

1 Is it safe to cross? Identification of 2 trains and their approach speed at level 3 crossings

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14 **Highlights:**

- 15 • Drivers' perceptions of oncoming trains and decision making regarding their crossing
16 behaviours were examined
- 17 • Drivers identified the presence of trains 2km away and their movement at 1.6km
18 away, with high variability between participants
- 19 • Most participants underestimated the speed of oncoming trains, particularly when
20 they were travelling at higher speeds

21 **Abstract**

22 Improving the safety at passive rail crossings is an ongoing issue worldwide. These
23 crossings have no active warning systems to assist drivers' decision-making and are
24 completely reliant on the road user perceiving the approach of a train to decide whether to
25 enter a crossing or not. This study aimed to better understand drivers' judgements regarding
26 approaching trains and their perceptions of safe crossing. Thirty-six participants completed a
27 field-based protocol that involved detecting and judging the speeds of fast moving trains.
28 They were asked to report when they first detected an approaching train, when they could
29 first perceive it as moving, as well as providing speed estimates and a decision regarding
30 when it would not be safe to cross. Participants detected the trains ~2km away and were
31 able to perceive the trains as moving when they were 1.6km away. Large differences were
32 observed between participants but all could detect trains within the range of the longest
33 sighting distances required at passive level crossings. Most participants greatly
34 underestimated travelling speed by at least 30%, despite reporting high levels of confidence
35 in their estimates. Further, most participants would have entered the crossing at a time when
36 the lights would have been activated if the level crossing had been protected by flashing
37 lights. These results suggest that the underestimation of high-speed trains could have

38 significant safety implications for road users' crossing behaviour, particularly as it reduces
39 the amount of time and the safety margins that the driver has to cross the rail crossing.

40 **Keywords:** rail level crossing; passive crossing; speed perception; speed estimates; motion
41 perception; gap acceptance

42 **1. Introduction**

43 Crashes between trains and road vehicles at rail level crossings are a substantial safety
44 issue for road and rail operations. Such crashes accounted for 45% of the overall fatal rail
45 incidents during 2014-2015 (Office of the National Rail Safety Regulator, 2015), although
46 they accounted for less than 1% of the overall fatal road incidents in Australia (Bureau of
47 Infrastructure Transport and Regional Economics, 2014; Office of the National Rail Safety
48 Regulator, 2015). The consequence of collisions between trains and road vehicles can be far
49 greater than those between road vehicles. While crashes between trains and road vehicles
50 are relatively infrequent, when they do occur, those involved are more likely to suffer fatality
51 or serious injury (Australian Transport Council, 2010). That is, train and road vehicle crashes
52 have higher per-crash casualty rates and are associated with a substantial economic cost of
53 116 million AUD a year (Evans, 2013). The economic and importantly, the human costs of
54 train and road vehicle crashes are clearly substantial and reducing these incidents is an
55 important priority for both rail and road safety. On every day for the last ten years,
56 approximately one person was fatally injured at level crossings in the European Union and in
57 the United States, close to one was seriously injured in the EU, and three injured in the US
58 (European Railway Agency, 2012b; Federal Railroad Administration Office of Safety
59 Analysis, 2016). These trends have not improved worldwide in the last decade.

60 The intersection between road and rail and use of rail level crossings is common. For
61 example, there are currently 23,500 rail level crossings in operation in Australia (Rail
62 Industry Safety and Standards Board, 2015). Rail level crossings are typically categorised
63 into two types of crossings based around the level of control at the crossing. Active
64 crossings employ automatic devices (e.g., flashing lights, with or without boom gates) that
65 are activated shortly before the arrival of a train and are designed to alert vehicle drivers of
66 an approaching train and prevent them from driving through the crossing when the train is
67 approaching. On the other hand, passive crossings employ static signage (e.g., cross bucks,
68 'give-way', or 'stop' signs) and are designed to warn the driver of the possibility of an
69 approaching train at any time, but require the driver to make the decision regarding whether
70 it is safe to cross. The majority of rail crossings around the world are passively protected.
71 Passive crossings represent 67% of public crossing in operation in Australia (Railway
72 Industry Safety and Standards Board, 2009), 75% in the United States (National
73 Transportation Safety Board., 1998), and 47% in Europe (European Railway Agency,
74 2012a). Passive crossings are mainly located in rural areas, where train speeds are
75 generally faster (e.g., Laapotti, 2015; Rudin-Brown et al., 2014).

76 To ensure that a road user who is stopped at a passive crossing has sufficient time to safely
77 traverse the crossing, a minimum sighting distance is required. This sighting distance is the
78 minimum distance at which an approaching train must be seen in order for the vehicle to
79 proceed and clear the crossing by the required safety margin. This is calculated for each
80 individual crossing taking into account its particular characteristics such as types of vehicles,
81 geometry, and train speed (Standards Australia, 2015). In particular, the required sighting

82 distance becomes greater with higher train speeds, where decisions regarding entering the
83 crossing need to be taken when trains are at relatively long distances away from the driver.

84 **1.1 Factors Associated with Drivers' Crossing Behaviours**

85 Collisions at level crossings tend to be the result of a combination of factors. Vehicle-related
86 factors have been shown to be relatively uncommon in railway level crossing collisions and
87 environment-related factors rarely occur in isolation from driver-related factors. Numerous
88 train crash investigations have found that driver errors rather than deliberate violations are
89 primarily responsible for train and road vehicle crashes (Baysari et al., 2009; Caird, 2002;
90 Salmon et al., 2013). Observational studies of actual rail level crossings report that 57-77%
91 of drivers will cross (the rail crossing) in the presence of an approaching train (Kasalica et
92 al., 2012; Tey et al., 2011). Additionally, observational studies identify that the majority of
93 drivers slow down and perform visual scanning behaviours as they approach the rail tracks,
94 prior to crossing (Kasalica et al., 2012; Meeker and Barr, 1989). The obvious checking for
95 the behaviour of trains exhibited by drivers supports the suggestion that perceptual errors
96 rather than deliberate violations underlie many train and road user crashes.

97 Several studies have found that short sighting distances and obstructed sighting lines are
98 associated with train-vehicle crashes (Caird, 2002; Laapotti, 2015). Notwithstanding the
99 issues associated with sighting distances, the ability of a driver to accurately perceive a
100 moving train with clear and unobstructed sightlines is still an under-researched area at rail
101 level crossing. Decision making related to gap acceptance is associated with sighting
102 distances and the ability to perceive a moving train. This is the amount of time or distance
103 that a driver judges acceptable to allow them to perform the crossing manoeuvre. Gap
104 acceptance has been studied predominately in relation to road vehicles merging into the flow
105 of traffic or driving through an intersection. These on-road and simulated driving studies
106 have found that shorter time of arrival at a junction, smaller gap distance, and faster
107 oncoming traffic speeds reduce the likelihood of a gap being judged to be acceptable and
108 the driver not performing the manoeuvre (e.g., Beanland et al., 2013; Bottom and Ashworth,
109 1978; Hunt et al., 2011). Similar results are reported by studies at rail level crossings where
110 the perceived time of arrival of the train, the distance, and/or the train speed are associated
111 positively with traversing a rail level crossing (e.g., Meeker and Barr, 1989; Meeker et al.,
112 1997; Tey et al., 2011). However, little research has examined gap acceptance in terms of
113 when drivers perceive it safe (or unsafe) to cross a rail level crossing when a train is
114 approaching.

