Visual performance at passive level crossings with long sighting distances

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VISUAL PERFORMANCE AT PASSIVE LEVEL CROSSINGS WITH LONG SIGHTING DISTANCES

Grégoire S Larue¹ ², Ashleigh Filtness¹, Joanne Wood³, Sébastien Demmel¹, Anjum Naweed² ⁴, Andry Rakotonirainy¹
¹Centre for Accident Research and Road Safety – Queensland, Queensland University of Technology (QUT), AUSTRALIA
²Australasian Centre for Rail Innovation, AUSTRALIA
³School of Optometry and Vision Science, Queensland University of Technology (QUT), AUSTRALIA
⁴Appleton Institute for Behavioural Science, Central Queensland University, AUSTRALIA
Corresponding Author: g.larue@qut.edu.au

SUMMARY
The third edition of the Australian Standard AS1742 Manual of Uniform Traffic Control Devices Part 7 provides a method of calculating the sighting distance required to safely proceed at passive level crossings based on the physics of moving vehicles. This required distance becomes greater with higher line speeds and slower, heavier vehicles so that it may return quite a long sighting distance. However, at such distances, there are also concerns around whether drivers would be able to reliably identify a train in order to make an informed decision regarding whether it would be safe to proceed across the level crossing. In order to determine whether drivers are able to make reliable judgements to proceed in these circumstances, this study assessed the distance at which a train first becomes identifiable to a driver as well as their ability to detect the movement of the train. A site was selected in Victoria, and 36 participants with good visual acuity observed 4 trains in the 100-140 km/h range. While most participants could detect the train from a very long distance (2.2 km on average), they could only detect that the train was moving at much shorter distances (1.3 km on average). Large variability was observed between participants, with 4 participants consistently detecting trains later than other participants. Participants tended to improve in their capacity to detect the presence of the train with practice, but a similar trend was not observed for detection of the movement of the train. Participants were consistently poor at accurately judging the approach speed of trains, with large underestimations at all investigated distances.

1. INTRODUCTION
The third edition of the Australian Standard AS1742 Manual of Uniform Traffic Control Devices Part 7 (AS1742 Part 7) provides a method for calculating the sighting distance required to safely proceed at passive level crossings protected by stop signs based on the physics of moving vehicles (1). The required distance becomes greater with higher line speeds and slower, heavier road vehicles so it may return quite a large sighting distance.

The standard is based upon the requirement that a road user stopped at the crossing must have sufficient time to traverse the crossing before an approaching train arrives at the crossing from the point where the road user can first see the train (2). The sighting distance – known as $S_3$ - is hence the minimum distance at which an approaching train must be seen in order for the vehicle to proceed and clear the crossing by the required safety margin:

$$S_3 = \frac{V_T}{3.6} \left( J + G_S \sqrt{\frac{W_R}{\tan Z} + \frac{W_T}{\sin Z} + \frac{2C_V + C_T + L}{a}} \right)$$

where $V_T$ is the speed of the train approaching the railway crossing; $J$ is the sum of the perception time and the time to depress the clutch; $G_S$ is a grade correction factor; $W_R$ is the width of the roadway (all lanes); $W_T$ is the width of the rail track at the crossing (outer rail to outer rail); $Z$ is the angle between the road and the railway track at the crossing; $C_V$ is the clearance from the vehicle stop line to the nearest rail; $C_T$ is the clearance or safety margin from the vehicle stop line on the departure side of the crossing; $L$ is the length of the vehicle stopped at the crossing; and $a$ is the average acceleration in starting gear of the vehicle stopped at the crossing.

In AS1742.7-2007, this formula has been demonstrated to provide inaccurate $S_3$ values at high train speeds for heavy vehicles and a margin...
Figure 1: Trial site. Trains were approaching on the right track.

Figure 2: GoogleMaps aerial view of the trial site. The section of the track that could be seen by participants is highlighted in black along with its length in km.

of “more than 15 seconds extra could be required to safely clear the crossing than what may have been allowed for in the road design” (3). It has to be noted that long four trailer road trains (‘quads’) are also operating in Australian regions such as the Pilbara (4), and these would require even longer sighting distances due to their heavier load and lower acceleration capabilities. Higher mass road vehicles are of particular concern for the safety of level crossings, due to the longer time they need to traverse the crossing, as well as the higher chance that any collision between such vehicles and a train would be catastrophic. (5).

