraction.

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References

Abernethy, B., Hanna, A., & Plooy, A. (2002). The attentional demands of preferred and non-preferred gait patterns. *Gait & Posture, 15*(3), 256-265. doi:https://doi.org/10.1016/S0966-6362(01)00195-3

Basch, C. H., Ethan, D., Rajan, S., & Basch, C. E. (2016). Technology-related distracted walking behaviours in Manhattan's most dangerous intersections *Injury Prevention, 20*, 343-346.

Bianchi, A., & Phillips, J. G. (2005). Psychological predictors of problem mobile phone use. *CyberPsychology & Behavior, 8*(1), 39-51.

Bureau of Infrastructure Transport and Regional Economics. (2019). *Australian Road Deaths Database: Fatal Crashes*. Retrieved from: https://www.bitre.gov.au/statistics/safety/fatal_road_crash_database.aspx

Centre for Road Safety. (2018). Get your hand off it. Retrieved from https://roadsafety.transport.nsw.gov.au/campaigns/get-your-hand-off-it/index.html

Coleman, H., & Scopatz, B. (2016). *Pedestrian and Driver Distraction: Overview & NHTSA Prevalence and Risk Study*. Paper presented at the 10th University Transportation Centre Spotlight Conference: Pedestrian and Bicycle Safety, Keck Centre, Washing, D.C.

Deary, I. J., Der, G., & Ford, G. (2001). Reaction times and intelligence differences: A population-based cohort study. *Intelligence, 29*(5), 389-399. doi:10.1016/S0160-2896(01)00062-9

Ferguson, R. W., Xu, Z., Green, A., & Rosenthal, K. M. (2013). *Teens and Distraction: An in-depth look at teens' walking behaviours*. Retrieved from Washington, D.C.:

Goodman, L. (2018). *KiwiRail Distracted users survey*. Retrieved from Christchurch, New Zealand:

Granié, M.-A., Pannetier, M., & Guého, L. (2013). Developing a self-reporting method to measure pedestrian behaviors at all ages. *Accident Analysis & Prevention, 50*, 830-839. doi:10.1016/j.aap.2012.07.009

Hatfield, J., & Murphy, S. (2007). The effects of mobile phone use on pedestrian crossing behaviour at signalised and unsignalised intersections. *Accident Analysis & Prevention, 39*(1), 197-205. doi:https://doi.org/10.1016/j.aap.2006.07.001

Hill, L., Rybar, J., Styer, T., Fram, E., Merchant, G., & Eastman, A. (2015). Prevalence of and Attitudes About Distracted Driving in College Students. *Traffic Injury Prevention, 16*, 362-367.

Huisingh, C., Griffin, R., & McGwin, G. (2015). The prevalence of distraction among passenger vehicle drivers: a roadside observational approach. *Traffic Injury Prevention, 16*(2), 140-146.

Kalhori, S. M., Mohammadi, M. R., Alavi, S. S., Jannatifard, F., Sepahbodi, G., Reisi, M. B., . . . Kasvaee, V. H. (2015). Validation and psychometric properties of mobile phone problematic use scale (MPPUS) in University students of Tehran. *Iranian journal of psychiatry, 10*(1), 25.

Künstler, E. C. S., Penning, M. D., Napiórkowski, N., Klingner, C. M., Witte, O. W., Müller, H. J., . . . Finke, K. (2018). Dual Task Effects on Visual Attention Capacity in Normal Aging. *9*(1564). doi:10.3389/fpsyg.2018.01564

Lajoie, Y., Teasdale, N., Bard, C., & Fleury, M. (1996). Attentional Demands for Walking: Age-Related Changes. In A.-M. Ferrandez & N. Teasdale (Eds.), *Advances in Psychology* (Vol. 114, pp. 235-256): North-Holland.

Lavie, N. (2006). The role of perceptual load in visual awareness. *Brain Research, 1080*(1), 91-100. doi:https://doi.org/10.1016/j.brainres.2005.10.023

Lin, M.-I. B., & Huang, Y.-P. (2017). The impact of walking while using a smartphone on pedestrians' awareness of roadside events. *Accident Analysis & Prevention, 101*(87-96).