115 Another factor related to gap acceptance is the speed of an oncoming train. Underestimation
116 of the speed of a train approaching a rail level crossing could put road users at risk of being
117 involved in a crash (Leibowitz, 1985; Meeker et al., 1997). For an observer, the travelling
118 speed of a large object typically appears slower than that of a smaller object travelling at the
119 same speed: this is known as the size-speed illusion (Leibowitz, 1985) and has been
120 confirmed using several rail simulator studies (e.g., Clark et al., 2013; Clark et al., 2016;
121 Cohn and Nguyen, 2003).

122 Field studies are critical to fully understand the ability to detect moving trains, accurately
123 judge their oncoming speeds and hence make safe crossing decisions. While simulator or
124 video-based studies provide some evidence regarding the difficulty of accurately detecting
125 moving trains, the lack of a three dimensional visual perspective and the fact that factors like
126 field of view, lighting and shading and other key variables cannot be accurately reproduced

127 by these approaches limits the transferability of findings to the real world. To date, only two
128 studies have specifically examined drivers' visual scanning behaviours at level rail crossing
129 (i.e., Grippenkoven and Dietsch, 2015; Young et al., 2015). These studies focused on the
130 approach to active rail level crossings in urban areas. They inform our understanding of
131 visual search strategies of drivers that are approaching rail level crossings (i.e. where drivers
132 look) but do not provide insight into the ability of drivers to accurately detect trains, estimate
133 speeds or judge whether it is safe to cross (i.e. what they perceive).

134 **1.2 Aims and research questions**

135 The present research aimed to understand road users' perceptions of approaching trains
136 and their decisions relating to when it is no longer safe to enter a passive rail level crossing
137 using a unique field-based paradigm. This study specifically answered the following research
138 questions: (i) at what distance are drivers first able to detect trains and when they are
139 moving?; (ii) are drivers capable of accurately estimating train speeds?; (iii) are drivers able
140 to judge their own speed estimation performance?; and (iv) does drivers' performance in
141 detecting trains and their movement affect their decisions to enter level crossings? A novel
142 methodology was developed to answer these research questions in a field study paradigm.

143 **2. Method**

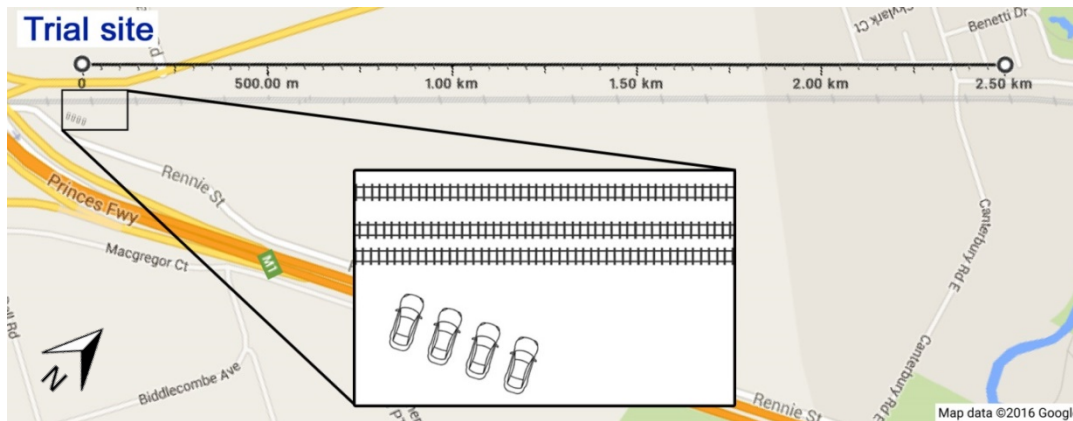
144 **2.1 Trial site**

145 The site selected for data collection was located on a rail maintenance track off Rennie St,
146 Corio, Victoria, on the Werribee line between the Lara and Corio stations, in the State of
147 Victoria, Australia. This site was selected from a number of potential sites because it
148 provided a long straight rail track with visibility above the longest sighting distances required
149 in Australia, relatively high train frequency during peak hours (3 tracks), and train speeds
150 over 100km/h (see Figure 1). The site was located between two active level crossings,
151 importantly, however, the level crossings were more than 2km away from the testing site and
152 their active equipment could not be seen or heard by participants. The research team and
153 the research participants were located further down the maintenance track off Rennie St (at
154 the observation point in Figure 2), in order to ensure that the participants were not distracted
155 by the nearby road traffic.



156

157 **Fig. 1.** Left: the trial site, trains were approaching from the right of the track; top right: the faster train,
158 a VLocity train; bottom right: slower train, a P class locomotive.



159

160 **Fig. 2.** GoogleMaps top view of the trial site. The section of the track that could be seen by
 161 participants is demonstrated with the measurement bar along the length of the rail tracks.

162 Visibility on one side was obstructed by bridges thus the site was appropriate for the study
 163 on one direction; only trains from Melbourne (i.e. west bound) were therefore included. On
 164 this side, the rail track was straight, and west bound trains could be seen as far as 2.5 km
 165 away (see

166 Figure 2). The layout of the rail tracks allowed for trains travelling from that direction to
 167 always be visible in the unlikely case of multiple trains arriving at this location at the same
 168 time, with trains on this line travelling at speeds between 100 – 140 km/h.

169 **2.2 Observed trains**

170 Six trains were scheduled to pass the trial site during the study observation period (between
 171 13:45 and 16:40). The first two trains seen by participants were used as practice trials to
 172 become familiar with the site configuration and the study procedures. Data was not recorded
 173 during this practice phase. Following the two practice trains, four more trains were scheduled
 174 to pass through the trial site (referred to as Trains 1 to 4); these four trains were used for
 175 data analysis. Specifically, Trains 1, 2 and 4 were VLocity trains, which were faster trains
 176 running around 130km/h at the location of the study (see top right panel of Figure 1), while
 177 Train 3 was a P class locomotive and was a 20km/h slower train running at 110km/h at the
 178 site (see bottom right panel of Figure 1).