AS1742.7 was reviewed in 2014-2015 and once released the revised standard will provide sighting distance values that are representative of the performance characteristics of current heavy vehicles albeit in some cases sighting distances will be considered extremely long.

Research has shown that road users significantly underestimate the speed of large, as compared to smaller, objects in the distance (6, 7); that road users do not adapt their safety gaps to oncoming train speeds (8), adopt similar safety gaps regardless of the speed of approaching trains (9); and the useful field of vision – that section of the field of view around the fixation point within which sources of information can be processed at a single glance (10) - constrains as a function of vehicle speed and driver age (11). Further, changes in speed can also have an effect on the perceived duration of the approach of an object (5).

At the upper end of the sighting distances proposed for the revised Australian standard (750 to 1,500 metres), industry has raised concerns regarding whether a driver would be able to reliably identify a train and assess its rate of approach. This information is required in order to make an informed decision regarding whether it would be safe to proceed across a given level crossing.

Therefore this research aimed to determine if a driver is able to make reliable judgements at extended sighting distances, by investigating the sighting distance at which a train is first identifiable as a train, when it is first perceived to be moving and the rate of approach of that train estimated, at distances greater than 750 metres at a site with an available sighting distance greater than that which is currently required in the standard (up to 2,500 metres).

Driver judgement itself was not investigated as it also depends on variables that are untestable within the scope of this study such as driver experience and familiarity with the vehicle (12). Instead, by seeking to measure the limitations of the ability of drivers to identify a train, the point at which it is first moving and its approach speed, this study sought to identify the point at which the information required to make judgements is unreliable.
2. METHOD

2.1 Trial Site

The site selected for data collection is located on a maintenance track off Rennie St, Corio, Victoria, on the Werribee line between the Lara and Corio stations. This section of the rail track provided a long straight track with good visibility, relatively high train frequency during peak hours (3 tracks), and speeds over 100 km/h (see Figure 1). The site was located between two active level crossings, however the level crossings were further than 2km away and their active equipment could not be seen or heard by participants.

The visibility at the site was adequate for the study only on one side, as the visibility on the other side was blocked by a series of three bridges. The sun was not in participants’ field of view when looking for trains and hence did not affect the results. Only trains from Melbourne (i.e. west bound) could thus be included. For that direction, the rail track was straight, with a small dip and could be seen as far as 2.5 km away (see Figure 2). The layout of the rail tracks allowed for trains travelling from that direction to always be visible in the unlikely case of multiple trains at this location at the same time, as the trains selected for this study were running on the track closest to the location where the vehicles were parked. Trains on this line travel at speeds between 100 – 140km/h.

The research team and the research participants were located further down the maintenance track off Rennie St, in order to ensure that the participants were not distracted by the nearby road traffic. Care was taken to ensure that the observer position represented that of a typical truck driver stopped at a passive crossing (e.g. height of a truck cabin, as the vehicles were parked 1.5 metres above the rail track, approximately 7 metres from the rail line at a 90 degree angle).

2.2 Experimental Design

A repeated measure design was used with train occurrence as a within-subject factor. All participants completed one testing session, which included visual acuity testing, practice observations and test observations. Six trains were observed by participants between 13:45 and 16:40.

2.2.1 Visual acuity testing

The testing session included assessment of visual acuity to ensure that drivers satisfied the visual requirements for an Australian driving licence. Testing was conducted in a controlled environment with adequate lighting (in an established Optometry practice) in Geelong. Visual acuity was assessed monocularly and binocularly with participants wearing the spectacles/contact lenses that they normally wore for driving. Three standard Early Treatment for Diabetic Retinopathy Study (ETDRS) charts (with different letter configurations to avoid learning effects) were used at a 3 metre working distance. 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, where each letter read correctly was 0.02 log units and visual acuity expressed in logMAR units.

2.2.2 Practice observations

Participants were individually instructed about the activities and procedures involved in the study. Participants who usually wore corrective lenses or spectacles were asked to wear them during the study. At the site, the first two trains that participants saw were used as practice trials, where participants could become familiar with the site configuration and the procedure. Data was not collected during this phase.

