GETTING THE ATTENTION OF DRIVERS BACK ON PASSIVE RAILWAY LEVEL CROSSINGS: EVALUATION OF ADVANCED FLASHING LIGHTS

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ABSTRACT
Improving safety at railway level crossings remains a priority for the rail industry internationally, as they remain a significant hazard. A high proportion of collisions occur at passive level crossings, because of their high prevalence and their lower effectiveness at mitigating the risks that road users encounter at such crossings. The unreasonable cost required to upgrade them to incorporate active warnings implies that such crossings will remain on the road, and that alternative approaches are required. Drivers tend to make errors at such crossings, and this can be related to approaching such level crossings at speeds that are too high, exhibiting reduced scanning behaviors to look for trains, and not complying with stop signs at the crossing. An alternative approach is to upgrade the advanced signage with active flashing lights activated by road vehicles, aimed at reducing looked-but-failed-to-see errors and reinforcing the behavior expected from road users at such crossings. A field trial was conducted in New Zealand, which evaluated how approach speeds and the visual scanning behavior of 27 drivers, recorded with an eye tracker, changed with such treatments. It was found that the presence of road vehicle activated advanced signage provided a range of benefits for drivers unaware of the presence of a passive crossings, such as increasing drivers' attention to road signs through drivers fixating on signage for longer durations and reduced (slower) approach speeds. Further research is needed to evaluate whether these benefits are sustained over time, and whether this can minimize complacency due to familiarity.

Keywords: Railway level crossing, Safety, Advanced warning, Inattention, Complacency

INTRODUCTION

Human performance and human errors have consistently been major contributors to railway accidents. After decades of safety improvements at level crossings, accident rates have decreased; however, the human factors leading to them have remained the same (*1*). This trend is unlikely to continue without alternative interventions. As level crossings remain a significant hazard, improving safety at level crossings remains a priority for the rail industry internationally. Between 2004 and 2013, railway level crossing incidents fell by 35% in the US (*2*). However, the trend has been increasing since 2009 with increased traffic volumes, with approximately 2100 collisions still occurring at railway level crossings every year (*2; 3*). These collisions result in an average 250 fatalities every year, highlighting that motorists are 20 times more likely to die when colliding with a train as compared to a road vehicle (*4*). The number of injuries at level crossings has also followed a similar trend, and around 725 injuries are recorded every year. Similar trends are observed in other parts of the world, such as Australia and New Zealand (*5-7*).

The large proportion of level crossings being passively protected (only a stop sign or give way sign), combined with their lower effectiveness in mitaging road users' risks at passive level crossings when compared to their active counterparts (when road and rail traffic volumes are taken into account) (*8*) results in a high percentage of fatalities occurring at passive crossings. The current approach to reduce risk at passive level crossings is to grade separate (replace by bridge or tunnel), close the crossing, or install active warning devices. However, the cost of such approaches for level crossing with low traffic and in rural environments cannot be justified, and only a subset of level crossings has been treated given limited funding (*9*) .

Trains cannot be stopped as easily as cars and need large distances to come to a halt. Level crossings are therefore governed by a simple rule: the road user must give way to trains. Almost all collisions are the result of the road user failing to obey this rule (*10*). At passive crossings, the road user is therefore expected to (i) detect the presence of the crossing, (ii) detect the presence of a train, and (iii) appropriately decide whether it is safe to proceed through the crossing by estimating the train's speed and arrival time at the crossing. Research has shown that drivers can make errors on each of these tasks, either intentionally or unintentionally. Overall, the evidence suggests that of all the driver-related factors, unintentional errors are far more commonplace than deliberate violations (*11-14*). The main factors leading to such errors are: insufficient sighting distances, or limited conspicuity of the warning signs and/or approaching train; drivers' lack of awareness of the required response to passive crossing warning signs; drivers' inability to correctly assess if sufficient time is available to safely complete the crossing (*15*), particularly due to poor ability to estimate the speed of trains as they approach (*16*); inattention as a result of complacency due to low expectations of encountering a train (*17*), or distraction (*18*); and the so-called "looked-but-failed-to-see" error (*10*), where drivers fail to identify hazards despite looking at the hazard's source, largely due to limitations in human information processing.