179 **2.3 Study design**

180 This field study involved high velocity trains in locations with high sighting distance. By
 181 nature, it was not feasible to observe more than four trains, as such trains are very
 182 infrequent. Therefore, the study design focused on specific context rather than train diversity
 183 and controlled for as many factors as possible (participant visual characteristics, lighting
 184 conditions, distraction). A repeated measures design was therefore used with train
 185 occurrence and multiple observation points per train as a within-subject factor. All
 186 participants completed one testing session, which included visual acuity testing, practice and
 187 test observations. In addition to the observational study, each participant completed a
 188 demographic questionnaire and a retrospective questionnaire.

189 **2.3.1 Visual acuity testing**

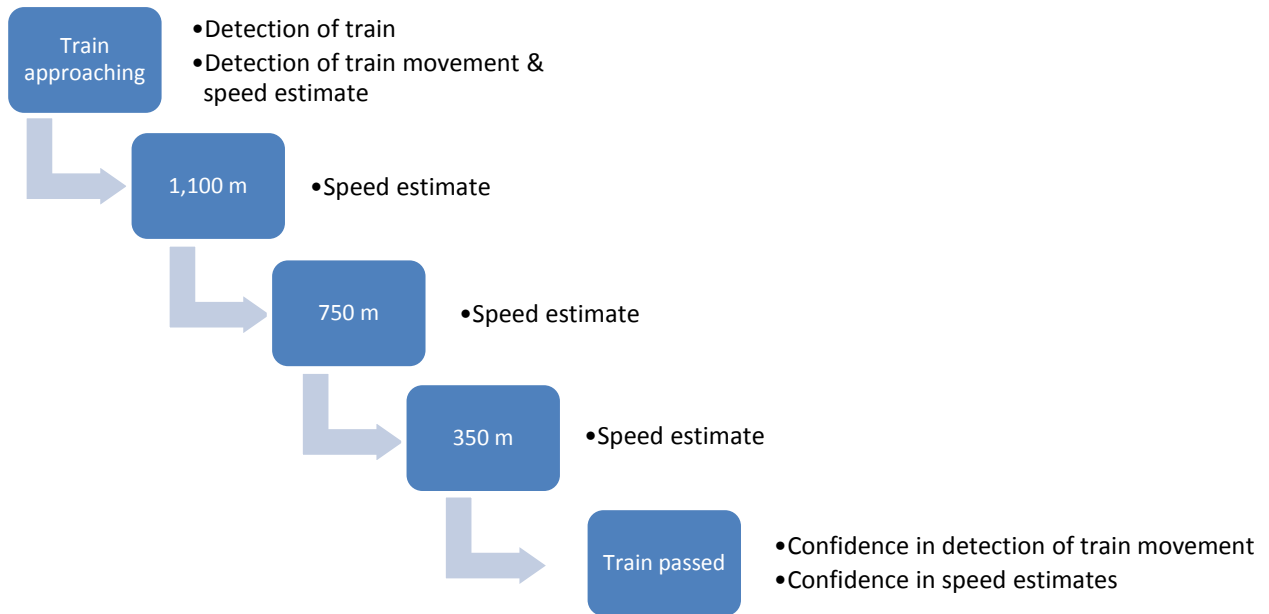
190 To ensure that drivers satisfied the visual requirements for an Australian driving licence, all
 191 participants underwent visual acuity tests in an established Optometry practice in Geelong.
 192 Visual acuity was assessed both monocularly and binocularly with participants wearing the

193 spectacles/contact lenses that they normally wore for driving using a standard logMAR chart
194 at a working distance of 3 metres. Participants were required to read the letters as far down
195 the chart as possible, guessing was encouraged and scoring was on a letter by letter basis.
196 Contrast sensitivity was measured in the same testing room using a Pelli-Robson chart at a
197 working distance of 1 metre with a +1.00D lens used to correct for the working distance;
198 scoring was as recommended on a letter by letter basis.

199 **2.3.2 Observations**

200 Participants were instructed to look for approaching trains from the East direction five
201 minutes before a train was due. At that moment, a laser range finder was pointed toward the
202 track and ready to measure train distance and speed (see left panel of Figure 1). When the
203 train was 2.5km away, the laser range finder was activated for automated measurements of
204 distance and speed every second. These measurements were recorded and used to
205 estimate the time needed for the train to reach three pre-determined distances (1,100m,
206 750m and 350m). These time estimates were updated at each new measurement obtained
207 from the laser range finder.

208 Participants reported the word 'Train' when they first saw the train, and this was immediately
209 recorded by the research assistant on the smartphone app. As soon as the participant
210 perceived that the train was moving they reported this with an estimate of the train speed
211 (rounded to the nearest 10km/h). The observation of train movement was immediately
212 recorded by the research assistant on the app, and then the speed estimate was recorded
213 on an observation sheet. At the three additional pre-determined distances, the smartphone
214 app sounded the phone's alarm at which point the participant provided three additional
215 speed estimates. Lastly, participants were requested to report the word 'Unsafe' when they
216 considered that, when stopped at the entrance of a passive crossing, they would not
217 traverse the level crossing due to the proximity of the approaching train. This was also
218 immediately recorded on the smartphone by the research assistant. Once the train passed
219 participants, they were requested to provide their confidence about the speed estimates they
220 had provided. This process is summarised in Figure 3. The ambient illumination (referred to
221 as lighting conditions in the remainder of the document) at the site was recorded in lux after
222 each train, both in the vehicle and outside, and provided the range of ambient illumination
223 observed during data collection as well as the variability of these measures between the
224 different data collection days.



225
226 Fig 3. Participants' activities as a train is approaching.

227 2.3.3 Demographic questionnaire

228 The demographic questionnaire assessed the participant's driving background and relevant
229 demographic information, such as age, gender, driving experience and experience with both
230 active and passive rail level crossings (including near-miss incidents).

231 2.3.4 Retrospective questionnaire

232 The retrospective questionnaire asked participants to reflect on their performance during the
233 trial. It covered participants' changes in confidence during the trial. The confidence in their
234 estimates of train movement detection and speed estimates was evaluated on a 7-point
235 Likert scale with higher values indicative of greater confidence (from *Extremely unconfident*
236 to *Extremely confident*, as described in Figure 7). Participants also responded to questions
237 about how difficult they found detecting and judging the speed of the oncoming trains, as
238 well as factors that might have influenced their ability to detect trains and judge their speed.

239 2.4 Participants

240 Participants were 36 healthy licensed adult drivers who were recruited from the general
241 public in the Geelong region of Victoria, Australia (closest city to the trial location). Power
242 calculation demonstrated that this sample size was required to attain a power of .9 at level
243 alpha .05 with medium size effects .25 with a correlation among repeated measures of .5.
244 Recruitment was stratified to obtain a participant population with an equal gender split and a
245 variety of ages and driving experience. All participants were required to have habitual visual
246 acuity (either with or without optical correction) that met Australian driving licensing
247 standards of 6/12 binocularly. Ethical clearance to conduct the study was obtained from the
248 QUT Human Ethics Committee (approval number 1500000219).

