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Train horns use at level crossings: A driving simulation study to examine their effectiveness in alerting motorist drivers

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1. Introduction

Train horns are primarily used as a critical warning tool to encourage safety-compliant behaviours from road users. Comparable to United Kingdom regulations (Hardy & Jones, 2006) in Australia, train horns should not be blasted without a valid reason and are required when a dangerous situation is anticipated (Queensland Rail, 2020). However, focus groups with Australian train drivers conducted by Naweed et al. (2021) revealed that train drivers viewed the train horn as an essential communication mechanism to interact with other road users. The train horn was described as an informative tool (i.e., to inform road users of an approaching train), often sounded multiple times to reinforce the imminence of a train's arrival, but also as an attentive tool to warn road users of danger (Naweed et al., 2021).

The review of the literature demonstrated that little work had been conducted to evaluate the effectiveness of train horns for alerting road users at level crossings with the approach of trains. The largest amount of research on train horns has focused on their negative effects on property prices (Bellinger, 2006; Meister & Saurenman, 2000), and health issues due to the noise residents living in the vicinity of level crossings are exposed to (Bunn & Zannin, 2016; Huang & Warner, 2010; Micheli & Farné, 2016; Trombetta Zannin & Bunn, 2014). Overall, the research suggested that these negative impacts outweigh the safety benefits of train horns. However, it is notable that limited information about the actual safety benefits of train horns was available.

A considerable amount of research has been conducted to evaluate road user behaviours at different level crossing types. Such research primarily includes in-situ observations or simulator studies. To date, no research has directly examined the safety benefits of train horns, but mainly focused on visual factors at level crossings, such as the type of signage at the crossing, the angle of intersection of the road and the rail tracks, or the presence of obstruction. The effect of auditory cues on safety at level crossings has not been evaluated independently of other factors, except for the United States train horn bans mentioned earlier. Only one other study considered auditory warnings, and this study combined field trial and driving simulation and focused on increasing vehicle drivers' situational awareness through in-vehicle audio warnings at level crossings when a train was approaching (Larue & Wullems, 2015).

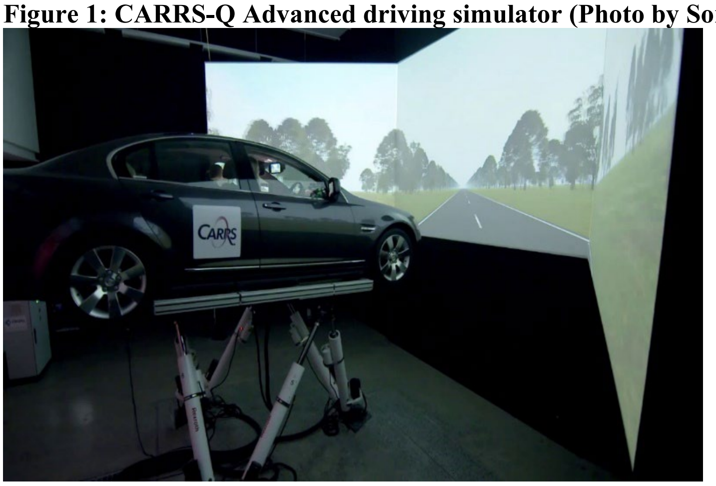
Overall, very little information is available on the effectiveness of train horns in warning road users, especially motorist drivers at the approach to level crossings. New evidence is needed to understand whether train horns remain beneficial for safety at level crossings in all contexts, as the road environment has largely changed since the last studies on train horns: high background sound volume environments, better soundproofing of vehicles and increased train traffic resulting in bells ringing at level crossings for extended periods of time. Moreover, given the relationship between noise complaints and usage of train horns during night conditions, it is important for research to consider the use of train horns at night, which has not been considered currently. The principal objective of this research is to understand how train horns are perceived by motorist drivers and how they affect the driver's behaviour around crossings in terms of safety by considering a range of relevant factors including level crossing type, train horn loudness, environmental noise and lighting condition (day/night).

2. Methodology

2.1 Apparatus

The study was conducted using the CARRS-Q Advanced Driving Simulator located at the Queensland University of Technology, as shown in Figure 1. It is a high-fidelity car simulator consisting of a full car body. The simulated environment incorporates 180 degrees of forward vision, a rear vision mirror and two side mirrors. Motion associated with operating the vehicle can be simulated in three dimensions via a 6 Degrees of Freedom motion system. The advanced driving simulator uses an interactive automotive modelling software SCANeR™studio 2022.1 to design scenarios.