Mackie Research & Consulting. (2016). *Kiwirail level crossing safety: Assessment of a prototype active "Look for Trains" sign*. Retrieved from Kiwirail

Mazaheri, M., Roerdink, M., Bood, R. J., Duysens, J., Beek, P. J., & Peper, C. E. (2014). Attentional costs of visually guided walking: Effects of age, executive function and stepping-task demands. *Gait & Posture, 40*(1), 182-186. doi:https://doi.org/10.1016/j.gaitpost.2014.03.183

Mwakalonge, J., Siuhi, S., & White, J. (2015). Distracted walking: Examining the extent to pedestrian safety problems. *Journal of Traffic and Transportation Engineering (English Edition), 2*(5), 327-337. doi:https://doi.org/10.1016/j.jtte.2015.08.004

National Highway Traffic Safety Administration. (2010). *Overview of the National Highway Traffic Safety Administration's Driver Distraction Program*. (DOT HS 811 299). Washington, DC: National Highway Traffic Safety Administration, Washington

Patla, E. A., & Vickers, N. J. (1997). Where and when do we look as we approach and step over an obstacle in the travel path? *NeuroReport, 8*(17), 3661-3665. doi:10.1097/00001756-199712010-00002

Pešić, D., Antić, B., Glavic, D., & Milenković, M. (2016). The effects of mobile phone use on pedestrian crossing behaviour at unsignalized intersections – Models for predicting unsafe pedestrians behaviour. *Safety Science, 82*, 1-8.

Pope, C. N., Bell, T. R., & Stavrinos, D. (2017). Mechanisms behind distracted driving behavior: The role of age and executive function in the engagement of distracted driving. *Accident Analysis & Prevention, 98*, 123-129.

Potts, A. (2016, May 2). Gold Coast City Council considers intersection safety lights to stop smartphone users from being hit by trams. *Gold Coast Bulletin*. Retrieved from https://www.goldcoastbulletin.com.au/news/council/gold-coast-city-council-considers-german-intersection-safety-lights-for-smartphone-users/news-story/3126b465d35ec19af85a638b28a36ae6

Prat, F., Gras, M. E., Planes, M., Font-Mayolas, A., & Sullman, M. J. M. (2017). Driving distractions: An insight gained from roadside interviews on their prevalence and factors associated with driver distraction. *Transportation Research Part F: Traffic Psychology and Behaviour, 45*, 194-207.

Rupp, M. A., Gentzler, M. D., & Smither, J. A. (2016). Driving under the influence of distraction: Examining dissociations between risk perception and engagement in distracted driving. *Accident Analysis & Prevention, 97*, 220-230.

Safe Kids Worldwide. (2014). Teens on the move. Retrieved from https://www.safekids.org/sites/default/files/documents/ResearchReports/skw_pedestrian_study_2014_final.pdf

Sammy, L., Robynne, S., Miranda, P. M., & Conrad, P. E. (2015). Gait Pattern Alterations during Walking, Texting and Walking and Texting during Cognitively Distractive Tasks while Negotiating Common Pedestrian Obstacles. *PLoS One, 10*(7), e0133281. doi:10.1371/journal.pone.0133281

Schwebel, D. C., Stavrinos, D., Byington, K. W., Davis, T., O'Neal, E. E., & de Jong, D. (2012). Distraction and pedestrian safety: How talking on the phone, texting, and listening to music impact crossing the street. *Accident Analysis & Prevention, 45*, 266-271.

Solah, M. S., Deros, B. M., Mohd Jawi, Z., Harun, N. Z., Hamzah, A., & Ariffin, A. H. (2016). The effects of mobile electronic device use in influencing pedestrian crossing behaviour. *Malaysian Journal of Public Health Medicine, Special Volume*(1), 61-66.

Sulleyman, A. (2017, 16 February). Traffic lights built into pavement for smartphone-using pedestrians in Netherlands. *Independent*. Retrieved from https://www.independent.co.uk/life-style/gadgets-and-tech/news/traffic-lights-pavement-smartphone-users-look-down-dutch-pedestrians-netherlands-a7584081.html

Timson, L. (2016, 27 April). German city installs traffic lights on the ground to help mobile phone zombies. *Sydney Morning Herald*. Retrieved from https://www.smh.com.au/world/german-city-installs-traffic-lights-on-the-ground-to-help-mobile-phone-zombies-20160427-gofwag.html

Wood, J., Chaparro, A., Hickson, L., Thyer, N., Carter, P., Hancock, J., . . . Ybarzabal, F. (2006). The Effect of Auditory and Visual Distracters on the Useful Field of View: Implications for the Driving Task. *Investigative Ophthalmology & Visual Science, 47*(10), 4646-4650. doi:10.1167/iovs.06-0306 %J Investigative Ophthalmology & Visual Science

Woollacott, M., & Shumway-Cook, A. (2002). Attention and the control of posture and gait: a review of an emerging area of research. *Gait & Posture, 16*(1), 1-14. doi:https://doi.org/10.1016/S0966-6362(01)00156-4