249 2.5 Materials

250 2.5.1 Laser range finder

251 A laser range finder was used to measure train distances and speed. The Newcon LRB
252 4000 CI laser range finder was used (see Figure 1) and set to record the distance and the
253 speed of detected objects. The measuring range of this equipment was 20 to 4,000m, with
254 an accuracy of +/- 1m. Speed measurements operated in the 5-400 km/h range, with an
255 accuracy of +/-2km/h. Each of the measurements took up to 0.3s and was taken
256 automatically every second. The output data were collected on a computer connected to the
257 device via a RS232 port. The computer was used to trigger measurements without touching
258 the device in order to avoid vibrations. The laser range finder was mounted on a Manfrotto
259 475B digital pro tripod, with associated Manfrotto 128LP head. A heavy tripod was used in
260 order to ensure that the device was in a stable position during testing.

261 2.5.2 Smartphones

262 Four Samsung S4 smartphones were used to record the participants' responses when they:
263 (i) first detected an approaching train; (ii) when they first judged that the approaching train
264 was moving; and (iii) considered it was no longer safe to enter the level crossing (see Figure
265 4). A fifth Samsung S4 smartphone was used to create a portable Wi-Fi hotspot, which
266 created a network between the four other smartphones and the computer linked to the laser
267 range finder. The data from the smartphones and the laser range finder was synchronised
268 with the software RTmaps version 3.4.10.



269

270 **Fig 4.** Graphical interface of the app developed to record participants responses

271 2.6 Procedure

272 Each session involved testing four participants simultaneously. Participants were recruited
273 from the general public through advertisement on local university job websites,
274 advertisement to volunteer groups, and snowballing effects. Participants were individually
275 instructed about the activities and procedures involved in the study. Participants who usually
276 wore corrective lenses or spectacles for driving were asked to wear them during the study.

277 Four participants were assigned to one of the four vehicles which were positioned side by
278 side, 80cm apart, and staggered to provide a comparable view from each driver's seat of
279 approaching trains along the rail corridor. The participant sat in the driver's seat and was

280 accompanied by a research assistant who was seated in the passenger seat to record the
281 participant's responses on the smartphones.

282 Five minutes before a train was due, the measurement equipment was started including: the
283 smartphone apps (developed and used to record participants' responses), the tripod-
284 mounted laser range finder in position to measure a train's distance and speed at a
285 predetermined position, located 2km downstream from the participants and RTmaps (the
286 software used to synchronise the data from all the devices used in this study). As the train
287 approached the predetermined location, automated measurements from the laser range
288 finder were triggered and occurred every second. The head of the tripod was turned when
289 required to follow the movement of the approaching train.

290 Between Trains 2 and 3, participants completed the demographic questionnaire. The
291 retrospective questionnaire was completed after the last train (Train 4).

292 **2.7 Data Analyses**

293 Generalised Linear Mixed Models with log link to take into account the lack of normality of
294 the sample data collected, and multivariate analysis of variance (MANOVA) were used to
295 analyse the data. Generalised Linear Mixed Models were run on R version 3.1.1 and
296 MANOVAs were run on SPSS version 21. These analyses were used to evaluate the effect
297 of train speeds and location of the train on the dependent variables. The main dependent
298 variables were the detection distances at which the train was (i) first recognised as a train,
299 (ii) judged to be moving; (iii) when the participants considered it was no longer safe to enter
300 the level crossing; and (iv) the participants' estimates of the train speed and their confidence
301 in their estimates of train speed.

302 **3. Results**

303 **3.1 Participant demographics**

304 The majority of participants (58.3%) held a full open licence with the remaining participants
305 holding a Provisional licence (first 2 years of unsupervised driving). A total of 20 males and
306 16 females completed the study, representing 55.6% and 44.4% in each category
307 respectively. The age of participants ranged between 18 and 63 years, with a mean age of
308 30.4 years (SD=14.2). All participants had completed high school with approximately half
309 having completed an undergraduate degree. The number of kilometres driven in a month
310 recorded by participants ranged from 40 to 4,500km, with a mean of 1,162km (SD=981).
311 Almost all (86.1%) participants had previously crossed an active rail level crossing with a
312 frequency of once a month or more and two thirds of participants reported having previously
313 crossed a passive railway crossing once a month or more. Over half of the participants said
314 they used train travel once a month or more, with approximately one quarter using rail travel
315 once a week or more. Two participants reported having previously experienced a near-miss
316 at level crossings and six participants were aware of someone else who had an incident with
317 a train at level crossings.

318 **3.2 Participants' visual acuity**

319 The participants' visual acuity and contrast sensitivity with spectacles/contact lenses if
320 habitually worn for driving are shown in Table 1. The mean habitual visual acuity in the right
321 eye was -0.16 logMAR, left eye -0.16 logMAR, and binocular was -0.18 logMAR. The mean

322 contrast sensitivity was 1.96 log units, and the range of contrast sensitivity was 1.90 and
323 2.05. These results demonstrate that participants had normal levels of visual acuity and
324 contrast sensitivity and all met the visual acuity requirements for driving.

325 **Table 1**

326 Participants' visual acuity results

Eye tests	Mean	Standard deviation	Range
Right visual acuity (logMAR)	-0.16	.06	-0.26 to -0.06
Left visual acuity (logMAR)	-0.16	.05	-0.22 to -0.06
Binocular visual acuity (logMAR)	-0.18	.04	-0.20 to -0.08
Binocular contrast sensitivity (log units)	1.96	.08	1.90 to 2.05

327

328 **3.2 Lighting conditions**

329 Table 2 provides details of the lighting conditions. Light levels ranged between 900-19,000
 330 lux for measurement outside the vehicles, and 300-10,000 lux inside the vehicle at the
 331 driver's position. The mean values typically decreased over the duration of the testing period
 332 within a given day and, the clear and bright conditions gradually reduced as the evening
 333 approached. Data was collected during clear weather conditions.