Driver behavior at passive level crossings has been extensively studied, particularly in Australia: a significant proportion of drivers tend to approach level crossings too quickly (*19-21*); compliance levels tend to be considerably lower than at active crossings (*19; 22*) as a result of reduced driver attention towards passive warning signs; and drivers tend to exhibit limited active search for trains while approaching crossings, as suggested by the reduced amount of head movements toward rail tracks (*21; 23; 24*). While drivers tend to look towards the advanced signage on the approach of level crossings, no research has assessed whether the poor driver behavior observed at level crossings is a consequence of a problem of maladaptive behavior (*25*) with drivers not understanding what they need to do at crossings, or a looked-but-failed-to-see error as suggested by Rudin-Brown, George and Stuart (*10)*. Tung and Khattak (*18)* have also shown that distraction is prevalent at railway level crossings in the US, reaching 30% on average, and resulting in similar risky approaches at crossings. With increasing road and rail traffic volumes, of the order of 35% in recent years in New Zealand for instance (*26*), the trend of increasing collisions at level crossings is likely. This suggests that alternative approaches should be investigated.

Transport agencies provide guidelines for signage at passive level crossings. The approach to passive level crossings is required, in most circumstances, to be equipped with static advanced warning signs (*27*). The Railroad-Highway Grade Crossing Handbook from the U.S. Federal Highway Administration (*28*) recommends that active advance warning systems be installed where approaching drivers are unable to see the railway crossing signal until they have passed the decision point. Similar recommendations exist in Australia for road intersections (*29*): flashing lights, installed in conjunction with advanced warning signs, should be installed at particularly hazardous intersections.

The high level of unintentional errors at passive level crossings (particularly in terms of stopping and actively looking for trains) raises the question of whether such active warnings should be used on a broader scale to attract the attention of road users as they approach level crossings, which are intersections with a significantly higher risk than road intersections. The effectiveness of such active advanced warning for road intersections suggests this. The majority of research into the effectiveness of this approach has occurred in the United States, and has focused on advanced warning at high-speed junctions. While early research conducted in rural Ohio (*30*) was not very positive, with higher vehicle approach speeds observed when the flashing lights were inactive, more recent work has shown reduction in severe crashes with advanced warning flashing lights on vehicle crashes at high-speed intersections in the U.S. (*31; 32*) and in Australia (*33*). The latter also highlighted a reduction of crashes involving heavy vehicles, which are known to be particularly at risk at level crossings. This is further supported by the study by Abdel-Rahim et al. (*34)* which has shown that increasing the conspicuity of level crossings with highly reflective warning signs resulted in fewer crashes at passive crossings, particularly at nighttime.

This alternative and affordable approach is currently being considered by the rail industry in New Zealand (*26*), with an effort to upgrade the advanced signage of passive level crossings with active flashing lights activated by road vehicles. This aims of this approach include both (i) increasing the conspicuity of the level crossing earlier for drivers, to reduce looked-but-failed-to-see errors, and (ii) indicating the behavior required by drivers, i.e. to stop and look for trains. The cost of such an approach represents a fraction of those involved in upgrading a level crossing to an active warning, as there is no need to interface this warning signal to rail signaling, and does not require the same safety integrity levels, leading to reduced redundancies in the design of the warning equipment. If effective, it can help in treating a larger number of level crossings, which would have otherwise remained with their current passive signs. Therefore, this study aimed to evaluate the changes in driver behavior with such active advanced warnings at passive level crossings. The study particularly focused on evaluating how approach speeds and gaze behaviors are modified with such treatments.

METHOD

Trial crossing with advance flashing lights

The trial crossing, with the installation of advance flashing lights, was located at one rural passive railway crossing near Marton, New Zealand. The crossing comprised traditional advanced signage, warning drivers that they were approaching a passive railway crossing, and a set of two yellow alternate flashing lights (100 mm diameter) which were activated when road vehicles approached. A radar detected vehicle movements approaching within 60 meters of the sign, and activated the lights for 4 seconds on detection of movement, regardless of whether a train was approaching or not. This amount of time was sufficient for the lights to be activated until drivers passed the activated warning sign. Yellow lights were used to provide a warning of the presence of the level crossing, and contrasted with the red lights used at active crossings to indicate the approach of a train." A message to 'Expect Trains' was also included in the advanced signage warnings.

