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Train Horn – Broader Social Effects and Pedestrian Simulations

Final Report

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Corresponding Personnel

Dr. Xiaomeng Li
Research Fellow
CARRS-Q, QUT
Email: xiaomeng.li@qut.edu.au
Telephone: +61 7 3138 4749 (office)

Paul Murray
Program Manager, ACRI
Email: paul.murray@acri.net.au
Telephone: +61 422 117 367

Project team members

Key Personnel Paul Murray (ACRI) Dr Xiaomeng Li (QUT) Tracee Pratt (ACRI) Paul Bennett (ARRB) Karin Cooke (TMR) Prof Andry Rakotonirainy (QUT)	Other Personnel Wanda Griffin (QUT, Research Officer) Melinda McDonald (QUT, Research Officer) Fatemeh Ghorbani (QUT, Research Officer) Pete Coughlan (QUT, Research Officer) Bryn Ellis (QUT, Research Officer) Zishuo Zhu (QUT, Research Officer) Lewis Cockram (QUT, Research Officer)

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Train Horn - Broader Social Effects and Pedestrian Simulations

Authors
Xiaomeng Li
Melinda McDonald
Fatemeh Ghorbani

Ethics Statement

Ethical clearance for human participant experiments was obtained from the Queensland University of Technology (QUT) (Approval Number: 5229).

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Executive Summary

Level crossings are crash-intensive locations. Train horns are commonly used at Australian level crossings as an essential warning tool to alert road users of approaching trains. However, research on the effectiveness of train horns as a device for warning level crossing users, especially vulnerable road users such as pedestrians, is limited. Another concern related to train horn use is their noise impacts on nearby communities and the environment. Specifically, concerns about train horns' impact on residents’ sleep disturbance and health functioning have been raised in recent years. It is a critical but challenging task to balance the safety function of train horns with the need to minimise the noise pollution caused by them.

This iMOVE CRC project aimed to examine the effectiveness of train horn use on pedestrians at level crossings and also investigate the negative noise impact of train horns on the local community. The first part of the project expanded on an earlier ACRI project that looked into train horn effectiveness from driving simulator experiments. It utilised virtual reality (VR) equipment on pedestrian participants, and the experimental design was informed by the ACRI project. The second part of the project conducted a subjective questionnaire study and an objective observation study consecutively to investigate the impact of train horn sounds on the sleep quality and mental health of residents who lived near train stations or railway lines. This project completed the investigation of both positive and negative impacts of train horn use in a wide range of road, pedestrian and broader community scenarios to inform transport industry organisations and policy makers of future train horn procedures and applications.

Methodology Summary

Stage 1: A kick-off workshop was conducted at the first stage with rail industry partners prior to the launch of the research to refine the project scope and methodology design.

Stage 2 Pedestrian simulations and analysis

- A VR experiment was conducted using the Oculus Rift VR headset and SCANeR studio software.
- Factors that were studied comprised level crossing control type (passive/active), train horn loudness (60dBA/80dBA), and environmental noise (music on/off).
- A total of 37 participants completed the study, comprising 24 females and 13 males.
- The think-aloud approach and a questionnaire were used during the experiment.

Stage 3 Online broader social effects survey

- A questionnaire was designed to collect participants’ emotional states, noise sensitivity, sleep quality, exposure to train horns, railway activity-related sound, vibrations, and light, etc.
- A few train stations were selected to distribute survey flyers around, i.e., Lawnton, Burpengary, Cannon Hill, Keperra, Alderley, Newmarket, and Windsor.
- N=334 participant responses (50% females and 50% males) were used for data analysis.
- Three participant groups were considered: train horn impact group (Zone 1), railway-related sound impact group (Zone 2) and non-impact group (Zone 3).

Stage 4 Actigraphy study

- N=36 participants were recruited to take part in data collection for seven days.

- Half of the participants were from impact zone around Newmarket, Windsor, Alderley, Lawnton and Cannon Hill stations. The other half was the baseline group.
- The GENEActiv device was used for participant sleep measurement. The NSRT_mk4 was used for measuring sound levels at participants' residences. The NGARA system was used for recording train horns at train stations.
- A Sleep dairy form and questionnaire were used for subjective data recording.

Project Findings

- Most pedestrians (82%) stopped at the level crossings after they perceived the approaching train and before the train horn was sounded.
- The use of train horns (on either loudness level) did not show any significant influence on pedestrians' walking behaviour and decision-making.
- Level crossing control significantly influenced pedestrian crossing behaviour, and pedestrians behaved more cautiously at active level crossings than at passive level crossings.
- Residents in the impact zone reported significantly poorer subjective sleep quality and longer sleep latency than participants living in the baseline zone.
- Night time train horn frequency and noise sensitivity were significant factors for predicting sleep quality in terms of good or poor.
- Increased train horn frequency at night and higher noise sensitivity increased the likelihood of participants being involved in the poor sleep quality group.
- Participants' emotional states, i.e., depression, anxiety and stress levels, were not influenced by train horns.
- Objective sleep metrics did not differentiate between the impact group and baseline group.
- The equivalent noise levels during day, night and evening time did not differentiate between the impact zone and baseline zone.
- Train horn sound impulsiveness rate was negatively associated with total sleep time.
- The maximum sound pressure level and sound impulsiveness rate of NGR trains were significantly higher than EMU/IMU/SMU trains.

Conclusions and Future Directions

The project provided a comprehensive understanding of how train horns influence pedestrians' crossing behaviours and residents' sleep quality and mental health. Pedestrians' crossing behaviours and decision-making were not impacted by the use of train horns but were more influenced by the active/passive level crossing control. Residents who live in close proximity to train stations or whistle boards reported poorer subjective sleep quality and longer sleep latency than those who live a bit further away from those infrastructures. However, this was not supported by objective data observation. Night time train horn frequency was associated with the likelihood of participants being classified in the good/poor sleep quality group, while train horn impulsiveness rate was negatively associated with participants' total sleep time. Based on the current project, future research could further examine the effectiveness of train horns on other types of road users, such as motorcyclists and cyclists, as it was suspected that train horns' effectiveness on road users was largely related to the road users' physical dynamics and behavioural/psychological attributes. The requirement of sounding train horns at active crossings as a practice could be re-reviewed, given the marginal effect of train horns observed on both motorists and pedestrians. Modifications on train horn acoustic features (e.g., impulsiveness rate) and the location to release train horn warnings could be further studied in the future to maximise its alertness effect and minimise the noise impact.

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Definitions

ACRI	Australasian Centre for Rail Innovation
CARRS-Q	Centre of Accident Research and Road Safety – Queensland
QUT	Queensland University of Technology
QR	Queensland Rail

1 Introduction

This report presents a comprehensive investigation into the use of train horns at rail level crossings undertaken by iMOVE Australia and the Australasian Centre for Rail Innovation (ACRI), focused on obtaining a deeper understanding of train horns' impact on the self-reported sleep quality and mental health of residents living near railway lines. This document consists of a brief illustration of Stage 2 (pedestrian simulations and analysis) and Stage 3 (online broader social effects survey) methodologies and main findings, as well as a more detailed report of Stage 4 research regarding the actigraphy study based on objective data collection analysis. Note that the detailed reporting of Stage 2 and Stage 3 studies could be found in the submitted milestone reports.

1.1 Background

Train horns have effects broader than for railway level crossings and road safety. Noise-related complaints and disturbances have regularly been reported by members of the community to many railway organisations. The sounding of train horns at night often leads to sleep interruption complaints, particularly in built-up environments. Despite this, there is very limited objective evidence of the direct cause and relationship of disruption between critical safety elements such as the train horn. This study looks to address this with an objective approach. The second part of this study will complete a series of pedestrian-based simulation experiments to fully understand the effectiveness and unintended impacts of train horns in the most common scenarios where humans interact with train horns as a warning device.

The last stage of the project - the actigraphy study, provides an objective assessment of the participants' sleep-wake timing and functioning when combined with an objective assessment of the environmental conditions. A subset of participants who completed the Stage 3 survey study were invited to take part in the actigraphic assessment of sleep-wake timing and functioning via actigraphs and its relationship with train horn noise. The study was conducted with residents living around level crossings, train stations and yards at moderate to high horn-use locations as well as a comparable control site.

1.2 Research objectives

The principal objective of this project is to understand the effects of train horns on residents living near railway lines, assess the impact of train horns on sleep quality and contextualise the findings on sleep timing and functioning with environmental noise due to train horns. The second objective of the study is to investigate how train horns are perceived by pedestrians and how they affect their behaviour around crossings in terms of safety.

1.2.1 Structure of the report

This Final Report has the following structure:

Section 1: Presents the background of the project and the research objectives.

Section 2: Presents a comprehensive literature review on train horn use, its positive and negative impact, and the impact of general traffic noise, with a focus on sleep quality research.

Section 3: Presents the methodology and main findings of Study 1 - pedestrian simulations and analysis.

Section 4: Presents the methodology and main findings of Study 2 – online broader social effects survey.

Section 5: Presents the detailed methodology and findings of Study 3 – actigraphy study.

Section 6: Presents the implication and discussion of the results.

Section 7: Summarises the limitations and future research directions generated from the project.

2 Literature review

Level crossings are recognised as a high-risk location for collisions between trains and other road users/pedestrians. If a vehicle or person enters the tracks without warning, it is incredibly difficult for train drivers to react and slowdown in time to prevent a collision (Larue et al., 2021a). Train horns are a safety feature used to mitigate the risk of collisions by audibly warning approaching level crossing users of the imminent train.

As outlined in the Rail Traffic Horn Use Code of Practice (Rail Industry Safety and Standards Board [RISSB], 2022), Australian rail network vehicles are generally required to be fitted with at least one operational horn. Railway drivers must sound the train horn at passive level crossings and can choose whether to sound the horn at active level crossings. When using the train horn at level crossings, it is to be sounded either at the whistle board (where fitted), when approaching the level crossing, or when on the level crossing. Train horns can be sounded at a low or high intensity level. The low intensity horn is for mandatory/non-emergency use, while the high horn is to be used in emergency situations only. The volume of the horn must also be loud enough to be heard above general environmental noise and other potential distractions (e.g., the use of personal devices), and the sound of the train horn must be clearly distinguishable from road vehicle horns.

While the purpose of train horn use is to improve safety by alerting level crossing users of the approaching train, this auditory warning system can also have an unintended negative effect on residents living near railway infrastructure. Balancing the need for safety with consideration for the health and wellbeing of residents is an ongoing challenge for rail transport operators. In Australia, addressing the complex issue of the impact of train horns is hindered by a lack of contextually relevant academic research that could provide valuable insight into the social costs and benefits of train horn use.

2.1 Level crossing safety issues

The Australian railway network includes more than 20,000 level crossings, each of which poses a potential safety risk to road users (Office of the National Rail Safety Regulator [ONRSR, 2022). Accidents occurring at level crossings account for the highest number of railway-related fatalities in Australia (Cikara et al., 2022). In the 2021-2022 reporting year, there were 41 reported collisions (causing six deaths and five serious injuries) and 742 near misses between trains and other road users/pedestrians at Australian level crossings (ONRSR, 2022). Collisions between trains and level crossing users have largely been attributed to crossing users (intentionally and unintentionally) violating the road rules. Intentional violations (e.g., crossing deliberately after warning systems have been activated) are largely considered to be a result of impatience (e.g., Freeman & Rakotonirainy, 2015; Larue & Naweed, 2020). For example, research examining driver behaviour found that of the approximately 60% of drivers who entered a level crossing once the lights were flashing, 1 in 10 had intentionally ignored the warning. In addition, level crossing violations have been observed to occur most frequently when the waiting time exceeds 3 minutes (Larue et al., 2020a). Research suggests that pedestrians are noncompliant more frequently than drivers, with nearly one-quarter of pedestrian participants in one study reporting deliberately entering an active crossing (Freeman & Rakotonirainy, 2015). Pedestrians also report a lower perceived risk of being struck by a train (Stefanova et al., 2018), which may account for the higher incidence of level crossing noncompliance compared to drivers.

However, collisions between trains and other road users/pedestrians are not exclusively due to noncompliance and also occur via unintentional violations of the level crossing rules. Factors that have been shown to influence unintentional violations by drivers include receiving inadequate warnings (e.g., Larue & Naweed, 2020), driver inattentiveness (e.g., Young et al., 2015), and driver distraction (e.g., Young et al., 2018). For example, Australian research showed that drivers who were texting while approaching a level crossing were significantly slower to react to warning systems, taking approximately 14.5 metres longer to brake in response (Young et al., 2018). Other studies suggest that drivers in busy urban areas pay little attention to level crossing infrastructure when approaching and instead rely on the behaviour of other drivers to alert them to the presence of trains (Young et al., 2015). For pedestrians, the limited available research on unintentional level crossing violations has focused primarily on distraction due to mobile phone use. Australian research has shown that although only a very small proportion (3%) of level crossing pedestrians are considered highly distracted, these individuals engaged with their mobile phones for a significantly longer time (Larue & Watling, 2022). Moreover, the proportion of distracted pedestrians observed in this study is significantly lower than in studies examining mobile phone distraction (and the associated adverse consequences) in pedestrians crossing road intersections (e.g., Horberry et al., 2019), indicating a need for further research to investigate pedestrian distraction in road and rail contexts.

2.2 Impact of train horns on level crossing safety

Historically, research examining the positive impacts and perceived safety benefits of train horn use has largely been extrapolated from the consequences of introducing train horn bans and time-of-use restrictions. For example, a study examining the effects of a nighttime train horn ban at select active level crossings in Florida, United States found that the overnight collision rate increased by 195% (from 39 collisions to 119 collisions) over the six years that the ban was active (Federal Railroad Administration [FRA], 1995a). Further research from the FRA found that the removal of train horn bans resulted in the number of collisions at level crossings (varying in type and location) decreasing by an average of 38% across the United States, with Florida reporting a 69% reduction (FRA, 1995b).

However, more recent research suggests that the ways in which train horns promote safety at level crossings are nuanced and depend on multiple factors. For example, different types of level crossing users rely on different environmental cues to inform their crossing behaviours. Drivers and motorcyclists have been shown to rely more on visual information at level crossings, whereas pedestrians and cyclists rely more on auditory information (e.g., Beanland et al., 2016; Mulvihill et al., 2016). Although these studies focused on the sound of crossing bells and the train itself, the findings suggest that the use of train horns may provide an additional layer of safety for pedestrians. The need for pedestrian warnings is particularly relevant as the incidence of pedestrian distraction is seen to be increasing, particularly in terms of mobile phone use (e.g., Horberry et al., 2019; Larue et al., 2020b; Simmons et al., 2020), and the sudden warning offered by train horns may mitigate the risk of collisions with distracted pedestrians.

Additional research indicates that the timing, volume, number and duration of time horns influence their effectiveness as a warning device for level crossing users. An Australian experimental study examining the detectability of train horns across various horn-related, participant-related and environmental factors found that longer duration horns and loudest blast horns were more likely to be detected (Larue et al., 2023). However, participants also found it more difficult to discern which direction the train was coming from when the horn was louder. A separate study noted that using the train horn once when closer to the level crossing provides a more effective warning to road users than sounding the horn multiple times upon approach (Larue et al., 2021). Moreover, findings from observational field and laboratory studies have shown that train horns are harder to detect at active level crossings with bells, which may render their use redundant (Larue et al., 2021; Larue et al., 2023). A recent case study examining an incident where a train collided with a truck at a passive level crossing also revealed that although witnesses heard a train horn, the driver of the truck reported that his windows were wound up, and he did not hear the horn until the train was close to striking (Nemire, 2023). When considering pedestrians specifically, some research suggests that the use of train horns may not effectively warn pedestrians who are listening to music using headphones due to the competition for auditory attention (Larue et al., 2023). Taken collectively, the current literature suggests that train horns may provide some safety benefits as a warning system in certain situations for certain populations of road users. However, further research is required to determine the ideal specifications for train horn use.

2.3 Broader social impact of train horns and railway-related noise

Despite the utility of railway networks and the safety benefits offered by auditory warning systems, the noise generated by train horns and other railway-related activity can have adverse social effects on nearby residents. Railway-related noise has been shown to negatively impact the physical health of residents, with associations being observed between noise exposure and an increased risk of hypertension (Petri et al., 2021), stroke (Seidler et al., 2018), cardiovascular disease (Herzog et al., 2019; Vincens et al., 2023), diabetes (Vincens & Waye, 2022) and sleep disturbance (Eriksson et al., 2017). Exposure to railway-related sound has also been linked to poorer overall mental health (Li et al., 2022), as well as specific psychological disorders such as depression (Siedler et al., 2017) and anxiety (Lan et al., 2020), and poorer cognitive functioning (Tassi et al., 2013). Outside of health impacts, railway-related noise has also been shown to have financial impacts on homeowners with research showing trends where property values decrease alongside increases in railway noise (Bellinger, 2006). Furthermore, recent research also suggests a relationship between railway-related noise and social inequality, whereby individuals with lower socio-economic resources may be exposed to more noise as they are unable to afford housing, railway infrastructure and/or appropriate sound insulation (Welch et al., 2023). While some of these outcomes may be mediated by other factors such as noise sensitivity (Welch et al., 2023) and policy and urban planning (Li et al., 2022), the boarder social impacts of railway-related noise warrant investigation, specifically within the Australian context.