334 **Table 2**

335 Lighting conditions during observations

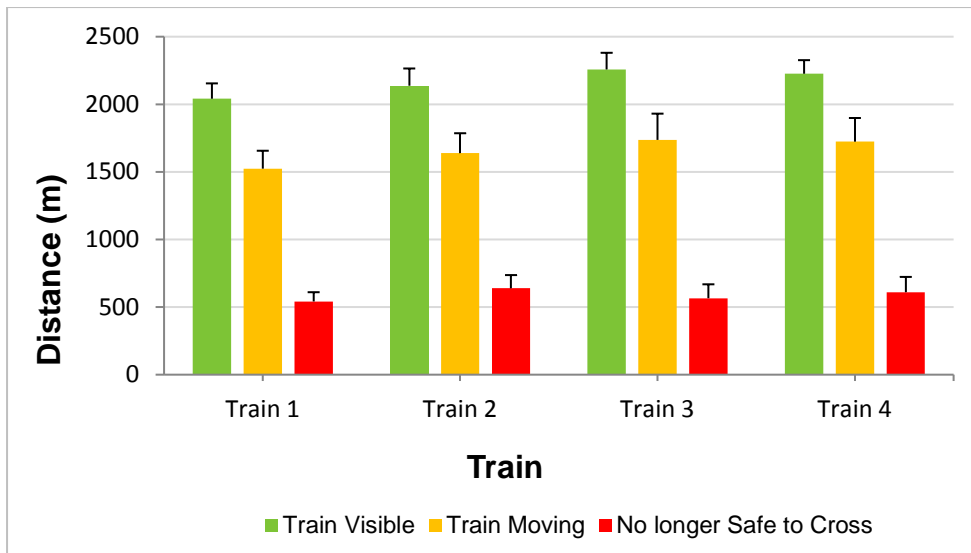
Train	Time	Lighting in vehicle (lux)		Lighting outside (lux)	
		Mean (SD)	Range	Mean (SD)	Range
T1	14:45	4,100 (1,872)	1,200-7,000	12,429 (4504)	7,000-19,000
T2	15:20	2,833 (2,016)	500-7,000	8,656 (5890)	900-19,000
T3	16:10	2,622 (2,288)	800-8,000	9,578 (6619)	1,500-19,000
T4	16:42	1,868(3,308)	300-10,000	4,288 (6062)	900-19,000

336

337 **3.3 Detection of train and train position when it becomes unsafe to cross**

338 Given that data was collected with four participants at the same time, the vehicle and
 339 participant position in the vehicle was assessed to see if it affected the outcomes. No
 340 statistical differences were found in responses ($p=.69$ for vehicle 2, $p=.30$ for vehicle 3 and
 341 $p=.06$ for vehicle 4, where vehicles are numbered from left to right). Therefore, results from
 342 all participants are considered together regardless of which vehicle they were seated in
 343 when completing the study.

344 Overall, trains were identified as a train by participants at an average distance of 2,149m
 345 (SD=306), with train movement being identified by participants at an average distance of
 346 1,644m (SD=411). Participants reported that it was no longer safe to enter a level crossing
 347 when the train was at a distance of 594m (SD=271) on average. The mean distances for
 348 each of the individual trains are presented in Figure 5.



349

350 **Fig 5.** Average distance at which each individual test train was detected (green), judged as moving
 351 (orange) and reported as too close to safely enter the level crossing (red). Error bars represent
 352 standard errors.

353 Statistical analysis conducted with Generalised Linear Mixed Models showed that while
 354 distances for Train 1 and 2 were similar, the third and fourth trains were both detected at
 355 longer distances (i.e. earlier). The first two trains were identified at an average distance of
 356 2,089m from the participant, while Train 3 was identified 169m sooner ($t=2.46$, $DF= 95$,
 357 $p=.016$), and Train 4 was detected 137m sooner ($t=2.16$, $DF= 95$, $p=.034$). It is possible that
 358 the difference for Train 3 is due to the fact that that train was different from the others, using
 359 a slower locomotive (see Figure 1). However, even if data from Train 3 is excluded -
 360 participants' detection ability improved with practice, with detection 153m further in the last
 361 two trials (7% further for Trains 2 and 4 relative to Train 1).

362 A similar analysis was performed for the distance where train movement was first detected
 363 and where participants reported it was no longer safe to cross. No improvement was
 364 observed for either of these variables with practice, and performance was consistent for the
 365 four different trains for the detection of train movement and the estimation of the location
 366 where it became no longer safe to enter a level crossing.

367 Importantly, these averages mask large differences between participants, which can be seen
 368 in Table 3. This table presents percentiles of the average distances where the train was first
 369 perceived. This distance ranges between 1,347 and 2,526m. The table also presents
 370 percentiles of the distance where the train movement was detected, which ranged between
 371 821 and 2,384m; and the distance where participants reported it was no longer safe to cross
 372 – ranging between 205 and 1,411m.

373 **Table 3**

374 Variability in performance between participants, as highlighted by the percentiles of train and train
 375 movement detections, and moment when it is no longer safe to cross.

Percentile	Train detected		Train movement detected		No longer safe to cross	
	Distance (m)	Time (s)	Distance (m)	Time (s)	Distance (m)	Time (s)
0%	1,347	39	821	24	205	6.1
15%	1,851	58	1,154	33	381	10
50%	2,276	67	1,680	49	505	15
85%	2,399	71	2,059	63	877	26
100%	2,526	73	2,384	71	1,411	39

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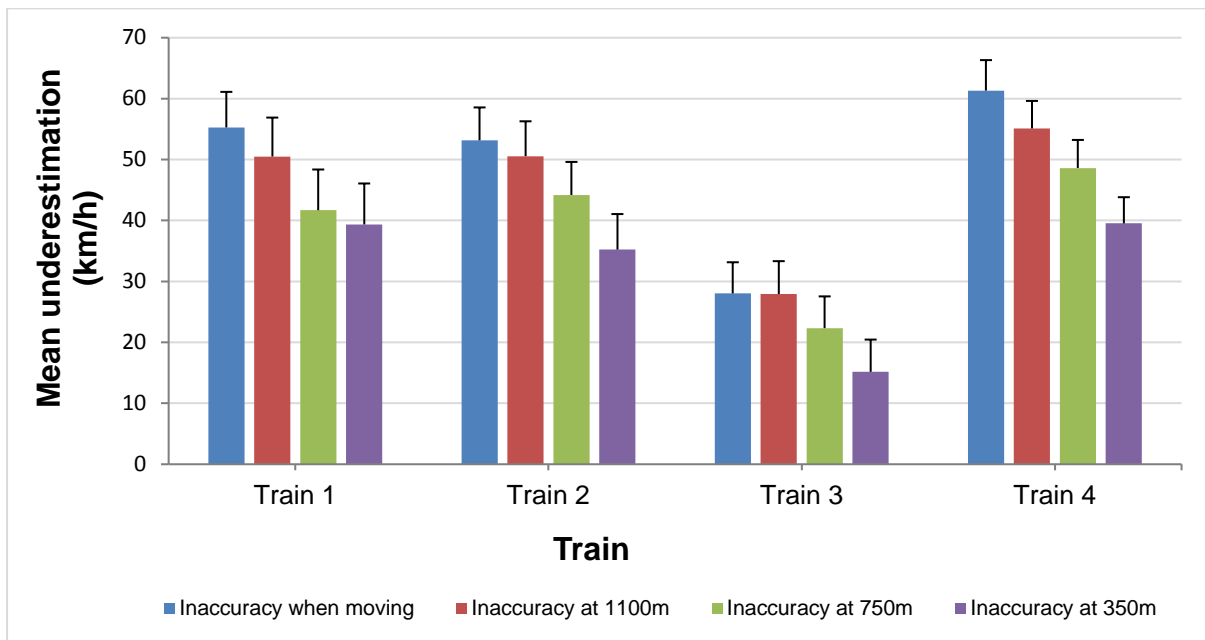
377 Table 3 shows the time it would take the train to reach the crossing, calculated from the
 378 speed and distance of the train. This is of particular interest for the time when the
 379 participants reported it was not safe to enter the crossing. On average, participants reported
 380 they would no longer enter the crossing when the train was 17.0s away on average
 381 (SD=8.0), with values ranging from 6.1 to 39.4s. The large majority of participants (29),
 382 corresponding to 80.6% of the sample, would have entered the crossing at a time when the
 383 lights would have been activated if the level crossing had been protected by flashing lights
 384 (i.e. 24s before the train reached the crossing). It should be noted that 6 participants (17% of
 385 the sample) reported that it was no longer safe to enter the crossing when the train was less
 386 than 10s away.