Comparison crossings

Two similar railway crossings were selected as comparison sites and were located approximately two kilometers away. Similarities between the trial and control crossings included: same road signage (except for the advanced flashing lights), 90-degree intersections, reduced visibility during the approach, and with one side having a long, straight approach, and the other side a short approach (due to the proximity of a T intersection).

Experimental design

The field testing used a repeated measures design with all participants completing the daylight condition, and one third of participants also completing the night-time condition. Two within-subject factors were considered:

1. Level crossing type: standard passive level crossing with a stop sign (control), and a passive crossing with advanced flashing lights activated by the approach of a road vehicle (trial); and
2. Lighting condition: day (27 participants) and nighttime (11 participants).

Driving route

A one-hour driving route was created (see Figure 1). This route started and ended at the Marton public library. The route first headed East, to allow participants to become familiar with the vehicle and the equipment. They drove through a variety of roads and intersections within and outside of the town of Marton, including roundabouts, stop intersections, give way intersections and active level crossings. Participants generally approached the first trial crossing around 20 minutes after starting the drive. The route involved travel through the control and trial crossings four times, twice in each direction.

Participants

Participants were healthy adults who were regular licensed drivers. They were recruited from the general public in the Palmerston North area.

Recruitment was stratified to obtain a sample with equal gender split and a range of ages and driving experiences. However, due to the small sample size, no direct comparisons were made between demographic groups. All participants completed a vision screening to ensure that they met the minimum vision requirements to hold a private driving license.

Ethical clearance was obtained from the QUT Ethics Committee (clearance number 1600000946).

Materials

Vehicle

A dual-control vehicle was used to drive the route, with an accredited driving instructor seated in the passenger seat to monitor safety of the vehicle at all times. The vehicle was an automatic 2007 Hyundai Accent dual control car. A pre-programmed GPS (DriveSmart 60; Garmin) provided directions to drivers to ensure consistency in the route.

Eye tracker

The ASL Mobile Eye-XG eye tracker was used to record participant's gaze behavior while driving. This eye tracker consists of lightweight goggles, and comprises two cameras each sampling at 30 Hz: a forward-facing scene camera and an eye camera that captures the infrared corneal reflection and pupil position of the right eye. A calibration procedure, which determines where gaze is located within the scene, was performed at the beginning of each drive. The eye tracker provides highly accurate points of gaze position to identify what participants fixate on or gaze at in the environment, with a tracking accuracy of 0.5 to 1.0° (*35*).

Smartphone

The vehicle was instrumented with a GPS (Samsung S4 smartphone) to obtain the position and speed of the vehicle every second during the driving task. An app was developed to record the details of the drive and to send the information from the GPS to a laptop synchronized with the eye tracker.

Synchronization interface

The software RTmaps version 3.4.10 was installed on the computer that was linked to the eye tracker. This software was used to ensure a unique recording time for the different devices.

Procedure

In the first session, participants completed the consent form and demographic survey. A vision screening was performed, assessing visual acuity and contrast sensitivity, to ensure participants had normal vision, using their habitual optical correction for driving, if required and met the visual standards for driving. Participants were not informed of the location of the study until they attended their driving assessment sessions and were not informed of the purpose of the study until after they had completed the study.

The driving instructor provided his dual brake automatic vehicle, which was driven by all participants. At the start of each session, researchers met participants and the driving instructor in Palmerston North.

Day sessions commenced at 10am or 2pm. Travel time to Marton required approximately 50 minutes of driving each way (driven by the driver instructor and one researcher). On arrival in Marton, one participant prepared for the first driving session and the other was informed that they were required to meet in one hour for their driving session.

Night sessions included one participant, with the research team and the driving instructor travelling together in the driving instructor's vehicle from Palmerston North to Marton. The first week of sessions commenced at 7:30pm and the second week at 8:30pm to ensure sufficient darkness with changing sunset times. Each night session was timed so that it was dark soon after arrival in Marton so that the night-time driving session could commence as soon after arrival as possible.