2.2.3 Test observations

The following four trains were used for data analysis and are referred to as Trains 1 to 4. Trains 1, 2 and 4 were VLocity trains, which were faster trains running around 130 km/h at the location of the study (see upper panel of Figure 3), while Train 3 used a P class locomotive and was a 20 km/h slower train running at 110 km/h at the site (see lower panel of Figure 3).

![Figure 3: Observed trains. Upper: faster train; Lower: slower train.](image)
The participants were instructed to look for approaching trains from the East direction five minutes before a train was due. At this point all of the measurement equipment was started including: the smartphone apps - developed and used to record participants’ responses, the laser range finder in position to measure trains at a predetermined position, located around 1.6 kilometres from the participants and RTmaps, the software used to synchronise the data from all the devices used in this study. As the train approached the predetermined location, automated measurements from the laser range finder were triggered and occurred every second (when measurements were successful). The head of the tripod was turned when required to follow the movement of the approaching train.

Participants reported the word ‘Train’ when they first saw the train. They were also required to report when they first recognised that the train was moving, and at that point required to provide an estimate of the train speed (rounded to the nearest 10 km/h). In parallel the phone provided alarms at three additional pre-determined distances (1,100 metres, 750 metres and 350 metres), at which points the participant also provided speed estimates. Lighting conditions were also measured after the train passed using a calibrated lux meter.

2.2.4 Participants

Participants were healthy adults who were regular licensed drivers and were recruited from the general public in the Geelong area (closest city to the trial location). Recruitment was stratified to obtain a participant population with equal gender split and a variety of ages and driving experience. However, due to the small sample size (N=36) no direct comparisons were made between demographic groups. All participants were required to have adequate vision (or corrected vision) to legally hold a private driving licence. Ethical clearance to conduct the study was obtained from the QUT Ethics Committee.

2.3 Procedure

The rail sighting study was conducted between the 25th May and the 4th June 2015 with one session undertaken on each week day. Each session involved testing of four participants simultaneously.

Four similar cars used for the study were strategically positioned side by side, 80cm apart, and staggered to provide a similar view from each driver’s seat of approaching trains along the rail corridor (see Figure 4). For the study each participant was assigned the driver’s seat and was accompanied by a research assistant who was seated in the passenger seat to record the participant’s responses.

In addition to the observational study, each participant completed a questionnaire. The questionnaire was completed between Trains 2 and 3 and recorded the participant’s background and relevant demographic information.

2.4 Materials

2.4.1 Laser range finder

A laser range finder was used to measure train distances and speed. The Newcon LRB 4000 Cl laser range finder was used (see Figure 5) and set to record both the distance away and speed of detected objects. The measuring range of this equipment is 20 metres to 4,000 metres, with an accuracy of +/- 1 meter. Speed measurements operate in the 5-400km/h range, with an accuracy of +/- 2km/h. Each of the measurements took up to 0.3 seconds. Measurements were taken automatically every second. The output data were collected on a computer connected to the device via a RS232 port. The computer was used to trigger measurements without touching the device in order to avoid vibrations. The laser range finder was mounted on a Manfrotto 475B digital pro tripod, associated with a Manfrotto 128LP head. A heavy tripod was used in order to ensure that the device was in a stable position during data collection even under the windy conditions at the trial site. The head had to be modified in order to connect the equipment both to the tripod and to the computer.
2.4.2 Smartphones

Four Samsung S4 smartphones were used to record the moment participants detected (i) the train and (ii) its movement. When a participant verbally gave feedback, the research assistant pressed the ‘Train visible’ or ‘Train moving’ button on the smartphone app. The phones were also set to ring: when the train was 1,100 metres away, 750 metres away and 350 metres away to prompt the participants to provide train speed estimates.

Another Samsung S4 smartphone was used to create a portable Wi-Fi hotspot, which created a network between the four other smartphones and the computer linked to the laser range finder.