387 The eight participants who reported having experienced a near-miss or being aware of
 388 someone else who had experienced a near-miss were combined into a sub-group. Their
 389 responses regarding the detection of the train, its movement or the moment when it was
 390 judged no longer safe to enter the crossing were compared to the remaining participants.
 391 Statistical analyses did not highlight any significant difference for any of these dependent
 392 variables, therefore results from all participants are considered together.

393 **3.4 Participants' estimates of train speed**

394 Participants consistently underestimated the speed of trains, with the exception of one
 395 participant who consistently overestimated train speed. In determining the level of
 396 underestimation in train speed this outlier was removed. Figure 6 demonstrates the mean
 397 km/h by which participants underestimated the train speed at each location and for each
 398 train. Overall, there was a significant main effect of Train Order [$F(2.36, 47.09) = 59.55$, p
 399 $<.001$, Partial $\eta^2 = .75$, $\epsilon = .79$]; with post hoc analyses demonstrating that estimations
 400 were more accurate for the slower moving Train 3 than Trains 1, 2 and 4 ($p<.001$). No other
 401 comparisons were significant. There was also a significant main effect of Train Location (first
 402 seen moving, 1,100m; 750m and 350m) [$F(1.53, 30.57) = 19.17$, $p <.001$, Partial $\eta^2 = .49$,
 403 $\epsilon = .51$], however post hoc analysis demonstrated that there was no significant difference
 404 between speed estimates when the train was first judged to be moving and at 1,100m away
 405 ($p = .118$). At these locations, errors of 47% and 41% were observed (averaging to 44%, as
 406 no statistical difference was observed). Participants became more accurate with their speed
 407 estimate as the train became closer. When the train was 750m from the participant
 408 estimates were significantly more accurate than when the train was first judged to be moving
 409 ($p = .003$) or at 1,100m from the participant ($p <.001$), with error rates decreasing to 36%. At
 410 350m, the mean speed estimate was significantly more accurate than at 750m ($p=.015$),

411 1,100m ($p = .001$) and when the train was first seen to be moving ($p = .001$), with error rates
412 decreasing to 29%.



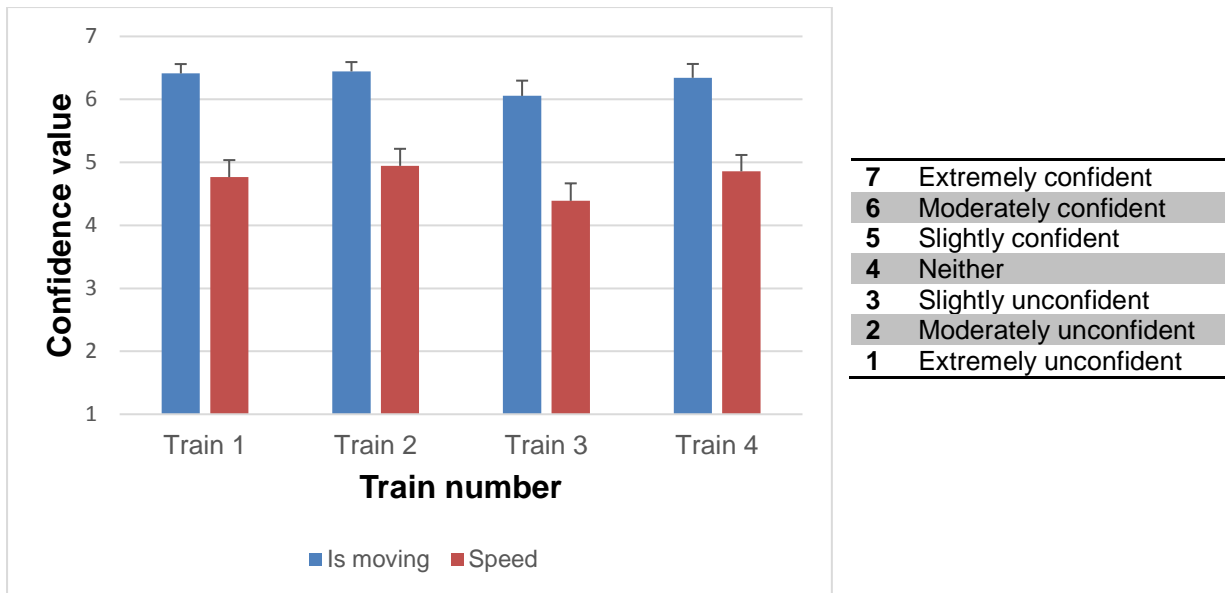
413

414 **Fig 6.** Mean km/h underestimation of train speed. Error bars represent standard error of the mean.

415 **3.5 Participants' confidence in their estimates of train speed**

416 Participants were asked how confident they were with their judgement that the train was
417 moving and how confident they were with their speed estimates. Confidence ratings were
418 made on a 7-point Likert scale, with higher scores indicating more confidence in the
419 estimate. Overall, the participants reported they were moderately confident that the train was
420 moving; however, they were less confident, on average, with their estimation of the speed of
421 the trains (see Figure 7). The participants' confidence ratings that the train was moving and
422 the confidence in speed estimates were compared across the different trains. Some
423 departures in normality were present with the participants' confidence reports and thus, non-
424 parametric Friedman ANOVAs were used. No significant differences were found with
425 participants' mean confidence ratings of the train is moving decision [$\chi^2(3) = 3.14, p = .37$]
426 and confidence of the speed decision [$\chi^2(3) = 6.17, p = .10$] between trains.