After arrival at the set-up location in Marton, the participant put on the eye tracking glasses and the eye tracking equipment was calibrated using a five-point calibration board held in front of the car by a researcher with the other researcher adjusting the eye tracking glasses. The smartphone with the GPS, and the synchronization between equipment were then started.

At the commencement of each driving session the participant was informed to drive as they normally would and that any traffic infringements resulting in fines would be required to be paid by themselves.

All driving sessions followed the same route which took a period of approximately one hour. During the drive the driving instructor was seated in the passenger seat and could use the dual brake pedal if required for safety and the two researchers were seated in the rear seats of the vehicle with the equipment. While the presence of researchers may have influenced participants' behavior, this approach was necessary for the safety of the participant. Importantly, participants were aware that the purpose of the research was not to assess their driving ability and researchers were present for all of the crossings, so the effect is likely to have had a limited impact on their behavior when approaching the various crossings."

Before each intersection, participants were informed to turn left/right or drive straight ahead. The instruction was provided 500 meters in advance of the intersection. The GPS was used by one researcher in the rear of the vehicle to ensure that each directional instruction was provided in an accurate and consistent manner for all participants.

The study route started and finished at the same location. At the end of the driving session, the researchers assisted the participant with removal of the eye tracking equipment. The same protocol was followed with the second participant during the day sessions. Participants who undertook a night and day drive completed the survey after their second drive only.

At the end of their participation, drivers were thanked, paid a NZD120 incentive and signed the receipt form. Participants and the research team then returned to Palmerston North. They were also asked to keep the nature of the study confidential until the conclusion of the data collection.

Data analysis

Measurements related to the level crossing included the approach speed of the vehicle (km/h), the distance to the crossing (m), and the amount of time stopped at the crossing (s). The following aspects of participants' eye tracking and gaze were recorded: number of fixations and total time spent fixating the relevant signs; time to first fixate relevant signs when approaching the level crossing; and the number of times and duration spent actively looking for trains (i.e. gazes at the rail tracks), and at what moment (during the approach, while stopped at the crossing, or while traversing the crossing).

Generalized Linear/Additive Mixed Models were used to analyze the data from this repeated measures design, using the R system for statistical computing (version 3.3.2). The analyses assessed the effect of the crossing (advanced flashing lights vs. control) and lighting condition (daytime vs. nighttime) on gaze and level crossing approach behaviors. The level of significance chosen for the study was set at $\alpha=0.05$. The participant sample size was chosen to reach a 0.9 power for large effect sizes.

RESULTS

Participant demographics and visual acuity

Twenty-seven participants (14 females, 42.7 ± 13.0 years old) completed the study. One participant failed to stop at the first encountered level crossing, thus the driver instructor was required to provide feedback to this participant that they needed to stop at the following crossings. Given that this participant was provided feedback on their driving behavior by the driver instructor (which was not the case for the other participants), it was considered invalid to evaluate the effects of the trialed signage for this participant, who was therefore not included in the analysis.

Participants had normal binocular visual acuity, better than 6/6 Snellen equivalent (mean -0.07 (0.08) logMAR), and had normal levels of contrast sensitivity (mean 1.96 (0.12) logCS).

When wearing the eye tracking glasses, participants did not experience vision restrictions when driving and only two participants reported minor discomfort when wearing the glasses for an extended period.

Distance to the advanced signage at first fixation

The distances from the approach sign where drivers first fixated the crossing signs are reported in Table 1 for the control and trial level crossings for the 26 participants who completed the field-based component of the study appropriately.

Statistical analysis showed that drivers first looked at the approach signage closer to the sign when they approached the crossing from the short road section (47.5 versus 132.2 m; t=-6.36, df=46, p<.001). Drivers were also found to look at the sign later the second time they approached a particular crossing during day time (89.1 versus 132.2 m; t=-2.95, df=46, p=.005), but earlier at night (145.6 versus 132.2 m; t=-2.56, df=46, p=.014). No significant differences were found overall in the distance at which drivers first fixated the control and trial signage (189.8 versus 219.0 m; t=-1.70, df=45, p=.096).

Total amount of time spent looking at the advanced signage

The total duration of the fixations on the approach sign is reported in Table 1. This duration was 0.78s on average for the control approach signage, and 1.60s for the active advanced signage trialed, representing a statistically significant increase by 0.84s (t=3.93, df=134, p<.001). There were no effects found for time of day, approach section type, the repetition of driving through the same level crossing, or any of the first order interactions between factors.