2.4.3 Synchronisation interface

The software RTmaps version 3.4.10 was installed on the computer linked to the laser range finder. This software was used to ensure a unique recording time for the different devices. Raw socket server components were used to communicate with the four smartphones, while a serial port component was used to communicate with the laser range finder. Components were created to listen to and record the laser range finder outputs, as well as trigger repetitive laser range finder measurements from the computer’s keyboard. A component was also created to record the buttons that were pressed on the smartphones, as well as the ID of the smartphone and the delays in the communication. The smartphone app also contained heartbeats, which were used by RTmaps to ensure that the communications between the computer and the smartphones was not lost, or could be restored after detection and reporting of the communication failure in the console window of the RTmaps software. Measurements of train speed and distances were used to trigger the alarm sounds played by the smartphones at the three locations of interest. The time when the alarm sound was provided was obtained as follows:

\[ t_i = \frac{d - d_i}{v} \]

Where:
- \( t_i \) is the time to wait before the train is in position \( i \) (in seconds);
- \( d \) is the last train position measured (in metres);
- \( d_i \) is the position of interest \( i \) (in metres); and
- \( v \) is the last train speed measured (in metres per second).

These values were also stored in the smartphones, to overcome any communication failures that could occur as the train was approaching, and increasing the chance that the alarm sound was provided at the appropriate time.

The laser range finder was continuously scanning for data (speed and distance) when the train reached a predetermined location. Each data point (time, distance, speed) was recorded by RTmaps in a text file.

At the three locations of interest 1,100 metres; 750 metres and 350 metres, RTmaps:
- sent a signal to the smartphones;
- recorded the time at which the signal was sent; and
- the smartphones played a sound to prompt participants to provide a speed estimate.

When the ‘Train visible’ or ‘Train moving’ button were pressed, the smartphone sent a message to RTmaps so that a timestamp was recorded, as well as the ID of the smartphone and the button pressed. Similarly, when the participant reported that they could see the train was moving, the research assistant pushed the ‘Train moving’ button. When any button was pressed, a tactile feedback was provided, as well as a change in the button’s colour for a couple of seconds.

2.5 Data Analysis

2.5.1 Dependent variables

The following train measurements were recorded:
- approach speed (km/h);
- approach distance in relation to participant measures (m).

Participant measurements were as follows:
- distance at which the approaching train becomes first recognisable (m);
- distance at which the approaching train first becomes identifiable as moving (m); and
- speed estimates at locations provided by the research team (km/h);

Environmental measurements were also recorded:
- ambient illumination (lux).

2.5.2 Statistical analyses

Generalised Linear Mixed Models were used to analyse the data of this repeated measures design. Generalised Linear Mixed Models were run on R version 3.1.1. These analyses were used to evaluate the effect of train speeds and location of the train on the dependent variables.
3. RESULTS

3.1 Participant Demographics

Thirty six participants completed the study protocol. Over half of the participants held an open licence with the remaining participants holding a P1 or P2 licence. Details of participants’ demographics can be found in Table 1.

3.2 Participants’ Visual Acuity

Group mean habitual visual acuity in the right eye was -0.16 log units, left eye -0.16 log units, and binocular -0.18 log units. All participants had visual acuity required to hold an Australian driver licence.

3.3 Distance Where Trains Become Visible

Trains were first identified as a train by participants at an average distance of 2,149 metres (SD=306). Eighty-five percent of participants identified the train further than 1,450 metres away, while the participant with the worst recognition first saw the train at a distance of 779 metres.

Statistical analysis conducted with Generalised Linear Mixed Models - with log link to take into account the lack of normality of the sample data collected - showed that while distances for train 1 and 2 were similar, the third and fourth trains were detected at further distances. The first two trains were identified at an average distance of 2,089 metres, while train 3 was identified 169 metres further away (t=2.463, DF= 95, p=.016), and train 4 was identified 137 metres further (t=2.155, DF= 95, p=.034). It has to be noted that the difference for Train 3 could be due to the fact that the locomotive was different to the other trains. However, these results show that - even when discarding data from Train 3 - participants’ detection ability improved with practice with detection 153 metres further in the last two trials (7% further). This suggests that participants learnt where the trains can be expected to appear on the horizon, as well as their particular features (such as the headlights).

Importantly, these averages mask large differences between participants. The limited number of participants does not allow the distribution to have converged. Four participants could be considered as outliers with very low values compared to the other participants. This reduced performance could be due to aspects of visual performance which were not measured, but all participants did have levels of visual acuity which were well above the minimum requirements for holding a driving licence. Other factors include lack of attention (participants were instructed to look for trains 5 minutes before the train arrived) or delays due to the equipment communications. Therefore, it is not possible to exclude such values.