427 A further examination of the participants' confidence in their speed estimates was performed
428 using bivariate correlations to examine the relationships between participants' confidence
429 levels in their speed estimates and the actual level of underestimation of those speed
430 estimates when they were the most accurate (i.e. when trains were 350m from the
431 participants). Spearman's rho bivariate correlations were performed due to the non-normal
432 distributions of the data. The correlations between participants' confidence and the level of
433 speed underestimation for Train 1, 2, 3, and 4 were $r_{rho} = .16, p = .41, r_{rho} = .31, p = .07, r_{rho} =$
434 $.31, p = .06,$ and $r_{rho} = .02, p = .92$ respectively. Regardless of train speeds, participants'
435 confidence levels of their judgements were not correlated to their actual speed
436 underestimation.



437
438 **Fig 7.** Mean confidence of train moving and train speed estimates for each train. Error bars
439 represent standard error of the mean.

440 3.6 Retrospective questionnaire

441 The majority of participants (86.1%) reported that they had no difficulty detecting the trains.
442 In contrast, four participants reported some difficulties detecting the trains; two of the four
443 participants reported these difficulties were only with the initial train sighting and that it was
444 easier to detect subsequent trains. The other two participants reported that their difficulty
445 was due to “objects next to the track” or with “distinguishing lights of the railway line from the
446 lights of the train”. Regarding the speed estimations, generally, all participants reported that
447 estimating the speed of the train was easiest when the train was closest (i.e., 350m mark)
448 and three quarters of participants (72.2%) found that speed estimation became easier as the
449 study progressed. This however, was not confirmed by the analysis of the speed estimates,
450 as no improvement was observed throughout the study. Paradoxically, two thirds of
451 participants (63.9%) reported it was harder to estimate the speed of the slow train (i.e., Train
452 3), even though their estimates of train speed for Train 3, were the least inaccurate overall.
453 Nonetheless, three participants found it harder to estimate the speed of the fast trains and
454 10 found the estimation of speed to be the same for both fast and slow trains. Overall, the
455 study results suggest participants were not entirely accurate with their speed perception of
456 fast travelling trains and the incongruity between the participants’ retrospective reports of
457 task performance and their actual task performance was substantial.

458 4. Discussion

459 The current study examined drivers’ perceptual abilities at identifying Australian high-speed
460 trains (100-140km/h). This included when the train was judged as moving as well as drivers’
461 decisions regarding gap acceptance for crossing manoeuvres in a field-based study. Data
462 was collected for four participants at the same time, in four separate vehicles. No difference
463 was observed due to the positioning of vehicles, which is not unexpected given that any
464 advantage of a particular vehicle position is small: the furthest vehicle was 15m further away
465 from the approaching trains than the closest vehicle, which was a small difference compared
466 to the distances of interest in this research (hundreds of metres). The position of the vehicle
467 was therefore not considered to be a confounding factor.

468 **4.1 Detection of trains and their movements**

469 All participants could identify trains travelling at 100-140km/h at long distances, which were
470 far beyond the longest sighting distances required at passive level crossing in Australia. It is
471 possible that trains were easy to detect even at a distance because they had daytime
472 running headlights (e.g., Cairney, 2003). Further, the distance that the participants first
473 detected the presence of a train on the rail tracks increased after the second observed train,
474 suggesting that the distance at which trains can be detected may be subject to practice
475 effects. That is, the participants might have learnt where the trains were due to appear on
476 the railway tracks in the distance, as well as the trains' particular features (such as the
477 headlights).

478 This study has shown that the movement of oncoming trains is much harder to detect than
479 simply perceiving the presence of a train in the distance. On average, the four trains were
480 perceived as moving 1,644m away, which was on average 505m closer to the participant
481 than when the trains were first perceived on the rail track. The present findings are
482 consistent with previous research that has demonstrated that it is difficult to visually
483 discriminate the movement of an approaching object, particularly when that object is a long
484 distance away as the rate of change in the optical size of the object is initially quite small
485 (Schiff and Oldak, 1990).

486 Large variability was observed between participants for the detection of trains and their
487 movement. The participant with the lowest performance identified that the train was moving
488 at a distance of 821m, which is within the range of the longest sighting distances required at
489 Australian level crossings (Standards Australia, 2015), demonstrating that drivers have the
490 ability to detect trains before it becomes dangerous to enter a passively protected level
491 crossing. At this distance, it would take approximately 23s for the faster VLocity train
492 travelling at 130km/h to arrive at the rail level crossing. Should the level crossing have had
493 an active level crossing device such as flashing lights installed, these lights would have
494 activated one second earlier (i.e., 24s before the train reached the crossing) than the train
495 would have been judged as moving for that particular participant.

496 **4.2 Accuracy of train speed estimations**

497 While participants were able to detect trains and their movement at the distances deemed
498 safe to make an informed decision regarding whether to enter a passively protected level
499 crossing, this study has demonstrated that participants were unable to accurately estimate
500 train speeds at any of the distances investigated. Speed was underestimated by at least
501 30% at all distances, and this underestimation was at its highest for the furthest distance,
502 reaching 44%. The speeds reported by participants were similar to those of motorway traffic,
503 suggesting that participants did not appreciate that trains can travel faster. Furthermore, this
504 underestimation did not improve with practice (results are similar for the four trains
505 observed). Speed estimations were more inaccurate at longer distances and for faster trains
506 (130km/h versus 110km/h). Numerous studies that have examined either speed perception
507 or the related concept of time-to-arrival of moving vehicles, have typically found speed
508 estimates are inaccurate (Caird and Hancock, 1994; Meeker et al., 1997; Savage, 2006).
509 Moreover, several studies have demonstrated that time to arrival estimates of approaching
510 vehicles is increasingly poorer the further away the approaching vehicle is from the driver
511 (Caird and Hancock, 1994; Schiff and Oldak, 1990).

512 **4.3 Self-assessment of speed estimations**

513 The present study demonstrates that participants' level of confidence with their estimates of
514 train speed was high, and not correlated with their actual level of underestimation/accuracy
515 for identifying the speed of the train.

516 **4.4 Effects on decisions to enter level crossings and safety**

517 The present study demonstrates that participants largely underestimated the speed of trains.
518 This means that drivers' ability to assess their risk of traversing a passive crossing will be
519 poor. In effect, when a driver erroneously believes they have sufficient safety margins to
520 traverse the crossing because of an underestimation of the travelling speed of a train, they
521 might cross with very limited safety margins (see Table 3). When stopped at a level crossing,
522 participants seem to make decisions about entering the crossing as if they were at a road
523 intersection, without appreciating that trains are very different (mass, ability to stop and
524 change direction) and travel at different speeds. For example, six participants reported that
525 they would enter the crossing when the train was less than 10s away. More generally, the
526 majority of participants (80.6%) reported that they would enter the crossing during a time
527 when flashing lights would be activated at an active level crossing. This underestimation of
528 speed may go some way to explaining results from previous research, where a substantial
529 proportion of drivers (57-77%) were observed to cross a passive rail level crossing when a
530 train approached (Kasalica et al., 2012; Tey et al., 2011). The decision a driver must make
531 about when it is safe to cross will be influenced by how confident they feel about their
532 perception of the train speed, which was shown in this study to be quite high, despite poor
533 performance. This study has also shown that experiencing a near-miss incident at level
534 crossings – or knowing someone who experienced such an event – did not make
535 participants more cautious in terms of deciding when it is safe to enter the crossing.