2.3.1 Train horns and railway traffic sound

The sound produced by train horns comprises multiple acoustic qualities, such as the volume, tone, and sharpness of sound. The most common acoustic quality of train horns investigated in the literature is volume. Train horn volume is commonly measured according to the sound pressure level (L_p). The sound pressure level is considered the closest parallel to human perception of loudness and is the standard measurement for research on noise-related health outcomes (World Health Organization, 2018). To emphasise the frequencies that align with the normal range of human hearing, A-weighting is applied arithmetically to measure sound pressure level and expressed in A-weighted decibels (dBA).

A commonly used measure in acoustical research is “Day-evening-night level” (L_{den}), which expresses the average noise level of a measurement area measured over an entire day (Lerchet et al., 2010; Seidler et al., 2023) and incorporates a ‘penalty’ for sound produced during the evening (5dB) and night (10dB) to account for annoyance and sleep disturbance caused as a result. Although L_{den} is ubiquitous in noise exposure research, some have suggested it is inappropriate to interpret alone when investigating the effects of single noise events (such as train horns) as although these events are significantly louder compared to environmental noise, and they are also very brief (Griefhan et al., 2000). Thus, interpreting the average sound level pressure of the entire night may provide misleading results. To address this issue, research investigating train horns and other railway-related noise often measured the mean highest sound pressure level recorded across all trains that passed throughout the night, which may be A-weighted ($L_{p,A,\text{max}}$, e.g., Amundsen et al., 2011) or not (dB SPL, e.g., Larue et al., 2021). Alternatively, some research adopts the measure $L_{Aeq,}$ which denotes the A-weighted equivalent continuous sound-pressure level, in dB, averaged over a specific time frame, such as an entire night (e.g., Aasvang et al., 2011), or a single hour (e.g., Rudzik et al., 2018).

In Australia, there are no standardised national guidelines for traffic noise (railway or road). Instead, each state and territory has individual guidelines set by the relevant governing body. However, the appropriate noise level ranges are relatively similar across jurisdictions. Generally, the noise limits for road traffic range between L_{Aeq} levels of 55-65 dBA during the day and 50-60 dBA during the night (e.g., Department for Infrastructure and Transport, 2021; Department of Transport and Main Roads, 2013). However, Brown and Bullen (2003) found that up to 20% of residents in urban areas of Australia’s mainland capital cities were exposed to $L_{A10,18h}$ (where L_{A10} is the noise level exceeded for 10 per cent of the measurement time, and $L_{A10,18h}$ is the average of L_{A10} noise levels from 6 am to midnight). the average noise levels over the 18-hour period between 6 am and midnight) over 63dB in road traffic noise, and up to 11% were exposed to over 68 dB. For railway traffic, the limits range between L_{Aeq} levels of 50-65 dBA for continuous measurements and $L_{p,A,\text{max}}$ levels of 79-87 dBA for single event maximum measurements. Depending on the time of day (day versus night), the type of railway line regarding whether it is new or existing/being upgraded, and the period of measurement (Department of Planning, Lands and Heritage, 2019: Department of Transport and Main Roads, 2019; Environmental Protection Authority, 2013). To be an effective warning system, train horns must compete with surrounding environmental noise to capture the attention of road users. Australian guidelines stipulate that the acceptable SPL for train horns is 96 dBA to 101 dBA in urban areas, and in non-urban, the minimum acceptable level (at 30m away from the train) is 106 dBA (RISSB, 2016). Recent research by Larue et al. (2021) investigating the use of train horns at 54 level crossings across Australian found that train horn volume ranged between 51.3 dBA and 116.2 dBA (M_{dBA} = 82.2, *SD* = 11.0), with 95% of horn sounding between 61.5 dBA and 106.3 dBA. On average, train horns were found to be 23.8 dBA (*SD* = 12.8) louder than environmental noise, and most horns (76.0%) were louder than the recommended threshold required (+15 dBA) to alert level crossing users of the presence of the train. However, a large amount of variability was noted in train horn use and characteristics of use (e.g., volume, duration, timing) across all factors investigated (i.e., urban versus rural locations, active versus passive crossings, within individual crossings), indicating a disconnect between policy and practice. Of relevance to the present research, the study found that some train drivers tended to use shorter, lower volume horns. This was interpreted as a potential attempt to avoid disturbing nearby residents while still appeasing required horn use regulations and further highlights the challenge of striking a balance between safety for level crossing users and consideration for health and wellbeing for the people who live near railway infrastructure.

2.3.2 Noise impacts of train horns

Research has primarily focused on the negative impacts of train horns, specifically regarding concerns about increased environmental noise in residential areas and decreased property values. For example, studies conducted in the United States have suggested an estimated average 4.1% decrease in property sale value for every 10dB increase in train horn exposure (Bellinger, 2006), with some research indicating that residents living in areas where train horn use is not banned may experience net property losses of up to US$1.0 billion (Schweiterman & Baden, 2001). Similar findings have been observed in Europe, with estimates from a Norwegian study suggesting that doubling the distance between houses and the railway line could increase property value by approximately 10% (Strand and Vågnes, 2001). However, recent Australian research offers contrasting findings. Studies conducted in Melbourne suggest that the increased frequency of trains, coupled with closer proximity to the station, can alter residential property values from -4.01% to 2.71% (Li et al., 2020), with some research suggesting an increase as high as 8.7% for residential properties within 800m of a train station (Zhang & Shukla, 2023). However, it should be noted that the estimation presented in the latter study was based on a proposed rather than existing train station, and neither study considered the impact of train horns or other train-related noises.

It has also been argued that residents are left to bear the cost of measures designed to increase level crossing safety. For example, a cost-benefit analysis by Cushing-Daniels and Murray (2005) showed that property values in areas where train horns were banned were significantly higher than those where train horns remained in use. Although the findings also showed that banning train horns could lead to an increase in level crossing accidents (up to approximately 0.15 accidents every 5 years) at a cost of almost $800K per level crossing (due to human life lost), the number of properties in the area would have to be significantly reduced (to no more than 160 properties) for the estimated benefits associated with lives saved to outweigh the losses in property value. The impact of increased environmental noise due to train horns also has been reported to impact the health and wellbeing of residents living near level crossings. One study reported that train horns were consistently sounded at volumes louder than the legal daytime limit, up to 47dB louder for homes closest to the railway line (Zannin & Bunn, 2014). The results from the accompanying survey showed that the majority of the 130 participants reported that train noise was a source of irritation (95%), led to poor concentration (88%), and caused headaches (96%). All participants (100%) also cited that, among all sources of environmental noise, train noise caused insomnia. Although the survey did not ask about train horns specifically, given that train horn volume frequently exceeded the legal limit, it is reasonable to assume that horn use contributed, at least in part, to these issues. Moreover, additional research by Bunn and Zannin (2016) showed that environmental noise levels in residential areas near level crossings could be reduced by 10-30 dB by stopping the use of train horns alone. Bellinger (2006) investigated the impact of train horn noise by gauging how much residents living near the railway line would be hypothetically willing to pay to stop train horn noise. The findings showed that participants were willing to pay up to $30.18 per month to stop train horn noise. Those who reported greater daytime annoyance, greater nighttime annoyance and lower sleep quality showed more willingness to pay, with stronger correlations observed between the latter two.

In sum, although there is evidence supporting the argument that train horn use creates a source of undue distress and financial burden for nearby residents, it could also be argued that you cannot put a price on human life and underscore the complexity surrounding the use of train horns.

2.3.3 Other negative outcomes from railway-related activity

Train horns are not the only aspect of railway-related activity associated with negative outcomes. Disturbance caused by other noises and the vibrations generated by passing trains have also been shown to adversely affect residents living near railway lines in terms of poorer health outcomes, annoyance, and sleep disturbances. Exposure to railway-related noise and vibrations has been linked to cardiovascular complications such as hypertension (Petri et al., 2021), ischaemic heart disease (e.g., Vincens et al., 2023), and heart attack (Seidler et al., 2016). For example, Seidler et al. (2016) found that the risk of heart attack increased by 2.3% for every 10dB increase in railway-related noise, with the odds increasing significantly when exposed to noise levels of 60dB or more during the night. Railway noise has also been shown to have the strongest association with elevated blood pressure when compared to road and aircraft noise (Petri et al., 2021).

Research has also shown an exposure-response relationship between railway-related activity and annoyance for residents living nearby. Findings from a meta-analysis by Guski et al. (2017) revealed that the odds of being highly annoyed were three times higher when railway noise levels increased from 50dB to 60dB, while similar linear relationships continue to be demonstrated in more recent literature (e.g., Brink et al., 2019; Romero Starke et al., 2023). Vibration caused by passing trains has also been shown to significantly impact annoyance (e.g., Seidler et al., 2023) to varying degrees depending on the type of train and the distance between the track and the place of residence. For example, research by Maclachlan et al. (2018) found that the odds of being annoyed by vibrations when living within 100m from the track ranged from 1.7 for passenger trains to 5.3 for freight and diesel trains. Moreover, vibrations were deemed to induce significant annoyance at distances up to 200m for passenger trains and 300m-400m for diesel and freight trains, respectively. The potential of an additive effect from the combination of railway-related noise and vibrations on annoyance has also been investigated with mixed results, with some studies observing with some studies suggesting an additive effect (e.g.,-Koziel, 2012), while others suggest there is little to no interaction (e.g., Maigrot et al., 2020).

The impact of railway-related activity on sleep disruption has been widely considered. Railway noise has been shown to have the greatest impact on self-reported sleep quality and physiological measures of sleep compared to road and aircraft noise (e.g., Elmenhorst et al., 2019), with research suggesting both immediate and long-term effects. In terms of immediate impacts, a systematic review of polysomnographic data by Basner and McGuire (2018) revealed that the probability of waking up increased by 35% for every 10dBA increase in railway noise. In addition, an experimental study that compared sleep quality and cognitive performance between long-term residents living near train lines and residents of quiet locations found that both groups reported poorer sleep quality following train noise exposure nights (Tassi et al., 2013). However, those who lived near train lines also exhibited poorer cognitive performance and higher levels of daytime sleepiness regardless of the noise exposure the previous night and despite not reporting significant daytime sleepiness. Overall, these results suggest that that long-term exposure to railway noise may result in chronic sleep-deprivation, evidenced by deficits in attention and performance, that individuals may not even realise they are experiencing. There is also evidence to suggest an exposure-response relationship between railway vibrations and sleep (e.g., Smith et al., 2013; Waye et al., 2019). For example, a study by Waye et al. (2019) that compared the effects of vibration on sleep observed in laboratory versus field studies found that the odds of sleep disturbance increased by 3.5 per unit of increased nighttime vibration exposure, with no significant difference observed between conditions. However, these findings have been criticised for failing to find a relationship between vibration and high sleep disturbance (Seidler et al., 2023). The combined effects of railway noise and vibrations on sleep have also been investigated, and current research appears to be in support of an additive effect. For example, some research examining physiological measures of sleep has indicated that noise and vibrations are processed simultaneously in separate brain regions, leading to an additive effective on depth of sleep and arousal levels (Smith et al., 2017).

2.4 Research on sleep quality under the impact of traffic noise

Adequate sleep (7-8 hours per night) is vital for maintaining and optimising physical, emotional, and cognitive health and performance (Chaput et al., 2020). The restorative functions of the different stages of sleep collectively serve to clear neurotoxic waste from the brain, modulate hormone levels to support immune function, and facilitate learning and memory consolidation (Léger et al., 2018; Steffey et al., 2023). Sleep deprivation refers to the state of having inadequate sleep duration and/or quality and can be considered acute (no sleep or reduced sleep duration over a short period of time i.e., a few days) or chronic (reduced sleep duration, including disrupted/fragmented sleep, over a longer period of time i.e., weeks/months) (Steffey et al., 2023). Recent meta-analyses and reviews have indicated links between sleep deprivation and an increased risk of all-cause mortality and adverse physical and mental health outcomes, including cardiovascular disease, diabetes, obesity (Itani et al., 2017), physical performance (Craven et al., 2022), anxiety (Pires et al., 2016), and depression (Pandi-Perumal et al., 2020). Research also suggests that the relationship between sleep and mood is bidirectional, with changes in one contributing to changes in the other (Watling et al., 2017). Further, inadequate sleep has been linked to deficits in areas of cognitive performance, including attention, memory (Olaithe et al., 2018), and working memory (Frenda & Fenn, 2016). Outside of health-related outcomes, inadequate sleep has also been shown to be a significant contributing factor to accidents, injuries and/or fatalities in the workplace (e.g., Uehli et al., 2014), and while driving (e.g., Moradi et al., 2019). Moreover, in Australia, the economic cost of inadequate sleep has been estimated at over AUD$45 billion, representing nearly 5% of the total burden of disease (Hillman et al., 2018).

2.4.1 Impact of traffic noise on sleep quality

Traffic noise (railway, road, and aircraft) has been shown to affect sleep by making it difficult for people to fall asleep, waking them up, or fragmenting their sleep (Welch et al., 2023). It has been suggested that of all the effects caused by traffic noise, sleep disturbance is the greatest contributor to disease burden (Eriksson et al., 2017). The impact of traffic noise on sleep has been shown to have an exposure-response effect. For example, a recent update to the ongoing World Health Organization (WHO) investigation into the effects of environmental noise on sleep found that the odds of self-reported sleep disruption increased by 2.5 to 2.9 for every L_{night} 10 dB increase in road and railway noise, respectively when the source of the noise was included in the question (Smith et al., 2022). When the source of the noise was not mentioned, the odds were lower (e.g., Bartels et al., 2021), suggesting that more accurate data may be elicited by prompting participants to consider specific noise sources (Welch et al., 2023). Similar results were reported by Schubert et al. (2023), who compared previous WHO (Basner & McGuire, 2018) findings to the LIFE-Adult cohort study and found that the odds of self-reported sleep disruption increased by 2.7 (road), 2.7 (railway), and 19.7 (aircraft) for every L_{night} 10 dB increase. The study also revealed that the threshold for intermittent noise resulting in 3% of the population being highly sleep disturbed varied from L_{night} 45 dB (WHO) to 51 dB (LIFE) for road traffic (although slightly different parameters were used across studies) and 45 dB (WHO) to 53 dB (LIFE) for railway traffic. For aircraft traffic, the LIFE study showed a significant increase in the percentage of highly sleep-disturbed individuals from 1% at L_{night} 35 dB to 32% at 45 dB, markedly different from the WHO study, where 15% of the population were seen to be highly sleep disturbed at the same L_{night} dB.

Findings related to self-reported sleep disturbance have been corroborated by experimental research examining physiological measures of sleep. For example, a laboratory study by Griefahn et al. (2006) using polysomnographic measures of sleep exposed participants to air (39-62 dBA, 195 events), road (50-74 dBA, 261 events), and railway (44-68 dBA, 172 events) traffic noise each night for a total of 9 nights. The results showed that compared to the nights without noise exposure, participants reached slow wave sleep 4.7mins later, woke up 8.7mins later, and total sleep time decreased by 9.4mins. These changes in sleep were shown to occur at lower levels (L_{eq} =34-44dBA) and at higher levels (L_{eq} = 50dBA). Participants also experienced a significant decrease in REM and slow wave sleep (11.7mins), with decreases in these sleep stages shown to occur gradually as the acoustic loud increased. Of the three traffic sources, railway-related noise was found to have the strongest effect on sleep. Polysomnographic studies conducted in participants' own homes have offered similar results. For example, Aasvang et al. (2011) found that REM sleep was significantly reduced when exposed to at least one railway noise event at over 50 dB. Conversely, other research suggests that individuals may become habituated to the noise. A polysomnography and actigraphy study by Basner et al. (2011) showed that although sleep was disrupted by exposure to road, rail, and air traffic noise, the effects were subtle and did not significantly impact objective measures of daytime cognitive functioning. Moreover, participants showed decreases in cortical and cardiac arousals during the course of the study, further suggesting they may have habituated to the repeated noise exposure. However, inconsistent findings on the impact of traffic noise on sleep may be due to differences in (non-traffic related) environmental characteristics of the area and varying methodological approaches adopted in different counties (Wrótny & Bohatkiewicz, 2021), and indicate that local research is required to accurately understand the effects of traffic noise in the location of interest. In the present context, recent Australian research analysed a subset of longitudinal survey data to determine the effects of neighbourhood characteristics, including environmental noise (comprising road, rail, air and industry noise), on disruptions to sleep duration, sleep disturbance, and napping (Edmed et al., 2023). The results indicated that residents who perceived the environment to be noisier were significantly more likely to report greater sleep disturbances and interruptions in sleep duration, even after controlling for relevant demographic, socioeconomic and health factors.