Figure 1: CARRS-Q Advanced driving simulator (Photo by Sonja de Sterke)



2.2 Participants

A total of 47 Participants were recruited to participate in the study. Participants were recruited through social media posts, and emails which were shared with QUT classified and casual staff groups. The study was also advertised on QUT Psychology Research Management System (SONA). All participants were required to have held a valid driver's licence. Eight participants commenced but did not complete the study due to motion sickness experienced in the simulator, and one participant completed the night drive but did not return to complete the second day session. Eventually, 38 participants completed the whole experiment with complete data collection. Among the 38 participants, 18 (47.4%) were female and 20 (52.6%) were male. The participants were aged between 18 and 67 years old, with an average age of 34.8 years old and a standard deviation of 13.9 years.

2.3 Scenario design

The study used a mixed experimental approach that combines both between-subjects design and within-subjects design. At different level crossings, participants encountered different virtual visual and sound designs, which are representative of the measurements recorded in the field in a previous study. Overall, the study design consisted of combinations of the following factors:

- Level crossing type (within-subjects design): passive crossing with give-way signs and active crossing with flashing lights and bells;
- Train horn (within-subjects design): no train horn, low loudness (60dBA), and high loudness (80dBA);
- Environmental noise (within-subjects design): driving with music and driving without music; and
- Time of day (mixed design): day and night.

The road network is 40 km long and is composed of 18 railway level crossings (2 LX types x 3 train horns x 2 repetitions + 6 LX without trains) and unsignalised road intersections. It is a regional highway with a speed limit of 100 km/h, and the speed limit is reduced to 80 km/h around crossings, as in WA and VIC. The give-way sign was provided at level crossings with one track only, and flashing lights were provided at level crossings with two tracks. The design and set-up of the active and passive level crossings followed the Australia Railway Crossing Standard (AS-1742-7). The train was a tilt train and located at the same distance to the level crossing before it was triggered. The train was triggered to drive at a constant speed of 80 km/h when the simulator car was 25s prior to crossing, so that the train could arrive at the crossing at approximately the same time as the car.

2.4 Procedure

The study was conducted in accordance with the Australian Code for the Responsible Conduct of Research (QUT Ethic Approval Number 5265). Upon arrival, each participant was presented the Participant Information Sheet for further review and signed a consent form before commencing the study. Each participant was then briefed on the safety and operating procedures of the advanced driving simulator and the purpose of the study. Participants then completed a familiarisation drive with the driving simulator. The formal drive comprised of two approximately 35-minute simulated driving sessions, each with a different scenario containing 18 railway level crossings, with a secondary task (listening to music) present for one drive and absent for the other. To increase their engagement, participants were allowed to tune the music volume to their comfort level before the drive started. As this study consisted of both day and night elements, 21 participants completed the two driving sessions in both day and night conditions and the remaining 17 participants completed day condition only. After the experiment, participants were offered incentives (a $50 shopping voucher or course credit for QUT undergraduate psychology students) to thank them for their participation.

2.5 Driving behaviour measures and analysis

For both drives, drivers’ behaviour variables were extracted regarding each of the twelve level crossings that had a train crossing. The variables and their definitions are described below:

(1) Brake reaction time to horns (in s). This variable measures the time from when the train horn was sounded to the time when the drivers started to brake.
(2) Maximum deceleration rate (in m/s^2). This variable measures the maximum value of the deceleration rate that drivers applied when they approached the level crossing.

(3) Speed at 10s after horn was sounded (in km/h). This variable refers to the instantaneous speed at the moment when the train horn was sounded for 10s.

For driving behaviour measures, Generalised Linear Mixed Models (GLMs) were developed with the behaviour variables as the dependent variable, and train horn (no/low-loudness/high-loudness), level crossing control (passive/active), time of day (day/night), music (on/off), and the interaction between train horn and other variables as independent variables. The significance level of statistical tests performed in this report was 0.05.