Duration of longest gaze at the advanced signage

The duration of the longest single gaze on the approach signage is reported in Table 1. The longest gaze on the approach signs was 0.52s on average for the control signage, and 1.0s for the trial signage, which is 0.51s longer (or double) compared to the control (t=1.77, df=134, p<.001). There were no effects found for time of day, approach section type, the repetition of driving through the same level crossing, or any of the first order interactions between factors.

Slowing down behavior

Approach speed profiles were obtained for each level crossing and each time of day condition (see Figure 2), and modelled using Generalized Additive Mixed Models (GAMMs). The parametric analysis of the GAMMs showed that drivers approached level crossings on average 1.5 km/h slower under night-time conditions for the control crossings (t=-4.04, p<.01), but 2.7 km/h faster at night with the trial active signage (t=2.66, p<.01). The second time they approached a stop sign crossing, their speed was on average 1.5 km/h slower (t=-6.14, p<.01), an effect which was not observed for the trial signage.

The smooth terms part of the GAMMs analysis showed that there were interaction effects between the distance to the crossing and the ‘Expect Trains’ (trial) signage (p<.01), the short approach section (p<.01), the long approach section (p<.01), and the night-time condition (p<.01). The model explained 94.8% (adjusted R squared) of the variance of the approach speed profile. It should be noted that the short approach was longer in the case of the trial site; however, approach speed 100 meters to the crossing were similar, allowing a fair comparison.

The main effect of the active advanced (trial) signage was an early deceleration during the long approach in the day. The magnitude of this early speed reduction during the approach can be seen in Figure 2, which compares the control and trial level crossings. Night-time driving resulted in speed reduction of a smaller magnitude.

Amount of time stopped at crossing

Changes in stopping behavior at the railway crossing were evaluated through the length of time drivers stopped; this duration is reported in Table 1. Given that all participants stopped, except for the participant for whom the driver instructor intervened given the risk posed by such behavior (and who was excluded from the analysis), stopping compliance was not considered.

Statistical analysis with GLMMs showed that, when considering the correlation between participants' level crossing approaches, drivers stopped at the trial level crossing for a shorter time than at the control (2.15 vs 2.51s; $t=-2.47$, $df=228$, $p=0.014$). This corresponds to a decrease of 0.36s. The analysis also revealed that participants were stopping for shorter times further into the drive. The amount of time stopped was found to decrease by 12 milliseconds for every minute of driving in this experiment ($t=-1.98$, $df=228$, $p=0.049$). Towards the end of the drive (after an hour of driving), participants stopped at the level crossings 0.72 seconds less than at the start of their drive. There were no effects found for the time of day, the length of the approach road, the repetition of going through the same level crossing, or any of the first order interactions between factors.

Amount of time looking for trains

The amount of time drivers spent looking for trains is reported in Table 1. This metric has been extracted for two predefined zones: during the approach to the crossing (where the visibility of the track may be reduced, and the sighting distance might not be appropriate for taking an informed decision about the presence of a train), and at the crossing (where the sighting distance is appropriate for detecting the presence of an approaching train).

Statistical analysis with GLMMs showed that the amount of time drivers spent looking towards the rail tracks for trains when approaching the crossing, was on average 1.8s for the control site with the long approach. Compared to this condition, participants looked for trains for a longer duration in the case of the short approach to the control signage, with a 0.9s increase ($t=3.94$, $df=173$, $p<.001$). This effect was less pronounced with the trial signage, with a smaller increase of 0.2s ($t=3.06$, $df=173$, $p=.003$). At night, they looked for trains for a shorter duration, with an overall reduction of 0.6s ($t=3.94$, $df=173$, $p<.001$). No other effects of the trialed signage were found during the approach of the crossing.

The analysis of the amount of time drivers spent looking for trains when at the crossing shows that drivers were looking toward the rail tracks 4.2s on average at the control crossing. The introduction of the active trial signage resulted in a 0.3s increase in this duration ($t=1.95$, $df=218$, $p=.052$). While this did not strictly reach statistical significance, this result shows a trend for longer time spent looking for trains when at the crossing with active signage. There were no statistically significant effects found for the time of day, approach section type, the repetition of going through the same level crossing, or any of the first order interactions between factors.