Sensitivity to noise has also been recognised as a direct and modulating factor of sleep quality and other factors relating to health (e.g., Hill et al., 2014; Wrótny & Bohatkiewicz, 2021). Noise sensitivity describes how psychologically and physiologically reactive an individual is to sound and the coping mechanisms they employ in response to sound (Hill et al., 2014). Highly noise-sensitive individuals have been shown to be twice as likely to experience insomnia than their low noise-sensitive counterparts (Park et al., 2017). When considering transport noise specifically, those with high noise sensitivity are more prone to adverse health effects due to transport noise exposure (Welch et al., 2023). For example, Marks and Griefahn (2007) found that when exposed to nighttime traffic noise, participants with higher noise sensitivity reported difficulties falling asleep, feeling less restored, and experiencing more body movements during sleep. Similarly, Smith et al. (2017) found that highly noise-sensitive individuals exposed to nighttime freight train noise and vibrations reported poorer sleep quality and experienced less slow wave sleep. Moreover, a study by Okokon et al. (2018) examining the relationship between traffic noise and psychotropic medicine use found a direct association between noise sensitivity and all psychotropic medication use, including sedatives.

Overall, there is ample evidence to support the notion that traffic noise and noise sensitivity can impact sleep quality directly and indirectly and suggests that both acoustic factors and the noise sensitivity of residents should be considered when considering the impact of transport noise.

2.4.2 Sleep quality measures

Sleep quality refers to a variety of sleep measures, including sleep onset latency, total sleep time, and awakenings can be assessed using subjective and objective measures (Fabbri et al., 2021). Subjective measures include sleep diaries and self-report questionnaires such as the Pittsburgh Sleep Quality Index (Buyesse et al., 1989), the Mini Sleep Questionnaire (Natale et al., 2014), and the Epworth Sleepiness Scale (Johns, 1991). The sleep diary is the most used subjective sleep measure and requires participants to make daily records of specific aspects of their sleep from the previous 24 hours. These observations can then be used to determine factors such as sleep onset latency, wake after sleep onset, total sleep time, as well as individual factors impacting sleep and self-reported ratings of quality of sleep (Natale et al., 2015). While the sleep diary offers numerous insights into sleep patterns, a drawback of this method is that is relies on participants consistently completing the task immediately upon waking, which can pose a time burden and may prove challenging for individuals with memory difficulties (Fabbri et al., 2021). The use of self-report questionnaires can counter these obstacles to some degree and has also been extensively used within research settings. The Pittsburgh Sleep Quality Index ([PSQI] Buyesse et al., 1989) is the most frequently used sleep questionnaire, showing consistently good reliability and validity (Mollayeva et al., 2016) and is considered the benchmark for perceived quality of sleep (Fabbri et al., 2021). The PSQI asks participants to answer questions about how they slept for the majority of nights over the past month, offering an average sleep pattern for that time frame. While questionaries such as the PSQI are less burdensome to participants' time, these measures, like sleep diaries, still rely on participants accurately remembering how they have slept (and over a longer timeframe) and only offer insights into the self-perceived quality of sleep.

Objective measures such as polysomnography and actigraphy offer a more accurate assessment of sleep quality based on physiological measures of sleep structure and indices of sleep quality. Polysomnography is considered the gold standard for sleep quality research and involves monitoring brain activity, blood oxygen levels, heart rate, respiration, and body position to determine factors such as sleep onset latency, wakefulness after sleep onset, total sleep time as well as the number of awakenings and time spent in each sleep stage (Mendonça et al., 2019; Krystal & Edinger, 2008). However, given the need for specialist equipment, polysomnography assessment is expensive to conduct and requires participants to commit a large amount of their time (often sleeping in laboratories over multiple nights), making it difficult to utilise widely within research. Actigraphy, in contrast, involves participants continually wearing a wristwatch-like device over a period of time and measures indices of sleep such as body movement, temperature, and light exposure used to calculate sleep duration and efficiency. Although actigraphy measures proxies of sleep, it is often favoured due to the lower cost of equipment, the reduced burden placed on participants, and the ability to continuously capture data over a relatively long timeframe (Krystal & Edinger, 2008), and sleep factors (e.g., sleep onset latency, total sleep time, awakenings) can be reliably inferred when actigraphic data is analysed alongside sleep diary data (Ancoli-Israel et al., 2003). There is debate within the literature concerning whether subjective or objective measures of sleep quality offer the most accurate appraisal (e.g., Cudney et al., 2022) and incorporating both has been advised as best practice (e.g., Landry et al., 2015).

3 Study 1: Pedestrian simulations and analysis

3.1 Methodology

3.1.1 Participants

Thirty-eight participants were recruited to participate via social media advertising, QUT email subscription lists, and the QUT Psychology Research Management System (SONA). One participant commenced but could not complete due to virtual reality (VR) motion sickness, and 37 participants finished the experiment with complete data. Participants were aged between 18 and 68 (M_{age} = 32.24, *SD* = 12.21), 64.9% were female (*n* = 24) and 35.1% were male (*n* = 13). Most participants reported holding a postgraduate degree (*n* = 18, 48.6%), or an undergraduate degree (*n* = 10, 27.0%).

3.1.2 Apparatus

3.1.2.1 Virtual reality headset and software

Participants wore and Oculus Rift S VR headset (see Figure 1) and SCANeR™ studio software (version 2022) was used to develop the virtual environment. The VR headset featured a resolution of 1280 x 1440, a screen refresh rate of 80 Hz, and a large field of view. The device had six-degree freedom of head movement and continuously monitored participants' head movement and eye positioning. These features were used to measure when participants checked for the train before entering the level crossing.

Figure 1: Oculus Rift VR device

3.1.2.2 Controller

When in the VR environment, participants controlled the movements using an Xbox adaptive controller with two buttons (see Figure 2). Pressing the green "A" button made the virtual character start walking at a constant speed. When participants pressed the green button again or held it, the walking speed increased until the maximum speed of 1.6 metres per second was reached. The red "B" button was the stop button. When participants pressed it once, the virtual character's walking speed would reduce, and when they held it, the character stopped walking.

Figure 2: Xbox controller buttons used to control walking speed

3.1.2.3 Smartphone

An iPhone 6 with earphones was used to simulate audio distraction. Predefined playlists were played for the sessions in which participants were required to listen to music. The playlist comprised music that participants would likely be familiar with (eighties pop/rock songs) and thus could become engaged in and distracted by (Brodsky, 2018).

3.1.3. Scenario design

3.1.3.1 Study Site

The study was conducted in a virtual environment replicating a typical Australian urban level crossing and included both passive control and active control crossings. Each participant completed two scenarios, each consisting of nine level crossing conditions based on the type of crossing (active or passive), the presence and loudness of a train horn (no horn, low loudness horn [60dBA]), or high loudness horn [80dBA]), and the presence of a train (train or no train). Participants listened to music during one of the two scenarios. Based on these conditions, eight types of level crossing environments were developed:

1. Active crossing with no train
2. Passive crossing with no train
3. Active crossing with no horn
4. Passive crossing with no horn
5. Active crossing with low loudness horn
6. Passive crossing with low loudness horn
7. Active crossing with high loudness horn
8. Passive crossing with high loudness horn

The two scenarios and the succession of level crossing environments between scenarios were counterbalanced.

3.1.3.2 Test Environment

The text experiment comprised two types of level crossings: passive and active (see Figure 3 and Figure 4). Participants started each walk 100 metres away from the crossing. They had a speed range of 1.0m/s – 1.6m/s and were able to select their preferred speed by pressing the buttons shown in Figure

2. Once the participant was 30 metres from the level crossing, a train, situated 420 metres away on the right, started approaching the crossing at a speed of 80km/h. In the scenarios where no train was present, participants were able to cross the level crossing when they felt safe to do so. In the active crossing scenarios, the pedestrian lights turned red, and crossing bells rang at the same time as the train started moving. The train horn was sounded when the train was about 10 s (following a uniform distribution between 8 s and 12 s) before reaching the level crossing.

Figure 3: Passive control level crossing

Figure 4: Active control level crossing

The virtual environment also included residential buildings, a one to two-lane road for vehicles, a 3.5-metre-wide footpath for pedestrians, and a selection of roadside elements (e.g., park bench, garbage bin, post office box, speed limit sign, and bus stop). Participants moved along the footpath towards the railway level crossing. They were only able to move forward and could not leave the footpath. When moving towards the level crossing, participants were asked to behave (i.e., change speed, stop, look around) as they normally would when approaching a level crossing in the real world. Once they started the scenario, they were required to continue walking until they had passed the level crossing completely. The scenario stopped automatically upon reaching a specific point on the opposite side of the crossing.

The participants' walking speed, distance from the level crossing, any times that they stopped, and the distance that the train was when they reached the level crossing, were recorded.

3.1.4 Procedure

The experiment comprised two simulated walking sessions, each containing nine approximately 3-minute walks where the participant crossed a railway level crossing. One of the walking sessions included a distraction task (listening to music via an iPhone), while the other did not. Participants were asked to complete the think-aloud protocol (i.e., vocalise their thoughts, actions, and what they could hear/see) for all walking sessions.

3.1.5 Data collection and analysis approach

3.1.5.1 Think-aloud protocol

The think-aloud protocol was used to investigate pedestrians' thought processes when approaching rail level crossings. During each scenario, participants were asked to verbally identify objects in their surroundings as they saw, heard, or experienced them (e.g., seeing traffic lights/signs or hearing a train horn), without offering an interpretation or analysis. The vocalisations were recorded (via written notes and audio recordings) and specific safety warning systems (e.g., train horns, bells, lights, signs) and environmental elements (e.g., other road users, bus stop) were noted in the order each was mentioned.

3.1.5.2 Behaviour, head/eye movement, and decision-making measures

All the objective measures in this study were obtained from the SCANeR™studio software and the recorded scenario video. The SCANeR™studio software output object (train and pedestrian) speed and location data at 20 Hz sampling rate and the video recorded the participant's field of view with head and visual movement. All the object variables are listed below:

1. Average speed 1 (in m/s)
2. Average speed 2 (in m/s)
3. Average speed 3 (in m/s)
4. Number of times of head/eye movement towards the train
5. Stop decision before/after horn (0/1)
6. Cross decision before/after train (0/1)
7. Reaction time to train (in seconds)
8. Train's distance to LC when pedestrians stopped (in metres)

3.1.5.3 Analysis approach

The analysis aimed to examine whether (and how) different environmental factors, including level crossing control, train horns and music condition, influenced pedestrians' behaviours, perceptions and decision-making while they approached the level crossings. For think-aloud measures, the chi-square test was mainly used to identify the correlation between environmental factors and the sequence of perceived objects. For the objective measures, Generalised Linear Mixed Models (GLMMs) were developed to examine the influence of the independent variables, i.e., level crossing control (passive/active), train horn (no/low-loudness/high-loudness), music (on/off), and the interaction between factors on the dependent variables.

3.2 Results

3.2.1 Think aloud

3.2.1.1 Whether the train horn was heard and its sequence of being detected

A total of 203 (68.6%) train horns (of a possible 296) were heard by participants. Participants heard the train horn more frequently than not in all conditions (i.e., low/high loudness horn, active/passive crossing control, and music on/off). The conditions in which the train horn was heard most frequently were the passive crossing condition (76.4%), the music off condition (70.9%) and the high loudness horn condition (70.3%). The train horn was heard least frequently in the active crossing condition (60.8%).

The results of three chi-square tests showed that there was a significant association between the sequence in which the train horn was heard and the level crossing control only (X^2 (7, 203) = 82.84, *p* <.001). Specifically, train horn was detected earlier at passive crossings compared to active crossings.

3.2.1.2 Train horn heard before/after train was seen

Results in this section only included level crossings where participants detected both the train and the train horn. The results showed that the train horn was heard after the train was sighted substantially more frequently than before the train was sighted across all conditions. When comparing train horn loudness (low vs. high), level crossing control (passive vs. active) and music (on vs. off), the train horn was detected before the train marginally more frequently in the low loudness horn, active crossing, music off, and music on conditions.

The results of three chi-square tests showed that there was no significant association between low and high loudness train horns (X^2 (1, 180) = 0.11, p = .830), between active and passive controls (X^2 (1, 180) = 0.89, p = .389), nor between listening or not listening to music (X^2 (1, 180) = 1.74, p = .203), and whether the train horn was heard before the train was sighted.

3.2.1.3 Notable features pedestrians detected

Participants were asked to verbalise what they saw and heard during each walk. At the passive level crossings, the passing road vehicles and the train were consistently the most frequently noted features across all conditions, followed by roadside facilities. In the no train horn conditions, static railway crossing sign was the third most frequently noted feature when music was both on and off. The train horn was the third most frequently noted feature in both the low loudness and high loudness horn conditions, when music was both on and off.

At active level crossings, the pedestrian lights were the most frequently noticed feature across all conditions. The passing road vehicles and the train were the second most frequently noted feature in all conditions. For the no horn conditions (both music on and off), the third most frequently noted features were the roadside facilities, and for the low loudness and high loudness horn conditions (both music on and off), the third most frequently noted feature was the crossing bells. The train horn was only reported as a notable feature once, as the fifth most noted feature in the high loudness/music on condition.

The level crossing features that participants reported looking and listening for (but were not present in the scenario) were also documented. The features that participants most frequently looked for were pedestrian lights and the train. The feature that participants looked for least frequently was static crossing signs.

3.2.2 Pedestrian behaviours

3.2.2.1 Walking behaviour

The results from a GLMM (Generalised Linear Mixed Model) showed that level crossing control was the only significant factor in pedestrians' average walking speed from the time that the train started moving to the time the horn was sounded (p <.001). Pedestrians walking speed was significantly slower at active crossings compared to passive crossings. No significant effect between horn loudness or music condition and participants' average walking speed was observed.

3.2.2.2 Head/eye movement

Pedestrians' head/eye movement was captured by VR video recording, and the number of times that they looked at the train was extracted. The GLMM results showed that this variable was significantly influenced by level crossing control (p =.019) and music condition (p =.028). Specifically, pedestrians checked for the train more often at passive crossings (compared to active crossings) and when they were not listening to music (compared to when music was playing). No significant impact was found for horn loudness or the interaction effect between factors.

3.2.2.3 Decision-making

In the scenarios where a train horn was present, pedestrians made the decision to stop before the horn was sounded in 81.0% (n = 222) scenarios. In the same scenarios, pedestrians made the decision to cross after the train had passed in 96.7% (*n* = 415) of scenarios. Participants only chose to cross before the train had passed in only 3.3% (*n* = 14) scenarios. Results from a series of Pearson chi-square tests showed that there was no significant association between level crossing control, horn loudness or music condition and pedestrians' stopping decisions or crossing decisions.

3.2.2.4 Reaction time to train

The GLMM results of pedestrians' rection time to the train showed that level crossing control was the only significant factor that influenced pedestrians' reaction time (*p* <.001), whereby pedestrians had a significantly shorter reaction time to the train at the active crossings compared to the passive crossings. No significant effect was found for horn loudness, music, or any interaction effect between factors.

3.2.2.5 Train's distance to level crossing when pedestrians first stop

The GLMM model identified two significant factors, which were level crossing control (*p* <.001) and music condition (*p* =.01). For level crossing control, when pedestrians came to a stop for the first time, the train's distance to the level crossing was longer at active crossings compared to passive crossings. For the music condition, pedestrians stopped when the train was at a longer distance to the crossing when the music was on compared to when there was no music. No significant effect was found for horn loudness or the interaction effect between factors.

4 Study 2: Online broader social effects survey

4.1 Methodology

4.1.1 Participants

Participants were recruited via two avenues - targeted letterbox drop and paid Facebook advertising. The final sample comprised 334 participants (286 from the letterbox drop and 48 from Facebook advertising). Participants were aged between 18 and 91 years (M_{age} = 44.62, *SD* = 15.71), with 49.4% (*n* = 165) female and 49.4% (*n* = 165) male. Two participants (6.0%) identified as other, and two participants (6.0%) preferred not to share their gender. Most participants reported holding a bachelor's degree or higher (*n* = 184, 55.0%) or a certificate or diploma (*n* = 85, 25.4%).

4.1.2 Survey measures

4.1.2.1 Train and train horn exposure measures

Participants were asked about the extent to which they noticed and were annoyed by train horns and other train-related activities (during the day and night) in the previous 12 months. Questions included "On a typical day, how often do you hear train horns when inside your home during the day (4 am-6 pm)?" and "Thinking about the last 12 months or so, when you are at home, how much does railway-related sound (excluding train horns) bother, disturb or annoy you?"

4.1.2.2 Depression, anxiety and stress scale

Experience of psychological distress was measured using the Depression, Anxiety and Stress Scale-21 (DASS-21) (Anthony et al., 1998). The questionnaire consisted of three 7-item subscales, capturing the extent to which participants experienced symptoms of depression, anxiety, and stress within the past week. Participants responded on a 4-point Likert scale, with higher scores in each subscale reflecting greater severity of each psychological state.