Overall, all participants were able to detect each of the trains at distances greater than 780 metres (see Figure 6). Fifteen percent of participants were not able to detect the train for every trial at distances greater than 1,450 metres. Half of the participants were not able to detect the train at each of their trials at distances greater than 2,180 metres.

3.4 Distance Where Train Movement Is Perceived

Train movement was identified by participants at an average distance of 1,298 metres (SD=485). Eighty-five percent of participants reported the train as moving at distances further away than 750 metres, while the last participant to judge that the train was moving reported its movement 581 metres away from the vehicle in which they were seated.

Statistical analyses conducted with Generalised Linear Mixed Models showed that train order had no effect on the distance at which it was identified as moving (i.e. approaching). Thus while participants’ ability to detect trains improved with practice, a similar effect was not observed for the detection of train movement. Given that data was

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<th>Table 1: Participants’ demographics</th>
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<td>Gender</td>
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<td>Use of active level crossings</td>
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<td>Train travel</td>
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collected with four participants at the same time, we analysed whether vehicle and participant position in the vehicle made a difference to outcomes, however, there were no statistical differences in responses. This is not surprising given that any advantage of a particular vehicle position is small: the furthest vehicle is 1.5 metres further than the closest vehicle, which is a small difference compared to the distances of interest in this research (over 700 metres).

Large variability between participants was observed for detection of train motion. Overall, all participants were able to detect the train movement at each of their trials at distances greater than 580 metres. Fifteen percent of participants were not able to detect the train for every trial at distances greater than 750 metres. Half of the participants were not able to detect the train at each of their trials at distances greater than 1,440 metres.

The cumulative distribution for both the train detection and the train movement detection are presented in Figure 6.

### 3.5 Participants’ Estimates Of Train Speed

Participants consistently underestimated the speed of trains, with the exception of one participant who consistently overestimated train speed. For determining the level of underestimation, this participant was removed for the further analysis of the level of underestimation in train speed. Figure 6 demonstrates the mean km/h by which participants underestimated the train speed at each location. Overall, there was a significant main effect of Train order \[F (2.36,47.09) = 59.546, p <.001, \text{Partial Eta}^2 = .749, \epsilon = .785\], post hoc analysis demonstrating that estimations were more accurate for the slower moving Train 3 than Trains 1, 2 and 4 (p<.001). There was no difference in the accuracy of train speed between any of the other trains.

There was also a significant main effect of train location (first seen moving, 1,100 metres; 750 metres and 350 metres) \[F (1.528,30.57) = 19.167, p <.001, \text{Partial Eta}^2 = .489, \epsilon = .509\]. Post hoc analysis demonstrated that there was no significant difference between speed estimates when the train was first seen to be moving and at 1,100m away (p = .118). At these locations, errors of 47% and 41% were observed (averaging to 44%, as no statistical
Participants became more accurate with their speed estimates as the train became closer. At 750 metres estimates were significantly more accurate than when the train was first seen to be moving \((p = .003)\) or at 1,100m \((p < .001)\), with error rates decreasing to 36%. At 350 metres the mean speed estimate was significantly more accurate than at 750 metres \((p = .015)\), 1,100m \((p = .001)\) and when the train was first seen to be moving \((p = .001)\), with error rates decreasing to 29%.

4. LIMITATIONS

This study used a real-world field study design, which is appropriate to address the research questions. This approach overcomes many of the limitations that are faced by similar studies that have been conducted in simulators, which while being easier to conduct from a practical perspective, have severe and potentially fatal limitations in terms of validity. This is particularly important given the fact that this data will be used to inform standards. There are however, some limitations of the study design because of its field-based approach that need to be considered.

It was not possible to use a passive level crossing for data collection due to the low rail traffic volume at such sites, as well as the difficulty in providing a safe environment for participants (given it was not possible to safely park a vehicle at a level crossing without obstructing the road). Further, such an approach would have also limited the number of participants that could be tested simultaneously.

In order to achieve adequate sighting distance, train speeds and train traffic, it was not possible to conduct the study at a passive level crossing without collecting data for an extensive period of time. The data collection was hence conducted on the side of a rail track in the proximity of an active crossing (2 km away).