3. Results

3.1 Brake reaction time to horns

For the n=928 observation with train horns, drivers started to decelerate after the train horn was sounded in 91.8% (n=852) of the observations. For the rest cases, drivers either decelerated before the horn was sounded or no deceleration was recorded. Drivers' brake reaction time to train horns under the impact of different factors was examined by GLMM, and the results were presented in Table 1. The model showed that crossing control type, horn loudness and the interaction between crossing control type and horn loudness had a significant effect on the brake reaction time to horns. Specifically, drivers at passive level crossings showed significantly longer reaction time to the horn compared to when they were at active level crossings. The low horn loudness was associated with a significantly longer reaction time compared to the high horn loudness. Regarding the interaction between crossing control and horn loudness, the difference found between low and high horn loudness was consistent for passive level crossings, while at active crossings, drivers' reaction time was slightly longer when high horn loudness was used compared to when low horn loudness was used.

Table 1: GLMM results of brake reaction time to horns

Model Term	Coefficient	S.E.	t	p	95% CI	
					Lower	Upper
Intercept	23.747	1.1847	20.044	<0.001***	21.422	26.073
Time (night)	.792	1.0055	.787	.431	-1.182	2.765
Music (on)	.339	.9008	.377	.707	-1.429	2.107
Crossing control (active)	-7.007	.9057	-7.737	<.001**	-8.785	-5.230
Horn (high)	-3.360	1.2008	-2.799	.005	-5.717	-1.004
Time*Horn (night*high)	-1.406	1.3144	-1.069	.285	-3.986	1.174
Music*Horn (on*high)	-.945	1.2498	-.756	.450	-3.398	1.509
Crossing control*Horn (active*high)	5.362	1.2539	4.276	<.001***	2.900	7.823

Note: The rest interaction items are set as referential contrast with coefficient being 0 and are not listed in the table (same for the tables below)

3.2 Maximum deceleration rate

The maximum deceleration rate that drivers applied while approaching level crossings was significantly influenced by crossing control type, horn loudness, the interaction between time of day and horn loudness, and the interaction between crossing control and horn loudness (see Table 2). In general, drivers tended to apply a larger deceleration rate at active level crossings compared to passive ones, and the high horn loudness was associated with a higher deceleration rate compared to the no-horn condition. For daytime driving, drivers used larger deceleration at low-loudness condition compared to the no-horn condition, while for night-time driving their deceleration in low-loudness horn was significantly lower than in no-horn condition. High-loudness horns led to a larger deceleration rate of drivers at passive level crossings. This means drivers braked later when there was a low-loudness horn than when there was no horn. crossings, but it was associated with a smaller deceleration rate for active level crossings.

Table 2: GLMM results of maximum deceleration rate

Model Term	Coefficient	S.E.	t	p	95% CI	
					Lower	Upper
Intercept	65.048	5.2930	12.289	<.001	54.665	75.431
Time (night)	3.205	4.0008	.801	.423	-4.644	11.053
Music (on)	6.718	3.6365	1.847	.065	-.416	13.851
Crossing control (active)	7.823	3.6365	2.151	<.05*	.690	14.957
Horn (high)	13.086	4.8287	2.710	<.01**	3.613	22.558
Horn (low)	5.375	4.8287	1.113	.266	-4.098	14.847
Time*Horn (night*high)	-8.426	5.4099	-1.557	.120	-19.038	2.187
Time*Horn (night*low)	-11.015	5.4099	-2.036	<.05*	-21.628	-.403
Music*Horn (on*high)	-7.430	5.1428	-1.445	.149	-17.518	2.659
Music*Horn (on*low)	-5.954	5.1428	-1.158	.247	-16.042	4.135
Crossing control*Horn (active*high)	-10.747	5.1428	-2.090	<.05*	-20.835	-.658
Crossing control*Horn (active*low)	2.563	5.1428	.498	.618	-7.525	12.652

3.3 Speed at 10s after horn was sounded

The speed at the moment when the train was sounded for 10s was significantly influenced by horn loudness, the interaction between time of day and horn loudness, and the interaction between crossing control and horn loudness. High-loudness horn significantly reduced drivers' speed after the horn was sounded for 10s in comparison to the no-horn condition. The low-loudness horns significantly reduced drivers' speed at night-time driving (compared to daytime driving) and at active level crossings (compared to passive crossings) when no-horn was used as a baseline.