4.1.2.3 Sleep quality scale

Sleep quality was assessed using an 18-item version of the Pittsburgh Sleep Quality Index (PSQI) (Buyesse et al., 1989). The questionnaire comprised four open-ended questions regarding participants' sleep habits in the past month and ten 4-point Likert scale items assessing the frequency of experiences related to sleep disruption, the extent to which enthusiasm for getting things done is impacted, and self-reported sleep quality. The scale provides a global sleep quality score based on 7 components (i.e., subjective sleep quality, sleep latency, sleep duration, sleep efficiency, sleep disturbance and use of sleep medication, and daytime dysfunction), with higher scores indicating lower quality of sleep.

4.1.2.4 Noise sensitivity scale

The 21-item Weinstein Noise Sensitivity Scale (WNSS) (Weinstein et al., 1978) was used to assess participants perceived sensitivity to noise. Participants were asked to rank the extent to which they agreed with statements relating to their affective response to noise on a 5-point Likert scale. Higher scores reflected higher levels of noise sensitivity after reverse coding relevant negatively keyed items.

4.1.3 Investigation sites

As recommended by QR representatives, the questionnaire data was collected via flyer dissemination in the areas surrounding seven train stations: Lawnton station, Burpengary Station, Cannon Hill Station, Keperra Station, Alderley Station, Newmarket Station and Windsor Station. The general criteria for selecting the stations are listed below:

1) There should be no multiple level crossings in the same area.
2) The level crossing needs to be in close proximity to stations.
3) There should be a good density of residential areas out to a few kilometres from the rail corridor for a couple of kilometres up and down from the station.
4) The station should have a sufficient mixture of passenger and freight train services.
5) The locations of whistle boards and, correspondingly, the train horn noise soundings should not be shielded by road overpasses.
6) There should be consistency across areas being either without noise barriers or entirely covered by noise barriers.

The study targeted three groups of participants who lived in three different areas selected according to the distance to a specific train station. Zone 1 represented the train horn impact area, Zone 2 represented the railway-related sound impact area, and Zone 3 represented the non-impact area. As shown in Figure 5, Zone 1 extended 400m (lateral) x 200m (horizontal) from the train station and whistle boards (centre points).

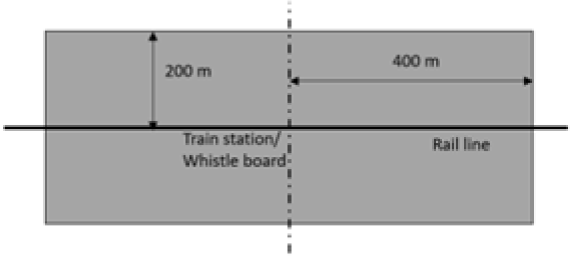


Figure 5: Train horn impact area (Zone 1) measure per station

Zone 2 covered the 200m area (horizontal direction) adjacent to railway lines at a 400 m lateral distance from train stations or whistle board locations. Zone 3 was investigated as a baseline zone where residents live in a similar geographical and environmental context (over 1km to train stations), but their daily activities should not be impacted by train horns or sound related to railways. The maps with different zones were embedded in the questionnaire so that participants could identify the specific area they resided in. An example of the Burpengary Station map is provided in Figure 6.

Figure 6: Burpengary Station map (yellow area represents Zone 1; green area represents Zone 2; orange area represents Zone 3)

For the questionnaire disseminated by Facebook advertisement, a more general population who live nearby train stations in the Brisbane region was targeted to help increase the sample size. Following the selection criteria, another 33 stations were identified and used as a landmarks with a radius of 5 miles (8 km approx.) within each station. No maps were provided in the questionnaire for the additional stations. Instead, participants were asked questions to determine their proximity to the nearest train station. The information was used to classify participants into the three impact zones for later analysis.

4.1.4 Procedure

The survey was conducted online and took approximately 30 minutes to complete. First, participants completed demographic items and questions relating to their residual proximity to railway infrastructure. Participants then answered questions related to their personality, their recent experience of psychological stress, their recent experiences related to sleep, and their sensitivity to noise. Following this, the survey asked participants about their exposure to train horn noise and other railway-related activity.

For the analyses, participants were divided into three groups (Zone 1, Zone 2, and Zone 3) based on their survey responses. Participants who did not identify a zone according to the embedded map were categorised based on their proximity to the nearest train station and/or railway tracks. Zone 1 participants lived within 450 m of the nearest train station, Zone 2 participants lived within 450 m to 1000 m from the nearest station and within 250 m of the nearest railway tracks, and Zone 3 participants lived over 1000 m from the nearest train station and railway tracks.

4.1.5 Data processing and analysis approach

4.1.5.1 Data cleaning and processing

The key variables involved in the analysis included participants’ demographic characteristics (age, gender), impact zones (Zones 1,2,3), rail travel experience (frequency), exposure to train horn sound, railway-related sound (excluding train horns), and vibrations and light caused by railway activities, emotional states (depression, anxiety, and stress), noise sensitivity and sleep quality indexes.

The depression, anxiety, and stress scores, as well as the noise sensitivity score, were calculated by adding up the Likert score of all items contained in each construct, with higher scores indicating greater experience of each construct. Relevant items from the PSQI were grouped into seven components: subjective sleep quality, sleep latency, sleep duration, habitual sleep efficiency, sleep disturbances, use of sleep medication, and daytime dysfunction. A global PSQI score was calculated by adding these components, yielding scores ranging from 0 to 21. The study used the general cut-off value of 5, with PSQI global score >5 indicating poor sleep (Buysse et al., 1989), and classified participants into good sleep quality group (PSQI global scores <5) and poor sleep quality group (PSQI global scores >5).

4.1.5.2 Analysis approach

The data analysis examined whether the train horn sound (represented by the residents’ impact zone) significantly influenced residents’ self-reported sleep quality and emotional states. The data was analysed using one-way ANOVA (or its non-parametric equivalent) and subsequent post-hoc pairwise comparison tests and binary logistic regression. As the distribution of the samples was imbalanced among three impact zones, with Zone 1 comprising far more participants than Zone 2 or Zone 3 (and no significant differences were observed between the latter zones), it was decided to combine Zone 2 and Zone 3 to form a low train horn impact group for relevant tests. A significance level of 0.05 was used for all statistical tests.

4.2 Results

4.2.1 Railway sound, light, and vibration exposure

4.2.1.1 Train horn exposure

Participants were asked if they were able to hear a train horn (and how frequently) while in their home on a typical day. The vast majority of participants in both Zone 1 (96.7%) and Zone 2 (90.8%) and over three-quarters of participants in Zone 3 (76.5%) reported that they could hear the train horn in their home. Overall, most participants in all three impact zones reported hearing a train horn 10 times or less during the day. A similar distribution of frequencies was reported for the number of times that participants heard train horns during the night. The perceived noticeability of separate acoustic qualities of the train horn (i.e., tonality, sharpness and loudness) was also assessed. Results from a Friedman Test showed that there was a significant difference between the noticeability and/or disturbance caused by the three features, $\chi^2(2, 286) = 100.76$, $p<0.001$, with the loudness of the horn considered to be more noticeable/disturbing by participants in all three zones.

4.2.1.2 Railway-related sound exposure

As well as train horn exposure, participants were also asked whether they could hear other railway-related sounds (excluding train horns) while in their homes on a typical day. Like the train horn results, most participants in Zone 1 (88.0%) and Zone 2 (84.6%) reported that they could hear railway-related sounds in their homes. However, just under one-third (35.3%) of Zone 3 participants reported hearing other railway-related sounds in their homes. When asked how frequently they could hear railway-related sounds in their homes during the day and during the night, like the train horn results, the majority of participants in all three zones reported hearing railway-related sounds 10 times or less both during the day and night. However, compared to the train horn results, a higher proportion of participants in Zone 1 and Zone 2 reported hearing railway-related noise 11 times or more both during the day (38.3% and 46.3%, respectively) and during the night (23.6% and 31.5%).

4.2.1.3 Light exposure caused by railway activity

The survey asked participants whether they could see light caused by railway activity in their homes during the night (between 6 pm and 4 am). The vast majority of participants in all three zones reported that they did not see any railway-related light in their homes. However, the proportion of participants who reported seeing railway-related light was higher in Zone 2 (25.4%) compared to Zone 1 (14.8%) and Zone 3 (2.9%). Only a small percentage of the sample (8.1%, n = 27) responded to the items relating to how frequently they saw railway-related light in their homes, and most of this subsample reported seeing the light less than 5 times per night.

4.2.1.4 Vibration exposure caused by railway activity

Participants were asked whether they could feel vibrations caused by railway activity when inside their homes. Most participants in Zone 1 (76.6%), Zone 2 (74.6%), and nearly all participants in Zone 3 (95.6%) reported that they could not feel railway-related vibrations. Like the light exposure questions, a small proportion of participants (18.3%, n = 61) responded to the items relating to the frequency of which they felt railway-related vibrations. Overall, most participants in this subsample reported feeling vibrations less than 5 times during the day and during the night.

4.2.2 Noise sensitivity

Participants' subjective noise sensitivity was examined by one-way ANOVA. The test result showed that there was a significant difference in noise sensitivity scores between the three impact zones, F(2, 287)=3.033, $p<0.1$. Specifically, the noise sensitivity score of participants from Zone 3 was significantly higher than those from Zone 1 ($p<0.05$) and Zone 2 ($p<0.05$).

4.2.3 Emotional states

A group comparison (Mann-Whitney Test) was first conducted between Zone 2 and Zone 3 participants regarding their depression, anxiety and stress scores. The results showed that there was no significant difference between the two groups. As such, Zone 2 and Zone 3 participants were combined as one group (Group 2) for comparison with Zone 1 participants. The test results showed that there was no significant difference in depression, anxiety and stress scores between Group 1 (train horn impact group) and Group 2 participants (baseline group).

4.2.4 Sleep quality

The seven components (C1-subjective sleep quality, C2-sleep latency, C3-sleep duration, C4-habitual sleep efficiency, C5-sleep disturbances, C6-use of sleeping medication, C7-daytime dysfunction) of the PSQI and the global PSQI score were first compared between Zone 2 and Zone 3 participants. Like the emotional states scales, as no significant difference was found between the two zones, they were combined to form one group (Group 2) for comparison with Zone 1 participants. Mann-Whitney tests conducted between Group 1 (train horn impact group) and Group 2 (baseline group) showed that there were significant differences in the subjective sleep quality score and sleep latency score. Specifically, the subjective sleep quality and sleep latency scores of Group 1 were both significantly higher than those of Group 2, with higher scores in the PSQI components representing poorer sleep quality.

A binary logistic regression model was developed to assess the impact of six independent variables (age, gender, train horn impact group, nighttime train horn frequency, daytime train horn frequency, and noise sensitivity) on the likelihood that participants would report having poor sleep quality. The full model containing all predictors was statistically significant, $\chi2$ (6, n=325) = 27.44, $p<0.001$, indicating that the model was able to distinguish between participants who reported good sleep quality vs. poor sleep quality. Only nighttime train horn frequency and noise sensitivity made a unique statistically significant contribution to the model, indicating that the increase in night-time train horn frequency and noise sensitivity was associated with an increased likelihood of self-reported poor sleep quality.

5 Study 3: Actigraphy study

5.1 Methodology

5.1.2 Participants

Participants who completed the online survey in the previous broader social effects study were invited to register to participate in the present actigraph study, and a total of 36 participants, aged between

31 and 75 (M_{age} = 48.47, *SD* = 11.82), completed the study. Just over half (52.8%) of participants were female (*n* =19), and 47.2% (*n* =17) were male. Most participants lived in a house (*n* = 22, 61.1%) or a townhouse (*n* =7, 19.4%%) and reported that they had lived at their current address for 10 years or less (M_{years} = 9.04, *SD* = 8.03). All participants lived within 2.5km of the nearest train station or railway tracks. The average distance to the nearest train station and railway station was 849.24 metres (*SD* = 761.90) and 713.79 metres (*SD* = 789.93), respectively, with most participants living within 650 metres to railway infrastructure. According to the participants' residence distance to the nearest train station or level crossing, the 36 participants could be divided into two groups: impact group (*n* =18) and baseline group (*n* =18). Participants from the impact group live in areas that are within 400m (lateral) x 200m (horizontal) of a train station or a level crossing, while participants from the baseline group came from areas that are between 1km and 3km distance from a train station or a level crossing.

5.1.2 Apparatus

5.1.2.1 GENEActive device

In this study, six GENEActiv device units were utilized as a fundamental tool for objective sleep measures. A GENEActiv unit is shown in Figure 7. The GENEActiv device functions as a body-worn accelerometer and data logger, resembling a wristwatch powered by batteries. Its design prioritises portability, allowing it to be comfortably worn across various body positions. Primarily designed for capturing data concerning body and limb movements during both daily activities and sleep, the device houses an internal motion sensor known as an accelerometer. This component accurately records the frequency and magnitude of motion throughout its usage. The gathered data can be conveniently retrieved by connecting the device to a charging cradle and utilizing accompanying software for download and analysis. Additionally, the GENEActiv incorporates a digital ambient light sensor, offering the capability to document the intensity of white light in lux units. Moreover, the device is equipped with a digital temperature sensor that measures the temperature in proximity to the body. This measurement is influenced by both the wearer and the surrounding environment, operating within a temperature range of 0 to 60 degrees Celsius and conducting readings at intervals of no less than 30 seconds. The measurement frequency of the device is selectable from 10-100Hz. This study selected a 30 Hz sampling frequency to ensure sufficient memory space for a minimum of 6 days logging period.

Figure 7: Wrist-worn accelerometer-based device, GENEActiv

5.1.2.2 Sound level metre datalogger (NSRT_mk4)

The NSRT_mk4 represents Convergence Instrument's latest iteration of an advanced smart integrating sound-level metre/datalogger. This version boasts a type 1 digital MEMS microphone, ensuring precise audio measurements, along with a highly accurate date/time clock. The device records L-peak, L-max, L-min and Leq levels with a log interval adjustable from 125ms (8 points per second) up to hours. Additionally, it features a non-volatile 128 Mb recording memory and rapid USB download capability. When operating on battery power, this device has the capacity to record sound pressure levels continuously for up to a week before reporting the data. Its compact size allows for convenient attachment to or integration within the monitored equipment, ensuring flexibility in its placement and use. In this study, a sampling rate of 2Hz was used to ensure sufficient memory space for a minimum of 6 days logging period. A typical short "Fast" time constant (125ms) was used to allow the measurements to track sharp changes. Note that the time constant only affects the calculation of L-min and L-max. Figure 8 shows three units of this device, and a total of 6 units were used in this study.

Figure 8: NSRT_mk4 sound level metre

5.1.2.3 ARL NGARA Real-Time Sound Acquisition System

The NGARA Sound Acquisition System provides complete measurement adaptability, enabling the simultaneous generation of various acoustic measurements, including:

- Rapid Sound Pressure Level (SPL-A)
- Rapid Sound Pressure Level (SPL-C)
- Equivalent Continuous Sound Level (Leq-A)
- Equivalent Continuous Sound Level (Leq-C)

Moreover, beyond these measurements, the NGARA platform possesses the capability to store raw audio data (in wav file format) directly to a hard disk. This feature empowers the system to effectively address the majority of our acoustic requirements through subsequent post-processing. The WAV data sampling rate was 48 Hz, and the sound pressure level was measured at 10 Hz. Figure 9 below shows the NGARA system, and two sets of the system were rented for data collection in this project.

Figure 9: NGARA system

5.1.3 Investigation area

As the participants of this study were mostly selected from the previous study (online survey), the investigation area was consistent with the sites selected in Study 2. After counting the number of participants in Study 2 who also expressed interest in Study 3 and their location, four train horn stations were selected as the train horn impact area, i.e., New Market, Cannon Hill, Lawnton, Alderley, and Windsor. The impact area was defined as 400m (lateral) x 200m (horizontal) from the train station or nearby level crossing. The baseline area was defined as a similar environmental context but over 1km away and within 3km distance from a train station. Participants from the baseline area are not limited to the above five train stations where impact group participants were recruited. Other than the five stations, the study also included participants from Lutwyche, Ferny Hills, Arana Hills, Narangba, Gordon Park, and Bray Park.

5.1.4 Procedure

For each of the five stations, the project team had an inspection and identified a suitable spot in the station office for installing the NGARA system. When the data collection period started, the NAGRA systems were left in the station office for one week to collect the train horn sound data. At the beginning of each data collection week, the team attended 6 participants' addresses to install the NSRT_mk4 sound level metre and the GENEActive device. All participants first read the Participant Information Sheet (see Appendix A) and signed the consent form. Following that, a research officer provided instructions to the participant on how to utilise the GENEActive. The officer proceeded to set up the GENEActive with specific software to commence data collection. Subsequently, the research officer identified a suitable location in the participants’ yard/balcony to install the NSRT_mk4. Basically, the NSRT_mk4 microphone needs to face towards the railway direction in an open area and it needs to be covered from the rain. The small sound recording device was securely affixed to the wall or fence of the balcony using tape, ensuring it was out of reach of pets. The NSRT_mk4 was also configured using a specific software to initiate sound level data collection. A sleep dairy form (as attached in Appendix B) was provided and explained to the participants for them to record the sleep starting and ending time, nap starting and ending time, GENEActive taken off and put back on time, daily exercise, daily caffeine/alcohol/medication taken, total sleep hours, number of awakenings and perceived sleep quality, etc. The data collection for each participant lasted for one week. The research team normally attended the participants on Sundays to set up the device and returned back on the following Saturdays to collect the device and sleep dairy form. For the NGARA system, the team installed them on Monday mornings, collected them on the next Monday morning and transported them immediately to the next stations for setup. For participants who were not available on Sunday, the team attended on Monday, and therefore, the data collection started on Monday. On the collection day, the participants were required to complete the questionnaire again (as attached in Appendix C), which is the same as the one they completed in Study 2 (online survey).