Participants were looking for trains over a longer period of time than is typical under normal driving conditions and were primed for the approaching trains – therefore the data represents that of an alerted driver and driver’s capacity to correctly detect trains may be overestimated.

The number of participants was limited, and factors explaining the performance of outliers could not be ascertained. However, we were able to control factors such as participants’ visual acuity (which was better than licensing standards), siting of the vehicle in an appropriate location and ensuring that participants maintained sustained attention to the task; we also avoided any technical delays by careful planning of each session.

The effects measured in this study were also limited to two types of trains travelling in the 100-140 km/h range due to the limited rail traffic available at the site.

Further studies are warranted to fully explore the range of other factors that may impact on performance at level crossings at longer sighting distances.

5. DISCUSSION

All drivers who participated and completed this study could identify a train at 750m. At a distance of 1,450m that number dropped to 85%. However a driver’s ability to identify the train as a threat is likely to be dependent on their ability to perceive that the train is actually moving. At distances closer than 580 metres from the vehicle, the trains were clearly identified as approaching by all participants. At 750m only 85% of people tested could recognise the train was approaching, and that number dropped to lower than 40% at 1,450m.

Large variability was observed between participants, highlighting important inter-individual differences in the ability to detect the presence of a train. As the study was conducted in good weather conditions, with high visibility, with participants having a visual acuity higher than that required to hold an Australian driving license, there is no compelling reason to consider the four participants with the lowest performance as outliers. This is particularly important with this study, as the sample size was relatively small \((N=36)\). It is important for safety to consider the ability of the worst participants when evaluating the distance required to ensure that the majority of the drivers can detect an approaching train. Further research with a larger sample size is required to fully explore the results provided in this study.

Nevertheless, the study clearly demonstrates that participants were unable to accurately assess fast train speeds at any of the distances investigated. Speed was underestimated by at least 30% at all distances, and this underestimation was at its highest for the furthest distance, reaching 44%. This finding is further supported by the lack of improvement with practice (results are similar for the 4 trains observed). Data showed a significant trend for less accurate speed judgements for longer distances and for faster trains \((130km/h versus 110 km/h)\). The accuracy of speed estimates deteriorated as the distance increased from the nearest point of measurement \((350 metres)\), that is, the point where their estimations were the least inaccurate.

These findings raise questions about road users’ ability to reliably assess the situation at a level crossing with trains running on a high speed railway line \((100-140 km/h range)\). Further research should focus on assessing whether the evaluation of train speed is an important factor in
drivers decision-making process at level crossings; and what potential effects the inability to judge the speed of high velocity trains might have on the perception of the train as a threat, and consequently the safety of the decisions taken by drivers at such passive level crossings.

Participants tended to improve in their capacity to detect the presence of trains with experience, but a similar trend was not observed for detection of train movement or the estimation of train speeds. Questions arise around whether training could be a viable solution for improving speed estimation, and further studies should evaluate whether providing feedback on train speeds would result in speed estimation improvements.

The findings of this study were used to inform the 2015 review of the Australian Standard AS1742 Manual of Uniform Traffic Control Devices Part 7. They were included in the revised version of the standard: when the required sighting distance provided by the formula \( S = \frac{v^2}{12g} \) becomes greater than 750 metres – due to the difficulty experienced by drivers to estimate the speed, or even see, an approaching train – a risk assessment should be conducted to determine whether further risk controls should be applied at that crossing. These controls include alternative arrangements for heavy vehicles, provision of active controls, relocation of the level crossing, reduction of train speed or grade separation.

6. CONCLUSION

This study has shown that the participants completing the study were all able to detect the presence of a train when it was 750 metres away. We have also shown that drivers are not able to detect the movement when it is first seen, and that a closer distance is required for participants to be able to determine that the train is moving. A train would need to be at 580 metres or less for all participants in this study to be able to detect train movement. Importantly, while participants were able to detect train movement, they were unable to accurately judge the speed of oncoming trains. Underestimation of train speed was higher at longer distances and higher train speeds, but underestimation was never less than 30%. These findings were used to inform the review of the Australian Standard AS1742 Manual of Uniform Traffic Control Devices Part 7, and were included in the revised version of the standard by taking into account drivers’ visual limitations while assessing the situation at a passive level crossing with a stop sign.

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