Table 3: GLMM results of speed at 10s after horn was sounded

Model Term	Coefficient	S.E.	t	p	95% CI	
					Lower	Upper
Intercept	90.804	1.6454	55.187	<.001	87.576	94.031
Time (night)	.364	1.2245	.297	.766	-2.038	2.766
Music (on)	-.038	1.1128	-.034	.973	-2.221	2.145
Crossing control (active)	-.528	1.1128	-.475	.635	-2.711	1.655
Horn (high)	-4.244	1.4776	-2.872	<.01**	-7.142	-1.345
Horn (low)	-.335	1.4776	-.227	.821	-3.234	2.563
Time*Horn (night*high)	-2.830	1.6554	-1.710	.088	-6.077	.417
Time*Horn (night*low)	-3.291	1.6572	-1.986	<.05*	-6.542	-.040
Music*Horn (on*high)	-.262	1.5737	-.167	.868	-3.349	2.825
Music*Horn (on*low)	.461	1.5746	.293	.770	-2.628	3.550
Crossing control*Horn (active*high)	.931	1.5737	.592	.554	-2.156	4.018
Crossing control*Horn (active*low)	-4.775	1.5746	-3.032	<.01**	-7.863	-1.686

4. Discussion

The use of train horns, especially high-loudness horns (80dBA in this study) was found to improve drivers' behaviour performance in the process of approaching level crossings, and the improvement was more substantial in certain environmental circumstances. Low-loudness horn (60dBA in this study) was considered less effective as a warning in influencing drivers' braking behaviour compared to high-loudness. Drivers' brake reaction time was a critical and commonly used measure in the literature to inform drivers' ability to avoid risks in safety-critical situations (Johansson & Rumar, 1971). In this study, drivers' brake reaction to horns was faster in high-loudness horn condition compared to low-loudness. It is possible that when drivers encounter a low train horn, the message may be interpreted not as a warning of danger but as drawing attention to the presence of the arrival train, thus resulting in a slower reaction than the louder train horn. The impact of high-loudness in shortening driver reaction time was more prominent at passive level crossings and night-time driving. Moreover, high-loudness horns were found to increase drivers' maximum deceleration rate at passive level crossings and reduce drivers' speeds after they were sounded compared to the conditions without train horns.

Compared to active crossings where drivers can rely more on the flashing lights to inform decisions, passive crossings require more attention from drivers based on the information they perceive and assess from the surroundings to make stop/go decisions. In a Victorian study, drivers reported that flashing lights represent a strong association with rail level crossings and indicate danger more actively (Rudin-Brown et al., 2010). Their study also found that driver compliance at passively controlled level crossings was unexpectedly low, and 40% of drivers made violations of the stop-sign controlled level crossing (Rudin-Brown et al., 2010). The finding of the current research highlights the safety benefits of using high-loudness horns at passive level crossings in prompting drivers to take a faster and more decisive deceleration action. Similarly, night-time driving constitutes more risks than daytime driving due to a number of factors, including driver sleepiness, low luminance conditions, road signs and markings, driver age and experience (Bella et al., 2014). An earlier deceleration at night-time guided by a loud train horn would be helpful to compensate for the negative impacts of night-time driving caused by sleepiness and reduced visual search capabilities.

The study did not find a significant role from music in influencing drivers' behaviours either by itself or by interacting with other factors. Listening to music was mostly designed as a distracting factor instead of an environmental noise in prior research, and the findings were mixed depending on the type of music used (Brodsky 2001; Karageorghis et al., 2021). It is suggested that more research should be conducted regarding the loudness and type of music to examine these features' intervention effect with train horn sound. Given the findings that a higher level of horn loudness played a more significant role at passive level crossings, the necessity of using train horns at active level crossings should be re-evaluated. The residential areas that have more active level crossings may consider train horns more of a noise nuisance than an effective safety measure. This signifies that the perspective of residents living near these crossings is highly likely to be an important performance-shaping factor and should be included in future research.

5. Conclusion

A driving simulator experiment was conducted in this research to investigate the effectiveness of train horns in raising drivers' awareness of the approaching train and improving their crossing behaviours at level crossings. The study examined a broad range of environmental factors, including environmental noise (in-vehicle music), level crossing control (active/passive), time of day (day/night), train horn loudness (no/low/high) and the interaction between them. The research findings show that high-loudness horns were effective in improving drivers' behaviour performance in approaching level crossings in certain environmental circumstances (e.g., night-time driving, passive level crossings). High-loudness train horns significantly shortened drivers' brake reaction time, especially for passive level crossings and night-time driving, and increased drivers' maximum deceleration rate and reduced drivers' speeds after the horns were sounded. Over, the study provided a better understanding of how drivers' behaviours were influenced by train horns in different level crossing contexts.

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