5.1.5 Data collection and analysis approach

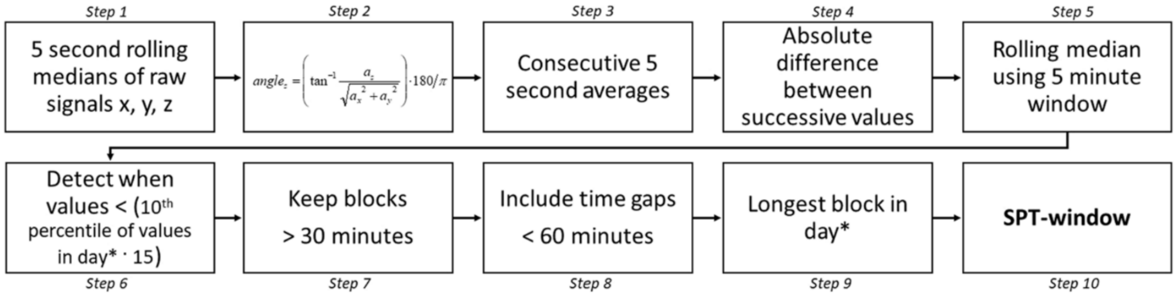
5.1.5.1 Actigraphy data

The analysis of actigraphy data collected by GENEActiv was conducted using the GGIR software integrated within R, a specialized library designed explicitly for this purpose. The analysis consisted of five distinct segments, commencing with the initial step of loading the data and storing essential variables for subsequent phases.

For all participants, the sensor was located on the wrist, and temperature served as an estimation method for participants’ bedtime. Auto calibration was applied to calibrate the data, and the minimum requirement for valid daily hours was set at 24. In this software, the participant’s bedtime, non-wear time, activity, and sleep period time were extracted. Two non-wear approaches were used to analyse the non-wear time. The non-wear approach utilised in this analysis was the 2023 method. Contrary to the 2013 version, which evaluates non-wear conditions by employing a long-size window and marking non-wear at the midpoint of the medium-size window, the 2023 version designates the entire long-size window as non-wear. Additionally, the 2023 approach aligns the left edge of the long-size window with the left edge of the medium-size window.

To detect prolonged inactivity, the algorithm used time thresholds of five and ten minutes, scanning for periods when angle variability dipped below the defined 5-degree angle threshold. ENMO, an acceleration metric accounting for negative values rounded to zero, has shown its effectiveness in delineating energy expenditure variability and highlighting activity patterns. Meanwhile, angle-z was computed as the Z-axis angle concerning the horizontal plane, intended for sleep period analysis and detecting activity duration.

The HDCZA algorithm was utilized for sleep period time detection, where "HDCZA" refers to the Heuristic algorithm examining the Distribution of Change in Z-Angle, described in van Hees et al.'s 2018 publication. The sequential steps of this algorithm are illustrated in Figure 10.



* Defined from noon to noon

Figure 10: The steps of HDCZA algorithm

Moreover, a minimum count of 20 valid hours within a 24-hour nightly period was used as the threshold for assessing sleep. Analysis was facilitated using the sleep log tool (i.e., data recorded by the sleep dairy form). The daily sleep and arm movement patterns output by GGIR are shown in Figure 11.

The variables below with definitions were extracted from the GENEActiv device and included in the analysis:

a) Total sleep time (nocturnal, in hours): the total amount of time asleep during the night, extracting the time scored as awake in between.
b) Sleep onset latency (in hours): the time elapsed between the start of the rest interval (i.e., lights off) and the start of the sleep interval.
c) Sleep efficiency (in %): the ratio of total sleep time to the total time in bed.
d) Wake bouts (in number): the frequency of discontinuous epochs calculated as wake during a nocturnal rest interval.
e) Wake after sleep onset (WASO, in hours): the time spent awake during the sleep interval.

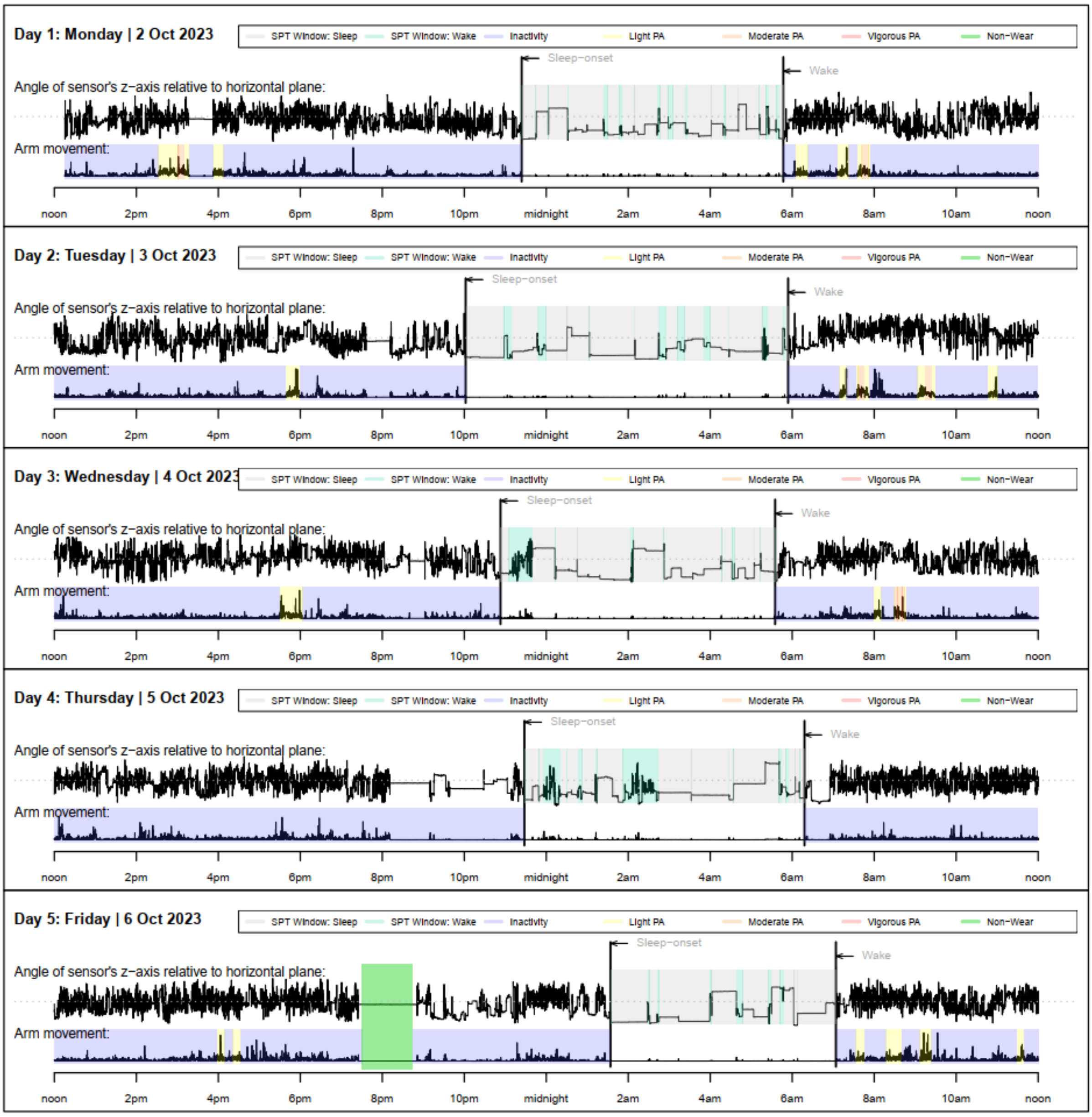


Figure 11: The sleep and arm movement patterns output by GGIR

5.1.5.2. Environmental noise data

In the first step, the audio data collected by the NGARA system was annotated using Audacity software to extract the train horn sounding time at each train station. Using the train horn sounding time list as a reference, the sound level data collected by the NSRT_mk4 was then processed to identify the train horn patterns and related acoustic information at participants' residences. It should be noted that due to the equipment issue, the NSRT_mk4 data of one participant from baseline zone was not usable and thus excluded from the analysis.

Considering the time difference of the internal clock between the NGARA system and the NSRT_mk4, we applied a 4-minute time window for detecting each train horn, encompassing 2 minutes prior to and 2 minutes after the train horn sounding time recorded by the NGARA audio data. Within this interval, the L-max peaks were identified, and each peak was then compared against a series of criteria to detect the train horn peak. The criteria employed were: The peak duration (defined as the time difference between start and end) should not exceed 10 seconds, and the maximum peak height should be above 10 dB. Because of the uncertain noise from the environment such as pets, animals, human noise and road traffic, it was likely that multiple peaks complied with the train horn pattern and those suspicious ones were excluded from the analysis. The typical train horn patterns detected from the NSRT_mk4 device are illustrated in Figure 12. Table 1 shows the number of valid train horns, the number of invalid train horns and the number of train horns recorded by NGARA audio data at each station.

Table 1: The total number of train horns detected by NSRT_mk4 and NGARA

Train Station	Number of valid train horns (NSRT_mk4)	Number of invalid train horns (NSRT_mk4)	Number of all train horns (NGARA audio)
Lawnton (n=4 participants)	194 193 208 197	24 28 14 23	225
Newmarket (n=6 participants)	156 130 130 151 147 137	3 13 11 8 12 22	159
Windsor (n=3 participants)	75 74 67	10 11 8	85
Alderley (n=2 participants)	195 173	26 48	221
Cannon hill (n=3 participants)	122 145 176	95 72 41	217

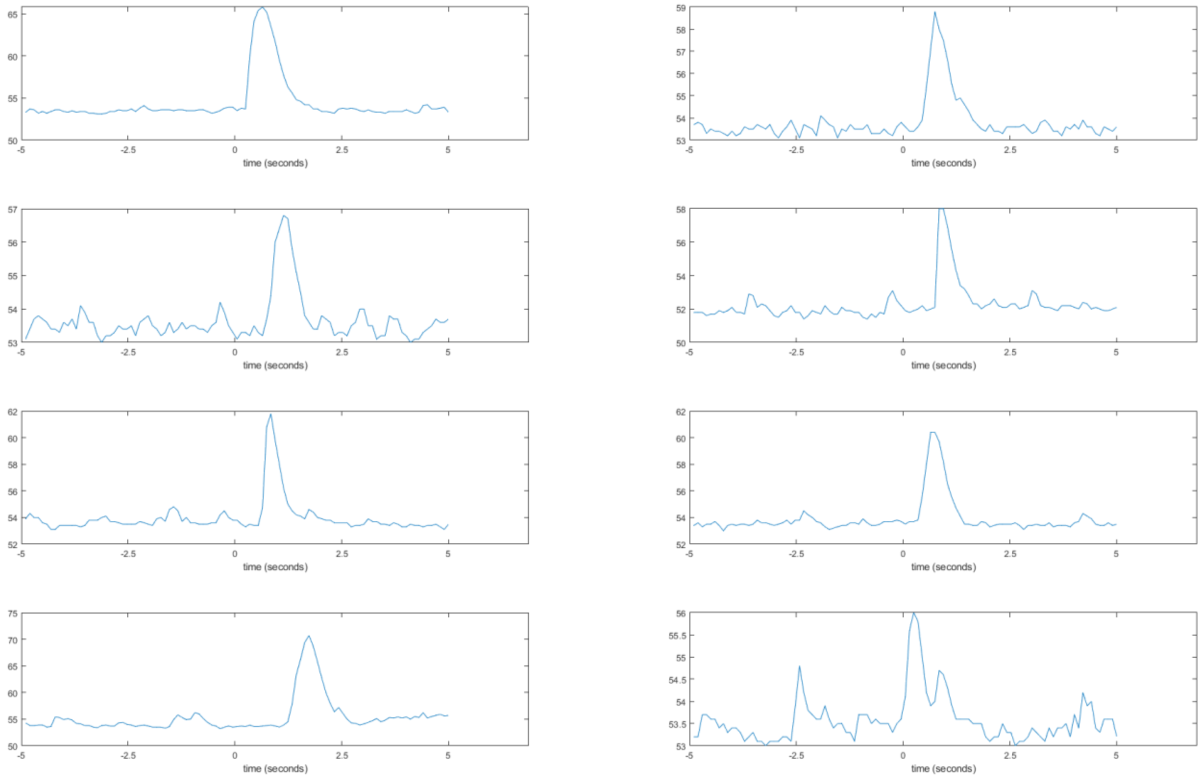


Figure 12: Typical patterns of train horns detected by NSRT_mk4

Once all the valid train horns from the NSRT_mk4 data were identified, the below variables related to train horns were extracted. Note that these variables applied to participants who came from the impact zone.

a) Average train horn duration (in seconds): the average duration of train horns that were sounded during evening and night hours (7 pm-7 am, Monday-Friday).
b) Max $L_{max,\ horn}$ (in dB): the maximum value of $L_{max,\ horn}$ of all train horns sounded during evening and night hours (7 pm-7 am) of each day. An average of Monday to Friday Max $L_{max,\ horn}$ was calculated and used.
c) Max $L_{max,\ horn}$ rise speed (in dB/s): the maximum value of $L_{max,\ horn}$ rise speed of all train horns sounded during evening and night hours (7 pm-7 am) of each day. $L_{max,\ horn}$ rise speed = $(L_{max,\ horn,\ peak} – L_{max,\ horn,\ start})/(t_{Lmax,\ horn,\ peak} - t_{Lmax,\ horn,\ start})$. An average value of Monday to Friday was calculated and used.

To measure the general environmental noise levels of all participants' residence during the day, evening, and night hours, the following variables were applied.

a) $L_{A,\ eq,\ day}$ (in dB): the average LEQ-A of all sounds during daytime (7 am-7 pm, Monday-Friday). The first hour was excluded if the data collection started on Monday.
b) $L_{A,\ eq,\ evening}$ (in dB): the average LEQ-A of all sounds during evening time (7 pm-11 pm, Monday-Friday).
c) $L_{A,\ eq,\ night}$ (in dB): the average LEQ-A of all sounds during night time (11 pm-7 am, Monday-Friday).
d) $L_{A,\ eq,\ 24h}$ (in dB): the average LEQ-A of all sounds during a whole day (24 h, Monday-Friday).

The NGARA system offers an accurate measurement of the train horn acoustic information. To extract this, a 10-second time window was applied, spanning 5 s before and 5 s after the train horn sounding time recorded by the NGARA audio data the time. Within this timeframe, all suspicious train horn peaks were first identified and listed in descending order based on their amplitudes. Secondly, the difference between the largest peak and the window's average amplitude was calculated. Dividing this difference by 2 yielded a threshold value. A potential train horn peak was identified if the difference between a specific peak and others in the window was above the defined threshold and the duration associated with the peak was less than 10 seconds.

In cases where the number of potential peaks exceeded 2, a narrower time window lasting 3 seconds (2 seconds before and 1 second after the “ground-truth” train horn sounding time) was applied. This process was reiterated, and if the count of potential train horn peaks was less than 1, it was identified as a train horn event. Figure 13 shows the typical patterns of train horns detected from the NGARA system. Similar to the NSRT_mk4, the NGARA system recorded all the environmental noise that could interfere with the detection of train horns, and thus, not all train horns were recognised. Table 2 shows the number of valid/invalid train horns that were extracted/excluded from each train station.