DISCUSSION

In this on-road study that involved the analysis of 26 drivers' behavior, the effects of an advanced trial signage activated by road vehicles during their approach of a passive railway crossing were evaluated. Effects on drivers' gaze at the sign itself and toward the rail tracks while at the crossing, as well as driving behavior in terms of speed and stopping were considered.

The findings showed that drivers first looked at the advanced (trial) flashing lights from a similar distance as the standard advanced signage at the control crossings. However, the first time they encountered the trial sign, they looked at it from a longer distance than the control. The sign was positioned before any other cue regarding the presence of the level crossing ahead was evident, and this suggests that drivers were attracted to the trial signage at an early stage of their approach to the crossing. This is a positive outcome, as it may have resulted in drivers preparing to stop at the crossing earlier. This finding was not observed for the short approach, but this could be due to the difference in the length of approach between the trial and control sites.

Participants looked at the trial sign for twice as long as they did the approach signage at the control sites. This demonstrates that drivers were paying more attention to this sign, and that the sign was successful at attracting drivers' attention. It is not possible to ascertain from this study whether this increased time was due to the sign itself (attraction to the sign from the flashing lights) or its novelty (drivers looking at the sign for longer to extract information). This could have been due to drivers needing more time to read the sign in order to extract meaningful information from it. However, the fact that similar fixation durations were found when participants approached the crossing subsequently, suggests that this difference could be largely due to the sign itself. It is difficult to evaluate whether the sign itself or its activation resulted in this increased fixation duration.

The analysis of the longest gaze duration at the active approach sign showed that, while drivers looked at the sign for longer, they still spent less than two seconds fixating on the sign at each gaze, suggesting that the sign does not create distraction from the main driving task of scanning the road ahead.

As drivers approached the level crossings, they looked for trains for longer periods of time during the short compared to the longer approaches. However, this finding was less pronounced when the active (trial) signage was present. This is likely to be due to the higher visibility of the tracks when travelling southward, and the fact that the approach was very short at this site and drivers were more focused on fixating on the active (trial) signage.

The study also showed that the advanced activated (trial) signage for level crossings did not result in drivers increasing their checking for trains during the approach to the crossing (where the sighting distance may not have been optimal) during either daytime and night-time conditions. Rather, the study suggests that drivers spent more time looking for trains when at the crossing, which is the location where sighting distance is optimal, to make an informed decision, with this latter finding almost reaching significance. This difference was found for both daytime and night-time conditions. This change, while positive, appears to be limited, and this highlights the importance of education for such advanced warning signs to convey, not only the presence of the crossing ahead, but also the need to look for trains while stopped at the crossing.

Drivers slowed down significantly earlier with the activated advanced (trial) signage in the case of the long road approach. However, while they slowed down earlier, their deceleration stopped in the middle of the approach, with the final approach speed at the trial crossing being similar to that of the control crossings. This suggests that drivers prepared to stop earlier at the trial level crossing, and conducted their preliminary search for trains at a slower speed during the approach to the crossing. This also suggests that they were able to assess the situation in a slower, and hence safer way, having more opportunity to stop the vehicle if needed.

In general, drivers completely stopped at all of the control passive crossings encountered in this on-road study. This can be explained by the reduced visibility of the rail tracks as drivers approached the crossings, and hence their limited ability to evaluate whether a train was approaching prior to them arriving at the crossing. Drivers tended to stop for shorter periods each time they drove through all of the passive (control) level crossings as the experiment progressed. This shows that drivers spent less time looking for trains while being completely stopped at the crossing. In fact complacency, due to the reduced likelihood of encountering a train, developed in participants quite rapidly, even though participants were unfamiliar with the control and trial locations, and were being monitored in the vehicle throughout the experiment. This negative effect was found to be stronger with the trial activated advanced signage, suggesting that this new sign might not be effective at reducing complacency when it is installed over a longer period of time. Indeed, while the current study focused on short-term effects, further research is imperative to evaluate whether the beneficial effects of such advanced warning signs are maintained over extended periods of time.