536 Potential solutions for improving safety at passive rail level crossings are limited. Certainly,
537 rail authorities in Australia are constantly upgrading rail crossings across the network;
538 however, it is impractical to upgrade all passive rail crossings to active rail level crossings
539 due to costs incommensurate to the level crossing risk, as such crossings are very
540 numerous, located in remote locations with no electricity and with low road/rail traffic. Thus,
541 improved knowledge and/or behaviours of road users is a more appropriate countermeasure
542 (e.g., Savage, 2006). It is unlikely that training drivers how to estimate train speeds would be
543 beneficial as participants' estimates of the trains speed did not improve with practice. In
544 contrast, the ability to detect the presence of trains did improve with practice. Australian road
545 rules require drivers do not enter a crossing when a train is approaching and there is a
546 danger of collision, leaving the evaluation of the risk to the driver. Therefore, training and
547 education campaigns should consider informing drivers about the human limitations of
548 accurately estimating oncoming train speeds and provide advice not to enter a level crossing
549 when a train is visible. Additional signs could also be placed at passive rail level crossings to
550 inform the driver that high-speed trains travel on this railway line and that speed estimation is
551 typically more difficult with high-speed trains. These countermeasures could result in safer
552 decision-making at passive level crossings. Indeed previous research has documented the
553 increased safety effects (i.e., speed approach reductions) of additional signage at rail level
554 crossings in both simulator (e.g., Lenné et al., 2011) and field-based studies (Ward and
555 Wilde, 1995).

556 **4.5 Strengths and limitations**

557 The present study used a unique real-world field study design which was specifically
558 designed to address the research questions. This approach overcomes many of the
559 limitations faced by similar studies that have been conducted in simulators or with videos,
560 which while being easier to conduct from a practical perspective, have limitations in terms of
561 validity and generalisability. Importantly, this study involved the development of a completely
562 novel methodology for the field evaluation of drivers' perceptions of a trains presence and
563 speeds and their decision-making at level crossings. These effects were assessed in a
564 sample of licensed drivers, stratified across age, whose results highlighted the inaccuracy of
565 their perceptions and decision-making.

566 There were, however, some limitations of the present study that should be considered when
567 interpreting the results. Participants were looking for trains over a longer period of time than
568 is typical under normal driving conditions and were primed for the approaching trains –
569 therefore the data represents that of an alerted driver and thus the driver's capacity to
570 correctly detect trains may be overestimated.

571 In order to achieve adequate sighting distance, train speeds and train traffic, it was not
572 possible to conduct the study at an actual passive level crossing due to safety and traffic
573 flow considerations. Thus, the data was collected at the side of a rail track rather than an
574 actual passive level crossing. Due to reduced train traffic and train variety in such
575 environment, it was not feasible to collect data with a higher variety of train and train speeds,
576 which would have provided a more comprehensive understanding of driver performance at
577 level crossings.

578 The purpose of this study was to explore for the first time perception and decision-making of
579 drivers regarding approaching trains in a field-based setting. We included a stratified sample
580 of participants to ensure representation of all ages of drivers up to 63 years old and who had
581 normal levels of visual acuity, (which also met the visual requirements for driver licensing)
582 and contrast sensitivity and were free of eye disease. The sample size of this study was not
583 sufficient to evaluate the effects of age on drivers' performance and decisions to enter level
584 crossings. We have therefore not looked at this particular issue, which, while of interest, is
585 outside the scope of this paper.

586 In addition, the study was performed during clear weather conditions only; it is possible that
587 different weather conditions or night conditions could result in different effects.

588 Lastly, the study results cannot be generalised to passive crossings with give-way signs as
589 all participants were in stationary vehicles during the study, or to other road users, such as
590 truck drivers.

591 **4.6 Future directions**

592 Further studies should seek to address the present study's limitations to better understand
593 the effects these different factors might have on the visual performance and decision-making
594 at level crossings.

595 In particular, our study only considered drivers alerted to the approach of a train. Drivers
596 stop at level crossings for short amounts of time, and may suffer from a range of distractions
597 while driving (such as speaking with other passengers, phoning, and even looking for trains

598 on the other side of the crossing). It would be of interest to understand how such effects
599 reduce the performance that we found in this study.

600 Given the specificities of trucks (longer vehicle frames and reduced acceleration capabilities)
601 and the extended risk they face at level crossings compared to typical sedan, there are
602 additional factors which need to be considered for truck drivers when crossing passive level
603 crossings, and further research should evaluate how such factors affect the results
604 presented in this paper.

605 This study focused on passive crossings with stop signs. Passive crossings with give way
606 signs present specific challenges (moving vehicle, sighting from a distance to the crossing)
607 and driver performance for such crossing should also be investigated. This would require the
608 development of a specific methodology.

609 **5. Conclusions**

610 The aim of the current study was to examine the accuracy of drivers' perceptual ability in
611 detecting the presence and movement of a train at a distance, and examine whether drivers'
612 performance in detecting trains affected their decisions to enter level crossings.

613 Distance from which drivers are first able to detect trains and their movement

614 The results demonstrated that participants were able to perceive a train at a distance of
615 ~2km and were able to determine that the train was moving after the trains had travelled
616 approximately 500m towards the participants' observation area. All participants were able to
617 detect the train at distances that are considered by Australian Standards allow drivers to
618 make safe decisions regarding entering the crossing.

619 Drivers' accuracy in estimating fast train speeds

620 All but one of the participants underestimated the travelling speed of the trains and the
621 magnitude of underestimation was greatest for the faster moving trains. The underestimation
622 was always greater than 30 percent below the actual train speed.

623 Drivers' evaluation of their speed estimates

624 The decision a driver must make about when it is safe to cross will be influenced by how
625 confident they feel about their perception of the train speed. This study has shown that
626 drivers were very confident in their speed estimates, despite poor performance by all drivers.

627 Drivers' decisions related to entering level crossings

628 Overall, the underestimation of train speed combined with the lack of drivers' knowledge
629 about their inaccurate perceptions could have significant safety implications with road users
630 crossing behaviours, with drivers entering level crossing with reduced safety margins. This
631 was highlighted in this study by the fact that most drivers reported they would enter the
632 crossing at a moment when it would have been activated if the crossing had active
633 protections. Further research is needed to examine if drivers decision making at rail
634 crossings can be improved and thus, increase the safety of both rail and road users.

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