Table 2: The number of train horns detected/excluded from ALR data

Train stations	Number of valid train horns	Number of invalid train horns	Number of all train horns (NGARA audio)
Lawnton	201	24	225
Newmarket	140	19	159
Windsor	67	18	85
Alderley	194	27	221
Cannon hill	195	22	217

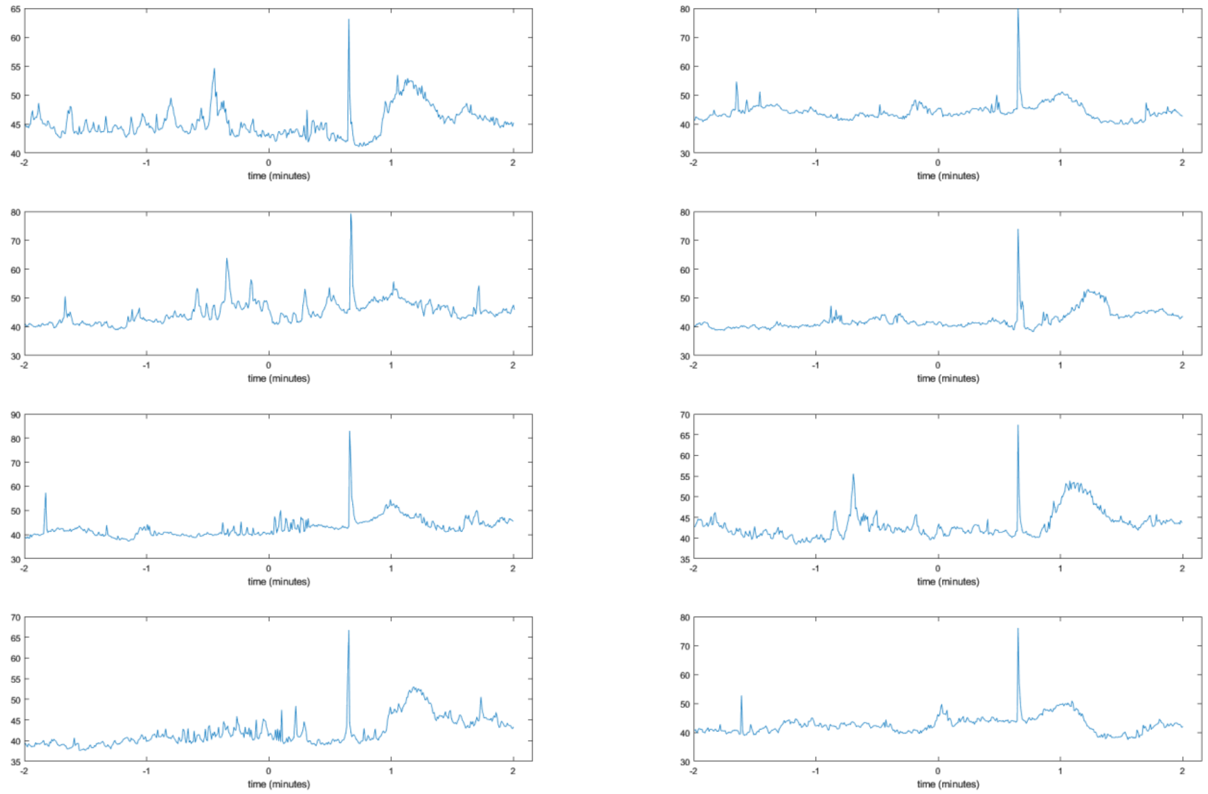


Figure 13: Typical patterns of train horn detected by NGARA system

With all the detected train horns from the NAGRA audio data, it is able to identify the train model that sounded the train horn using the four-character Train Identification System. According to the Vizirail Reports provided by the Queensland Rail team, which contain detailed train service ID, and actual arrival and departure times, the train model of all passing trains (with horn detected) at each station was affirmed. The trains were mostly divided into the following types: NGR, EMU (Electric Multiple Unit), IMU and SMU.

Based on the valid train horns that were detected by the algorithm, the variables below were extracted as measures of train horn acoustic features.

1. Maximum $L_{p,\ A,\ horn}$ (in dB): the maximum $L_{p,\ A}$ of all train horns that were sounded during evening and night hours (7 pm-7 am) of each day. The average of Max $L_{p,\ A,\ horn}$ from Monday to Friday was calculated and used.
2. Maximum $L_{p,\ A,\ horn}$ rise speed (in dB/s): the maximum value of $L_{p,\ A,\ horn}$ rise speed of all train horns that were sounded during evening and night hours (7 pm-7 am) of each day. $L_{p,\ A,\ horn}$ rise speed = $(L_{p,\ A,\ horn,\ peak} - L_{p,\ A,\ horn,\ start})/(t_{Lp,\ A,\ horn,\ peak} - t_{Lp,\ A,\ horn,\ start})$. An average value of Monday to Friday was calculated and used.

5.1.5.3. Subjective data

The questionnaire comprised the same items (apart from a small number of demographic items) as the online survey used in the previous broader social effects study. Specifically, the survey included questions relating to participant's exposure to train horns and railway noise in their homes, their recent experience of psychological distress (via the 21-item Depression, Anxiety and Stress Scale), their perceived sleep quality (via the 18-item version of the Pittsburgh Sleep Quality Index), and their perceived sensitivity to noise (via the 21-item Weinstein Noise Sensitivity Scale).

5.1.5.4. Data analysis approach

The analysis of data in this study could be divided into three parts. Firstly, a descriptive analysis was conducted on the subjective data collected in the questionnaire. This part mainly demonstrated the participants' real-world exposure to train horns and their perception of train horns. Secondly, the train horn acoustic characteristics (e.g., loudness, impulsiveness rate) were compared between different train models (NGR vs EMU/IMU/SMU). Furthermore, the general environmental noise levels between the impact and baseline groups were compared. The two group comparisons were conducted using the independent sample t-test or its non-parametric alternative (Mann-Whitney U test) if the normality assumption was violated. Thirdly, the objective sleep measures were compared between the impact and baseline groups. A Generalised Linear Model was developed to examine the factors that influenced participants' total sleep time in the impact group. The significance level of the statistical tests was 0.05.

5.2 Results

5.2.1 Subjective data report

5.2.1.1 Exposure to train horns and perceptions

Participants were asked if they heard train horns when inside their homes. As displayed in Table 3, the majority of participants in both groups reported that they do train horns inside their homes, with a higher proportion observed in the train horn impact group (94.4%), compared to the baseline group (77.8%**)**.

Table 3: Train horn exposure in each group

Group	Yes		No	
	n	%	*n*	%
Train Horn Impact (*n* = 18)	17	94.4	1	5.6
Baseline (*n* = 18)	14	77.8	4	22.2

Participants were also asked how frequently they hear train horns inside their homes on a typical day (4 am -6 pm) and a typical night (6 pm-4 am). As shown in Figure 14 and Figure 15, all participants from the baseline group reported hearing train horns 10 times or less during the day and less than 5 times during the night. Most participants from the train horn impact group reported hearing train horns 10 times or less during the day (66.7%, *n* = 12) and during the night (72.2%, *n* = 13). Over one-fifth of participants in the train horn impact group reported hearing train horns 11 to 20 times during the day (22.2%, *n* = 4) and over one-quarter during the night (27.8%, *n* = 5). A small proportion of participants from the train horn impact group reported hearing train horns more than 20 times during the day (11.1%, *n* = 2). No participants in either group heard train horns more than 20 times during the night.

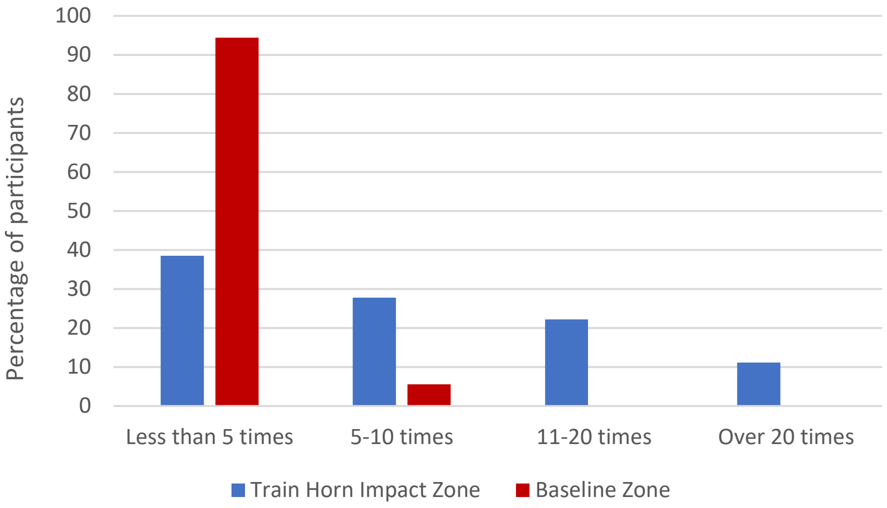


Figure 14: Frequency of hearing train horns during the day

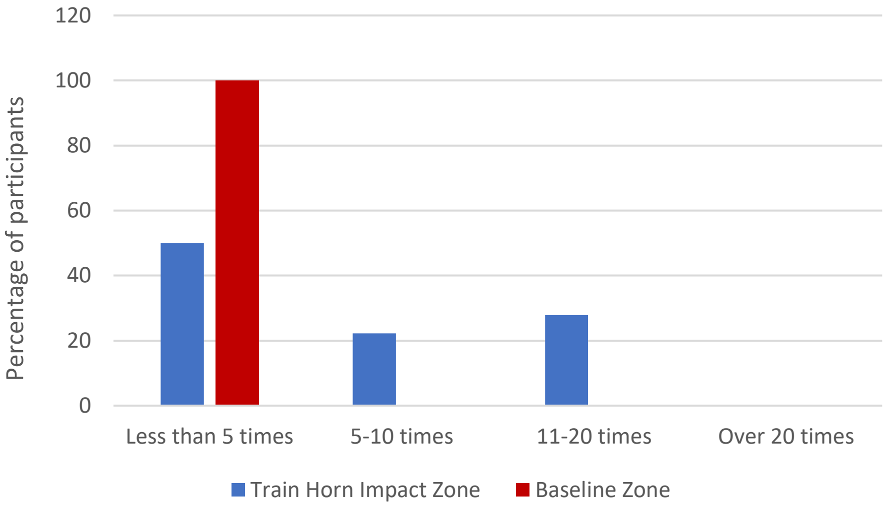


Figure 15: Frequency of hearing train horns during the night

The survey also assessed the extent to which participants were bothered, disturbed or annoyed due to hearing a train horn inside their home in the last 12 months on a scale of 1 (Not at all) to 5 (Extremely). As displayed in Figure 16, 33.7% of participants in the train horn impact group reported feeling *slightly* annoyed (*n* = 6), followed by *moderately* annoyed (27.8%, *n* = 5) and *not at all* annoyed (16.7%, *n* = 3). A small proportion of participants in this group reported being *very much* annoyed (11.1%, *n* = 2) or *extremely* annoyed (11.1%, *n* = 2) by train horns in the previous year. Most participants in the baseline group reported being not at all annoyed (61.1%, *n* = 11), and the remaining 7 participants reported being *slightly* (27.8%, *n* = 5) or *moderately* (11.1%, *n* = 2) annoyed.

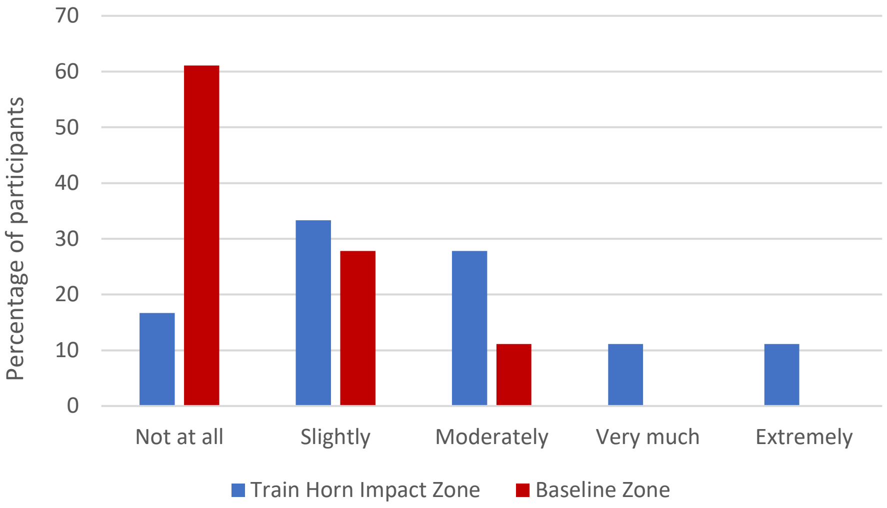


Figure 16: Degree to which participants were bothered, disturbed or annoyed by train horns

5.2.1.2 Exposure to other railway noise and perceptions

The survey asked questions about whether participants could hear other railway-related noises (excluding train horns) inside their homes. Like the findings pertaining to train horn exposure, Table 4 shows that most participants in the train horn impact group reported hearing railway noise inside their homes (94.4%). However, for the baseline group, exactly half of the participants reported hearing railway noise, and the other half reported they did not hear railway noise.

Table 4: Railway-related sound exposure in each zone

Group	Yes		No	
	n	%	*n*	%
Train Horn Impact (*n* = 18)	17	94.4	1	5.6
Baseline (*n* = 18)	9	50.0	9	50.0

For the frequency they heard railway-related noise (excluding train horns) in their homes during the day (4 am-6 pm) and during the night (6 pm-4 am), as displayed in Figure 17 and Figure 18, a very similar pattern of responses to the train horn items was received. Similar to the results pertaining to train horn exposure, all 18 participants in the baseline group reported hearing railway noise less than 5 times during the day and during the night. Most participants in the train horn impact group also reported hearing railway noise 10 times or less during the day (72.7%, *n* = 13) and night (88.8%, *n* = 16), and, compared to train horn exposure, more participants reported hearing railway noise 5 times or less during the day and night.

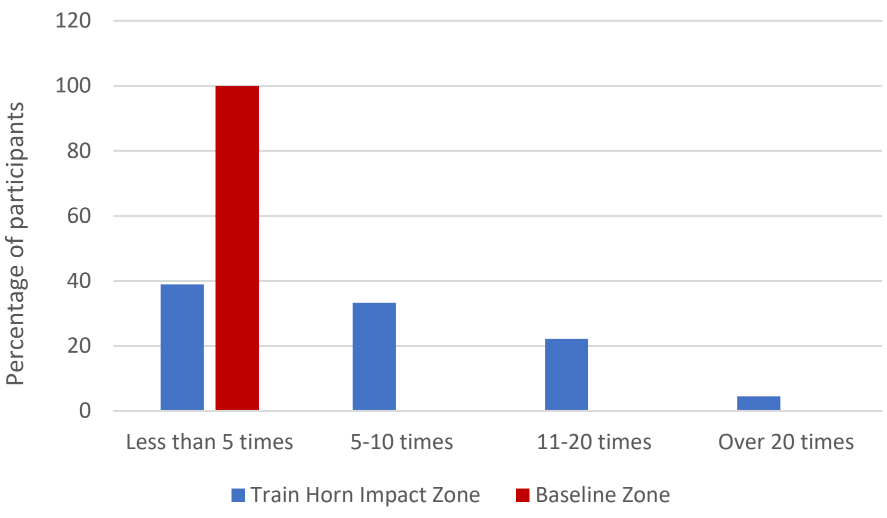


Figure 17: Frequency of hearing railway-related sounds during the day

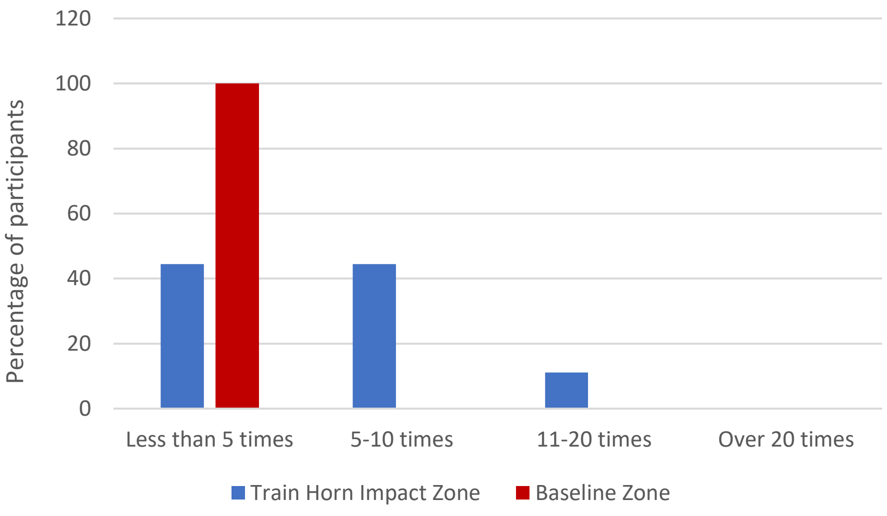


Figure 18: Frequency of hearing railway-related sounds during the night

Participants were also asked to rate the extent to which they felt bothered, disturbed, or annoyed due to hearing railway-related noise (excluding train horns) inside their home in the last 12 months on a scale of 1 (Not at all) to 5 (Extremely). As shown in Figure 19, the pattern of responses given by the train horn impact group was similar to those given for train horn annoyance, with 33.3% of participants reporting feeling *slightly* (*n* = 6), 22.2% reporting *moderately* (*n* = 4) or *not at all* (*n* = 4) by railway noise, and 2 participants each reporting feeling *very much* (11.1%) or *extremely* annoyed (11.1%). For the baseline group, the pattern for railway noise annoyance was similar to the pattern observed for train horn annoyance, except that a greater proportion of participants reported being *not at all* annoyed (83.3%, *n* = 15), and a small proportion reported being *slightly* (11.1%, *n* = 2) or *moderately* annoyed (5.6%, *n* = 1). No participants in the baseline group reported being *very much* or *extremely* annoyed by railway noise in the previous 12 months.