The eye tracking data suggested that drivers did look at the trialed signage for a longer period of time compared with the control advanced sign. Such longer gaze duration suggests that the new signage did atract the drivers' attention, given that longer gaze durations relate to increased attention (*36; 37*). Such signage could therefore be effective at attracting the attention of drivers, and this could mitigate the effects of distracted driving at railway level crossings. However, drivers' attention to road signs has been shown to depend on a range of factors, including age and driving experience, thus further research is required to confirm whether such effects are dependent on drivers' demographics. Indeed, it is important to ensure that the positive effects observed for the drivers in this study are also extended to those who are the most likely to make errors or to be complacent at level crossings.

In addition to the evaluation of this particular warning signage for passive level crossings, this study has developed a novel approach using eye tracking technology to evaluate the effectiveness of road signs, and could be used by road agencies as a criterion when evaluating new road signs. This methodology could also assist with the identification of road signs that are ineffective and should be removed, as well as evaluating new road signs before they are included in the MUTCD.

CONCLUSION

Road vehicle activated advanced signage can provide a range of benefits at level crossings for drivers unaware of the presence of a passive level crossing, such as attraction of drivers' attention to road signs, gaze behavior and speed choices. This was observed even though the level crossings selected already had high compliance rates. The positive effects of the signage might be even larger at level crossings with low road rule compliance. This study only focused on the short-term effects of the active signage, involving drivers who were unfamiliar to the presence of the control crossing and the trial signage. Further research is imperative to evaluate whether the beneficial effects of such advanced warning signage are maintained over extended periods of time. If so, such signage could help in reducing complacency at level crossings, factor known to contribute to crashes. If the activated sign was shown not to be effective as a long-term intervention, it would still have value in being installed as a short-term intervention that could be relocated between sites of interest, to attract the attention of drivers unfamiliar with a level crossing or distracted while approaching the crossing, or to remind complacent drivers of the potential arrival of trains.

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Author contribution statement

The authors confirm contribution to the paper as follows: study conception and design: Larue, Watling, Black, Wood; data collection: Larue; analysis and interpretation of results: Larue, Watling, Black, Wood;

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Figure 1: Trial site (Marton, New Zealand) and itinerary (Yellow stars: control level crossings; Green star: trial level crossing, Orange arrow: start and end of the itinerary)

Figure 2: Approach speed profile

Table 1: Effects of the active advanced (trial) signage compared to the traditional (control) sign (Standard Deviation in brackets)

		Long road approach		Short road approach	
		Day	**Night**	**Day**	**Night**
Distance to the advanced signage at first fixation (m)	Control	98.4 (63.5)	189.7 (75.0)	51.9 (24.5)	96.3 (75.7)
	Trial sign	119.5 (50.1)	95.0 (62.4)	24.8 (24.8)	24.3 (24.4)
Total amount of time spent looking at the advanced signage (s)	Control	0.66 (0.6)	1.17 (1.0)	0.68 (0.9)	0.92 (0.8)
	Trial sign	1.59 (1.6)	2.03 (1.4)	1.67 (1.6)	1.44 (1.0)
Duration of longest gaze at the advanced signage (s)	Control	0.39 (0.2)	0.76 (0.7)	0.62 (0.9)	0.55 (0.4)
	Trial sign	1.06 (1.3)	1.14 (0.6)	1.03 (0.9)	0.96 (0.6)
Amount of time stopped at the crossing (s)	Control	2.3 (1.5)	2.4 (1.5)	1.9 (1.2)	2.2 (1.3)
	Trial sign	1.6 (1.2)	1.9 (1.1)	2.0 (1.7)	1.7 (1.2)
Amount of time looking for trains - During approach (s)	Control	1.68 (0.91)	2.1 (1.32)	2.83 (1.93)	1.95 (1.04)
	Trial sign	1.33 (0.58)	1.35 (0.86)	1.32 (0.21)	1.71 (0.73)
Amount of time looking for trains - At crossing (s)	Control	4.05 (1.66)	4.21 (1.67)	4.00 (1.72)	4.54 (1.68)
	Trial sign	4.54 (1.66)	4.30 (1.65)	4.42 (1.65)	4.25 (1.68)