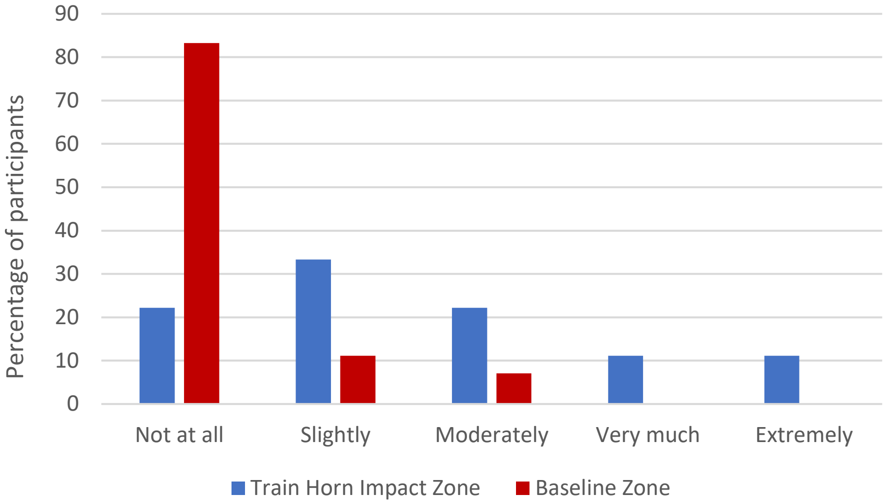


Figure 19: Degree to which participants were bothered, disturbed or annoyed by railway-related sounds

5.2.2 Train horn acoustic characteristics and environmental noise analysis

To examine the train horn difference between the EMU (Electric Multiple Unit), IMU (Interurban Multiple Unit), SMU (Suburban Multiple Unit) trains and the NGR (New Generation Rollingstock) trains, two train horn acoustic features, i.e., $L_{p,A,max}$ as a measure of loudness and maximum $L_{p,A}$ rise speed as a measure of impulsiveness rate, were compared. Among the five stations, Cannon Hill station was observed with a comparable number of NGR trains and EMU/IMU/SMU trains. In contrast, New Market, Windsor and Alderley stations all had an over-representative proportion of EMU/IMU/SMU trains, while Lawnton station had much more NGR trains than EMU/SMU/IMU trains. Therefore, the Cannon Hill station dataset was used for train horn acoustic feature analysis.

As listed in Table 5, the Mann-Whitney U test results showed that the two train horn acoustic features had significant differences between NGR trains and EMU/IMU/SMU trains. More specifically, the $L_{p,A,max}$ and maximum $L_{p,A}$ rise speed of NGR trains were significantly lower than those of EMU/IMU/SMU trains (see Figure 20).

Table 5: Mann-Whitney U test of train horn acoustic characteristics

Variables	Train type	N	Mean (S.D.)	Mann-Whitney U	Z	p
Maximum $L_{p,A,horn}$	EMU/IMU/SMU	84	73.80 (10.10)	2166.00	-4.225	<0.001
	NGR	83	67.40 (8.70)			
Maximum $L_{p,A,horn}$ rise speed	EMU/IMU/SMU	84	11.86 (8.77)	2848.00	-2.041	0.041
	NGR	83	8.54 (6.70)			

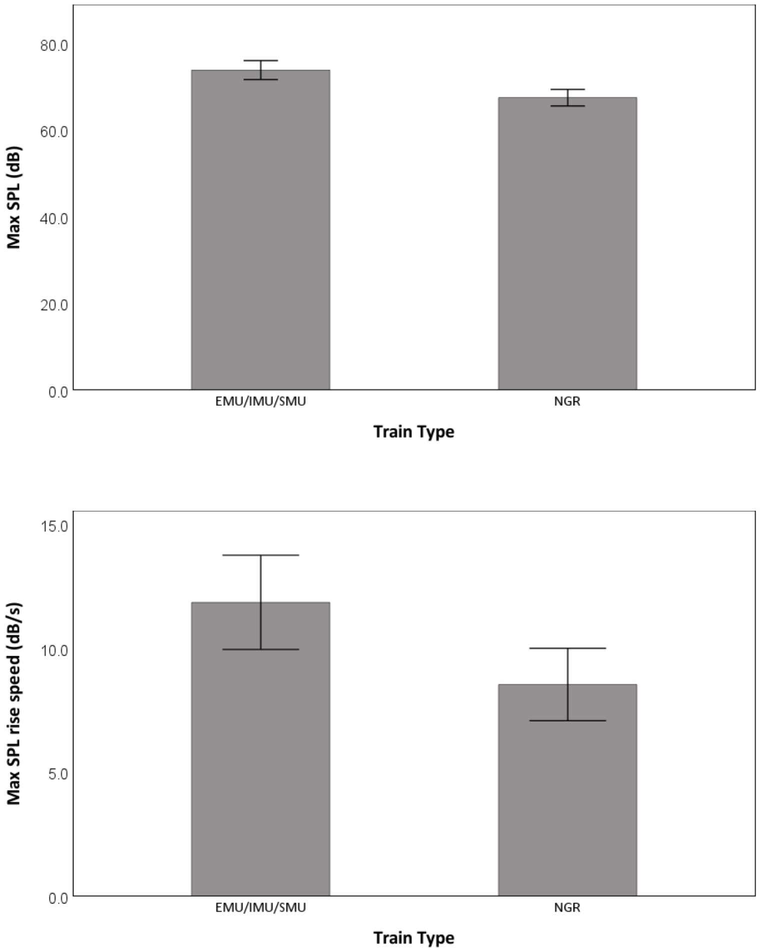


Figure 20: Maximum $L_{p, A, horn}$ and Maximum $L_{p, A, horn}$ rise speed of EMU/IMU/SMU and NGR trains

The residence environmental noise levels of all participants were compared between the impact and baseline groups. However, no significant difference was observed for the $L_{A, eq}$ measure of day, evening, night times and 24 hours between the two types of residential areas (see Table 6).

Table 6: Mann-Whitney U test of residential noise measures

Variables	Train type	N	Mean (S.D.)	Mann-Whitney U	Z	p
$L_{A,eq,day}$	Impact	18	48.54 (2.60)	120.00	-1.089	0.276
	Baseline	17	47.39 (3.26)			
$L_{A,eq,evening}$	Impact	18	43.23 (3.83)	127.00	-0.858	0.391
	Baseline	17	42.07 (3.97)			
$L_{A,eq,night}$	Impact	18	40.90 (3.47)	109.00	-1.452	0.146
	Baseline	17	39.32 (4.06)			
$L_{A,eq,24h}$	Impact	18	44.99 (3.01)	113.00	-1.320	0.187

Variables	Train type	N	Mean (S.D.)	Mann-Whitney U	Z	p
	Baseline	17	43.67 (3.26)			

5.2.3 Objective sleep measure analysis

The objective sleep quality was measured by four indexes: total sleep time, sleep onset latency, sleep efficiency, wake bouts and wake after sleep onset. As most of the measures do not comply with normal distribution, the nonparametric test (Mann-Whitney U test) as an alternative of the independent sample t-test was applied to examine the difference in the sleep measures between the impact group and the baseline group. The Mann-Whitney U test results show that there was no significant difference in any of the four sleep quality measures between the two groups, as listed in Table 7.

Table 7: Mann-Whitney U test of sleep measures between two groups

Variables	Group	N	Mean	S.D.	df	t	p	95%CI	
								Lower	Upper
Total sleep time	1	18	7.52	1.02	34	0.547	0.588	-0.485	0.842
	2	18	7.34	0.94					
Sleep onset latency	1	18	0.30	0.19	34	-0.078	0.938	-0.132	0.121
	2	18	0.31	0.18					
Sleep efficiency	1	18	0.79	0.06	34	0.135	0.893	-0.038	0.043
	2	18	0.79	0.06					
Wake bouts	1	18	14.11	3.94	34	0.039	0.969	-2.534	2.634
	2	18	14.06	3.68					
Wake after sleep onset	1	18	1.15	0.54	34	0.664	0.511	-.2139	.4214
	2	18	1.04	0.38					

A generalised linear model was developed to assess the impact of a number of factors on participants' total sleep time. The train station was entered as a control factor. In addition to the station, the model identified four significant factors of total sleep time. As shown in Table 8, the four factors were age, years in the address, distance to station and train horn maximum $L_{A,\ max}$ rise speed. Specifically, age (B=-0.097) and train horn maximum $L_{max,\ horn}$ rise speed (B=-0.122) were negatively associated with total sleep time, while years in address (B=0.099) and distance to station (B=0.004) were positively associated with total sleep time. This indicates that (1) as age increased, participants were more likely to have reduced total sleep time; (2) larger $L_{max,\ horn}$ rise speed was associated with reduced sleep time; (3) a longer time living in the current address and a longer distance to train station were associated with longer sleep time.

Table 8: The generalised linear model result of total sleep time

Parameter	B	S.E.	95% CI		Hypothesis Test		
			Lower	Upper	χ2	df	p

Intercept	10.183	1.9507	6.359	14.006	27.248	1	<0.001
Station=Windsor	0						
Station=Alderley	4.673	0.9077	2.894	6.452	26.499	1	<0.001
Station=Cannon Hill	2.613	0.6265	1.385	3.841	17.393	1	<0.001
Station=Lawnton	5.499	0.9365	3.664	7.335	34.487	1	<0.001
Station=New Market	3.752	0.6651	2.449	5.056	31.826	1	<0.001
Age	-0.097	0.0288	-0.153	-0.040	11.297	1	<0.001
Years in address	0.099	0.0409	0.018	0.179	5.802	1	0.016
Distance to station	0.004	0.0019	5.404e-5	0.007	3.957	1	0.047
Max $L_{max,horn}$ rise speed	-0.122	0.0433	-0.206	-0.037	7.882	1	0.005
Sample	17						
AIC	47.716						
BIC	56.048						

6 Discussion

The iMOVE CRC project conducted three studies to comprehensively examine both the positive and negative impacts of train horn use at level crossings. Study 1 used a virtual reality experimental setup to investigate pedestrians' behaviours and perceptions at level crossings by considering the loudness of train horns, the active or passive level crossing control and environmental noise (listening to music). This study contributed to a deep understanding of how pedestrians' perception, decision-making and waking behaviour were influenced by the various horn-leading situational factors at level crossings. Study 2 focused on examining whether and how train horns impact residents' sleep quality and mental health based on a self-reported questionnaire survey. Study 3 further applied objective measures on the sleep quality and train horn noise to validate the findings of Study 2, with an additional glance at the acoustic characteristics of train horns from different train models. Study 2 and Study 3 provide new knowledge for the authorities and public to understand the extent to which train horns may impact nearby communities' daily life functioning from both subjective and objective perspectives.

6.1 Effectiveness of train horns in alerting vulnerable road users

Although train horns are commonly used as a safety feature at level crossings to mitigate the collision risk between trains and road users, there has been little research that evaluated the safety benefits of train horn use and its impact on road user behaviour, especially among the vulnerable road users such as pedestrians. The virtual reality experiment in Study 1 with pedestrians as participants examined a range of level crossing environmental factors, including train horn loudness (60 dB vs 80 dB), level crossing control (active vs passive), and environmental noise (listening to music). As a key factor of focus, the impact of train horns on pedestrians' walking behaviour, head/eye movement, and decision-making was not observed in this study. Pedestrians were found to have made the stop/go decision before the train horn was sounded in over 81% of the scenarios, and most pedestrians came to a stop to check for the train before the horn was sounded. The think-aloud approach showed that train horns were barely rated as a notable feature by pedestrians at both active and passive level crossings, which helps explain why the train horns played a minor role in influencing pedestrians.

The level crossing control, on the other hand, was identified as the most critical factor in this study that influenced pedestrians' walking behaviour and decision-making at level crossings. At the stage after the train started to move and before the horn was sounded, pedestrians applied a significantly lower speed at active level crossings than at passive level crossings. Pedestrians' reaction time to trains was also shorter at active level crossings compared to the passive ones. The results indicate that pedestrians behaved more cautiously at active level crossings than when they were at passive ones. This is expected to be attributed to pedestrian lights at active crossings, as it was rated as the most notable feature by pedestrians at active crossings. The expectation is consistent with a previous study conducted in Victoria, in which drivers reported that flashing lights represent a strong association with rail level crossings and indicate danger more actively (Rudin-Brown et al., 2010).

The insignificant impact of train horns on pedestrian crossing behaviour in this research does not mean there is no safety value of sounding train horns at level crossings. A prior project undertaken by the CARRS-Q team, funded by ACRI (ACRI LC17B), showed that the use of train horns, specifically high-loudness horns, significantly improved motorists' behaviour performance (i.e., reduced reaction time, larger deceleration rate) when approaching level crossings at night-time and at passive level crossings. As vulnerable road users, pedestrians tend to perceive higher risks on roads and behave more cautiously than vehicle drivers at space when interactions with vehicles occur (Redmon, 2003). Due to the low speed and a relatively open visual field, pedestrians do not need to spend much effort in checking and stopping for trains in comparison to motorists. Thus, even without train horns, there is a low likelihood for pedestrians to take risks and cross before an approaching train. The different impact of train horns on different types of road users seems to be more subject to the physical and psychological attributes of the road users.

6.2 Impact of train horns on mental health and sleep functioning

Study 2 and Study 3 of the project collectively addressed the question regarding whether and to what extent train horns impact residents' sleep quality and mental health. Study 2 was based on a subjective questionnaire, and it was conducted with a larger participant sample (n=334) comprising three areas of residents, i.e., train horn impact area (Zone 1), railway-related sound impact area (Zone 2), and non-impact area (Zone 3). Study 3 was based on objective device measures, and it utilised a small group of participant samples (n=36), which could be divided into train horn impact group and baseline group. The results show that the subjective study findings and objective study findings were not entirely consistent.

First of all, it should be noted that the residence's distance to the nearest level crossing or train station was consistently used as a criterion for grouping participants in Study 2 and Study 3. When examining the difference in sleep quality between participant groups, the subjective study found that two components of sleep quality were significantly different between groups, i.e., subjective sleep quality and sleep latency. Participants from impact group reported poorer sleep quality and longer sleep latency than participants from baseline group. However, in the objective study, no significant difference was found between groups in any of the objective sleep quality measures, including sleep onset latency. In other words, the objective measures demonstrate that participants from the impact group slept as good/ poor as participants from the baseline group during the investigation period. The research suggests that train horns may not have that significant impact on sleep as residents subjectively believed. Although the NSRT_mk4 installed at participants' residences detected most of the train horns sounded during evening and night hours, it is likely that the train horn sound was buried and merged with the environmental background noise. Moreover, the residential building material was able to absorb or block the outside noise and mitigate its impact to some extent, especially for buildings where acoustic retrofitting or treatments were applied (Setunge & Gamage, 2016).

In the subjective study, night-time train horn frequency was identified as a significant contributor to the classification of participants into good sleep or poor sleep groups. This variable was not used in the modelling of the objective study, considering that it is closely related to a particular station. Instead, the objective study identified that train horn impulsive rate (maximum $L_{max,\ horn}$ rise speed) was a significant contributor to the participants' total sleep time. Studies that used objective measures to examine railway noise's impact on sleep were limited, and most of them have applied the maximum noise level (L_{max}) of a single noise event or the nighttime equivalent noise level (L_{eq}). For example, Aasvang et al. (2008) found that as railway noise (measured by $L_{p,A,eq,night}$ and $L_{p,A,max}$) increased, the proportion of participants' self-reported noise-induced sleep problems increased. Another study by Aasvang et al. (2011) found that the maximum level ($L_{p,A,Fmax,night}$) of railway noise was significantly associated with the time spent in REM (Rapid Eye Movement) sleep. To the best of our knowledge, our study was the first that confirmed a specific train horn related acoustic feature's relationship with sleep.

Lastly, the present research did not observe any difference in participants' emotional states (i.e., depression, anxiety, and stress) between the impact group and baseline group. The low association between train horn or railway noise and emotional distress is consistent with findings from several previous studies (Stansfeld & Matheson, 2003; Hegeweld et al., 2020). A meta-analysis by Hegeweld et al. (2020) found a significant positive relationship between aircraft noise and increased risk of depression, but not for railway or road traffic noise, and there was also no significant association between anxiety and railway noise. Research also suggests that when railway noise reaches a certain level, people at risk of noise-related depression (e.g., prone to insomnia or annoyance) consciously adopt strategies to reduce their noise exposure (Stansfeld & Matheson, 2003). The mixed findings in this area were partially attributed to the low quality of evidence with a need to apply more exact measurements of exposure (e.g. the time participants actually spend within the home) and the possible psychological and behavioural adaptations.

7 Limitations and future research

While the research design employed in this study was comprehensive and drew on an innovative mixed methods approach to create rich insights and findings, there are invariably some demarcations that need to be drawn around the applicability of the findings, mainly because of limitations in the scope and resources of the research.

(1) For the pedestrian simulation study, it is acknowledged that some additional behavioural differences may exist between simulation and real-world observation, where participants perceive no or a lower level of risk in the virtual environment and behave differently to real life. However, the study compared behavioural responses to the train horn when approaching a crossing in different context settings and used a combination of quantitative and qualitative information obtained from participants.

(2) The walking operation of pedestrians in Study 1 was performed by participants pressing buttons that were connected to the VR device. A real-world walking set-up was not applied due to (1) constrains of space, which requires a quiet room with at least 150m in length to simulate the level crossing area, and (2) participant proneness of motion sickness by wearing the VR device. In the future,

an augmented virtual reality approach is recommended if an appropriate experimental space can be guaranteed to examine pedestrians' real-world walking behaviours.

(3) The subjective questionnaire study has the common limitation of all survey-based studies, in which the validity of results largely depends on the authenticity of the participants when they answer the questions. In Study 2, the participants were made aware that their participation was completely anonymous, and they were encouraged to answer the questions honestly and frankly with no need to worry about any negative outcomes from their participation. The key measures of the study, such as sleep quality, noise sensitivity and emotional states, were collected by subjective self-reported data, which may have discrepancies with the real situation, especially for the sleep quality.

(4) The last objective study has a relatively small sample size (n=36), with participants mainly recruited from 5 train station areas, and the actual data collection period on each participant was only five days. Although the sample size is sufficient to support the statistical analysis performed in the study, it is suggested that if time and budge allowed, a larger sample size recruited from a wide range of train stations and a longer period of sleep and noise pattern observations should be undertaken to enhance the generalisability of the current research findings.

(5) Due to practical and operational concerns, the NGARA sound acquisition system was installed inside the station office. This has potentially increased the difficulty of detecting "ground-truth" train horns (especially the short gentle horns) from the audio data with the interferences of various other environmental noises. It would be ideal if the equipment could be setup at a location closer to the whistle boards or level crossings where train horns are normally sounded, assuming that a waterproof area and power supply are available. For the residence noise monitoring, it would be better in the future if another set of NSRT_mk4 could be installed in participants' bedrooms to record the indoor noise level.

Overall, the project applied a mixed research design by combining simulations with real-world observations and linking subjective measures with objective measures to provide a comprehensive understanding of how train horns influence pedestrians' crossing behaviours and residents' sleep quality and mental health. In summary, the findings of the research indicate that pedestrians' crossing behaviours and decision-making were not impacted by the use of train horns but were more influenced by the active/passive level crossing control. Train horns were perceived by most pedestrians during the experiment, but they were not picked up as a very notable feature. Subjective data suggest that residents who lived in close proximity to train stations or whistle boards reported poorer subjective sleep quality and longer sleep latency than those who live a bit further away from those infrastructures. In contrast, objective data did not disclose any difference in sleep metrics between residents from the two types of areas. Night time train horn frequency was associated with a higher likelihood of participants being classified in the poor sleep quality group, while train horn impulsiveness rate was negatively associated with participants' total sleep time. No significant impact was found from train horns on participants' mental health (depression, anxiety and stress).

The project findings have shed light on several future research directions and train horn use suggestions. Firstly, train horns were found to play a minor role in alerting pedestrians. As a comparison to the findings in the previous project ACRI LC17B, motorists seemed to be more reliant on train horns to initiate an early deceleration and adjust their deceleration rates at level crossings. The different impacts are expected to relate to the road users' physical dynamics and behavioural/psychological attributes. To confirm this, future research could examine the effectiveness of train horns on other types of road users, such as motorcyclists and cyclists. Our hypothesis is that road users who travel at higher speeds on roads receive more safety benefits delivered by train horns.

Secondly, the safety features at active level crossings, especially the traffic lights, were the dominant factor for pedestrians to make stop/go decisions. This is in consistent with findings from the motorists driving simulation experiment in ACRI LC17B, in which participants were less reliant on train horns to take decelerations at active crossings compared to passive crossings. This indicates that the requirement of sounding train horns at active crossings as a practice could be reconsidered, given the marginal effect of train horns observed on both motorists and pedestrians. Thirdly, night time train horn frequency and maximum $L_{max,\ horn}$ rise speed were identified as significant contributors of participants' sleep quality and total sleep time, respectively, in Study 2 and Study 3. To mitigate the noise impact, reducing the use of train horns at night and solutions to lower horn impulsiveness rate could be considered. Lastly, the main purpose of sounding train horns at level crossings is to alert road users of the approaching trains. The current Rail Traffic Horn Use - Code of Practice requires train drivers to use train horns at whistle boards, when approaching the level crossing, or on the level crossing. To maximise the alertness of train horns on road users and minimise the disturbance on residents near railway tracks, a fixed horn-releasing device installed at level crossings could be an option to reinforce the impact area, while the horn on trains can be mainly used for emergency and other necessary communication purposes.

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Appendix A

PARTICIPANT INFORMATION FOR QUT RESEARCH PROJECT
– A Field-based Study –

Investigating the use of train horns at rail level crossings

The broader effects of environmental noise transmission on sleep-wake cycles of residents.

QUT Ethics Approval Number 5229

Research team

Principal Researcher:	Dr Xiaomeng Li, Research Fellow,
Associate Researchers:	Professor Andry Rakotonirainy, iMOVE Australia, CARRS-Q
Research Officers:	Ms Wanda Griffin, CARRS -Q Ms Melinda McDonald, CARRS-Q Mr Bryn Ellis, CARRS-Q Mr Pete Coughlan Ms Fatemah Ghobani Ms Zishuo Zhu Mr Lewis Cockram Centre for Accident Research and Road Safety – Queensland (CARRS-Q), Queensland University of Technology (QUT)

Why is the study being conducted?

This actigraphic study is being undertaken as part of a research project for the Australasian Centre for Rail Innovation (ACRI) and iMOVE Australia. This research project will examine the effect of environmental noise on your sleep health and daily functioning. The research is looking for 3 groups of residents to participate. Group 1 residents who live in proximity to an operational train environment (e.g., level crossing, train stations and yards), group 2 residents who live close to rail track or who live away from rail infrastructure.

You are invited to participate in this research project because you are aged over 18, currently live in Townsville or the Brisbane Region and when you completed the first survey of this study you nominated that you are interested and available to participate in the actigraphic study.

What does participation involve?

Your participation in the study will be done in your home and daily life locations. You will be asked to wear an actigraph for a period of 5 nights and days while you go about your normal activities. An actigraph (see photo) is an unobtrusive device similar to a watch that uses a highly sensitive accelerometer to measure sleep schedule variability, sleep quantity, and sleep quality statistics as well as an ambient light sensor to track exposure to sunlight. The actigraph will measure your sleep-wake timing and functioning including sleep disturbances, night-time arousals and daytime activity movements.

A separate decibel recorder will also be located externally at your residence. It is a small piece of equipment (see photo) that can be placed on a tripod under your home, or in the garden or balcony (if you live in a unit). This device will record the levels of environmental noise conditions e.g., noise, vibrations, light, train frequency and horn sounds to enable an objective assessment of the environmental noise conditions. The decibel recorder only records the level of sound pressure not the actual sounds (talking or conversations). To participate in this study a member of the research team will require access to your premises/garden. A convenient and suitable time will be organized with you to bring, set up and then collect the equipment from you.

You will also complete an online survey at the end of the data collection period about the duration and consistency of your sleep, environmental noise experiences and factors leading to sleep disturbances during the data collection period.

Your decision to participate or not participate will in no way impact upon your current or future relationship with QUT (for example your grades), the Australasian Centre for Rail Innovation or iMOVE Australia.

What are the possible benefits for me if I take part?

It is expected that this research project will not benefit you directly. However, it may benefit others in the community who live close to rail infrastructure in the future. This research study is expected to provide specific information to the transport and rail industry about the effect of railway noise and train horn sounding on the resident's sleep health and functioning of those who live in close proximity to rail infrastructure.

To thank you for your participation you will receive a $150 Coles/Myer gift card at the conclusion of your participation. Should you after commencing the study for any reason be unable to complete the study you will receive a $10 Coles/Myer gift card.

What are the possible risks for me if I take part?

There are nominal risks associated with your participation in this research project. You may feel some discomfort from wearing the actigraph 24 hours a day for the 5nights and days.

You may feel some discomfort having research officers coming to your residence to deliver, install and collect the equipment.

Should you for any reason be unable to complete the 5-nights and days study, you can stop participation at any time and contact the research team listed below to organise a convenient time to collect the equipment. Should you stop participation in the actigraph study any data collected by the actigraph will be removed, the code that identifies your survey data will be deleted so that your survey data is non-identifiable.

QUT provides for limited free psychology, family therapy or counselling services for research participants of QUT research projects who may experience discomfort or distress as a result of their participation in the research. Should you wish to access this service please call the Clinic Receptionist on **07 3138 0999** (Monday–Friday only 9am–5pm), QUT Psychology and Counselling Clinic, 44 Musk Avenue, Kelvin Grove, and indicate that you are a research participant. Alternatively, Lifeline provides access to online, phone or face-to-face support, call **13 11 14** for 24 hour telephone crisis support. For people aged up to 25, you can also call the Kids Helpline on **1800 551 800**.

What about privacy and confidentiality?

All comments and responses will be treated confidentially unless required by law, or regulatory or monitoring bodies, such as the ethics committee. Every effort will be made to ensure that the data you provide cannot be traced back to you in reports, publications, and other forms of presentation. The research project is funded by the Australasian Centre for Rail Innovation (ACRI) and iMOVE Australia and they will not have access to the data obtained during the research project.

Any data collected as part of this research project will be de-identified and stored securely as per QUT's Management of research data policy. Please note that non-identifiable data from this research project may be used as comparative data in future research projects or stored on an open access database for secondary analysis.

Please note individual feedback obtained through the study will not be published, with only summarised findings released to ACRI, employers and the public. You may choose not to answer any question that you feel uncomfortable about or withdraw from the study without penalty.

Any data collected as part of this research project will be stored securely as per QUT's Management of research data policy. Data will be stored for a minimum of 5 years, and can be disclosed if it is to protect you or others from harm, if specifically required by law, or if a regulatory or monitoring body such as the ethics committee requests it.

How do I give my consent to participate?

We would like to ask you to sign a written consent form (enclosed) to confirm your agreement to participate.

What if I have questions about the research project?

If you have any questions or require further information please contact one of the listed researchers:

Project Research Officer	wm.griffin@qut.edu.au	(07) 3138 8774
Dr Xiaomeng Li	xiaomeng.li@qut.edu.au	(07) 3138 4749

What if I have a concern or complaint regarding the conduct of the research project?

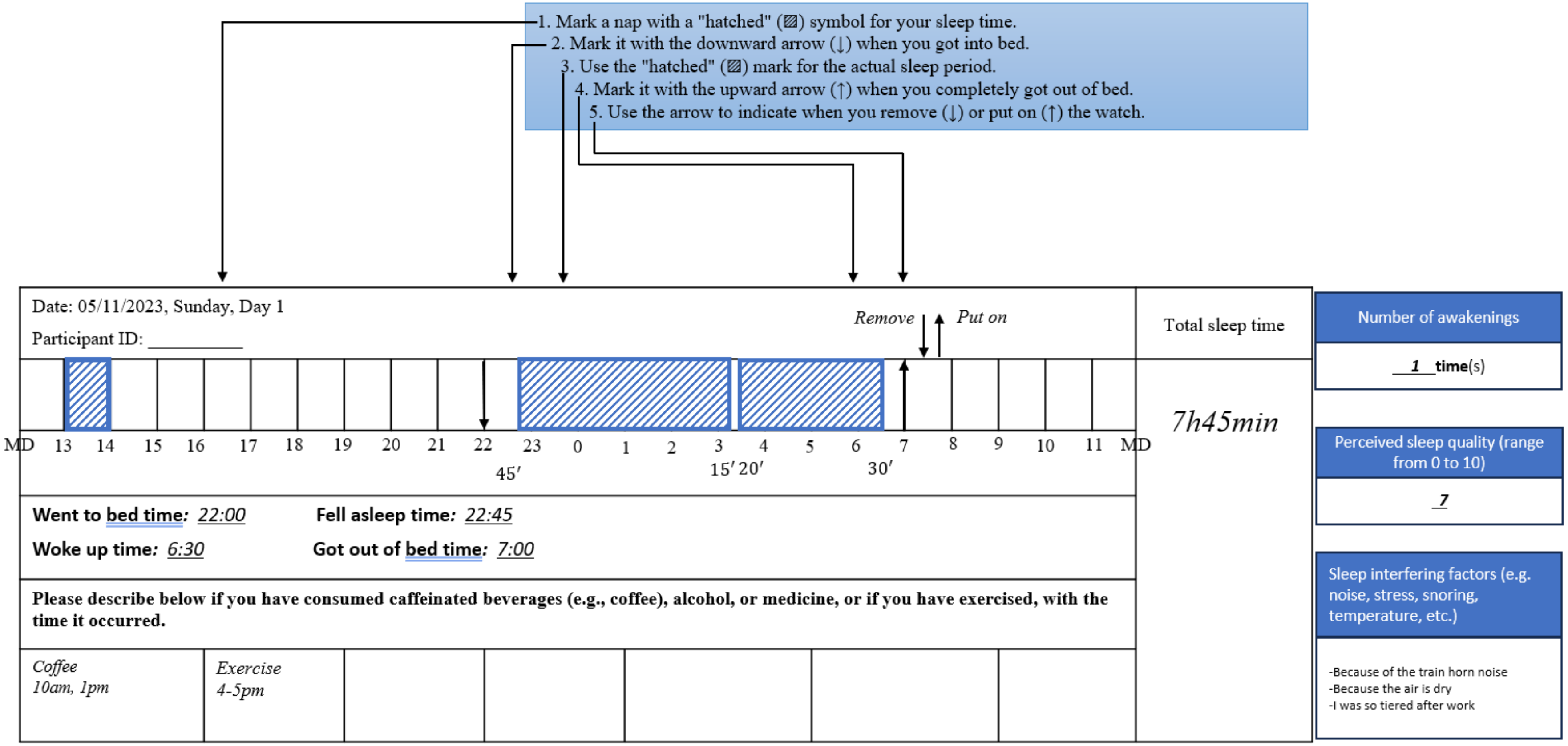
QUT is committed to research integrity and the ethical conduct of research projects. However, if you do have any concerns or complaints about the ethical conduct of the research project you may contact the QUT Research Ethics Advisory Team on (07) 3138 5123 or email humanethics@qut.edu.au. The QUT Research Ethics Advisory Team is not connected with the research project and can facilitate a resolution to your concern in an impartial manner.

THANK YOU FOR HELPING WITH THIS RESEARCH PROJECT.
PLEASE KEEP THIS SHEET FOR YOUR INFORMATION.

Appendix B

Sleep diary (example page with instructions)

Sleep Diary – Please complete the sleep diary right after waking up each day. Below is an example.



1. Mark a nap with a "hatched" (▨) symbol for your sleep time.
2. Mark it with the downward arrow (↓) when you got into bed.
3. Use the "hatched" (▨) mark for the actual sleep period.
4. Mark it with the upward arrow (↑) when you completely got out of bed.
5. Use the arrow to indicate when you remove (↓) or put on (↑) the watch.

Date: 05/11/2023, Sunday, Day 1

Participant ID: ___________

Went to bed time: *22:00*

Fell asleep time: *22:45*

Woke up time: *6:30*

Got out of bed time: *7:00*

Please describe below if you have consumed caffeinated beverages (e.g., coffee), alcohol, or medicine, or if you have exercised, with the time it occurred.

Coffee *10am, 1pm*	*Exercise* *4-5pm*					

Total sleep time

7h45min

Number of awakenings

1 **time**(s)

Perceived sleep quality (range from 0 to 10)

7

Sleep interfering factors (e.g. noise, stress, snoring, temperature, etc.)

-Because of the train horn noise
-Because the air is dry
-I was so tiered after work

Appendix C

Survey completed by participants following actigraph phase

1. Participant ID: _______

2. Please write the code you created in the Survey Study (Mothers name and month of birth, i.e., Bea02) _______________

3. What is your age?________

4. What is your gender?

[ ] Female [ ] Male [ ] Other [ ] Prefer not to say

5. What is the highest level of education you have completed?

[ ] Less than Year 12 [ ] Completed Year 12 [ ] Certificate or Diploma [ ] Bachelor's Degree

[ ] Master's Degree or higher [ ] Other (please specify______________)

6. How long have you lived at your current address (in years)?___________

7. How often do you travel by rail?

[ ] More than once per day [ ] Daily [ ] 1-2 times each week [ ] 1-2 times each month

[ ] 1-2 times each 6 months [ ] Once a year [ ]Less than once a year [ ] Never

8. How far is your residence from the nearest railway station (in metres)? _______

9. Which location is your residence in?

[ ] Cannon Hill [ ] Lawnton [ ] Burpengary

[ ] Windsor [ ] Alderley [ ]Newmarket [ ] Keperra

[ ] None of these areas. Please provide a post code_________

10. How far is your residence from the nearest rail tracks (in metres)?__________

11. What type of building do you live in?

[ ] Apartment [ ] House [ ] Townhouse [ ] Unit [ ] Other (please specify__________)

12. Below are a number of characteristics that may or may not apply to you. Please indicate the extent to which you agree or disagree with that statement.I am someone who....

I am someone who…	Disagree strongly	Disagree a little	Neither agree nor disagree	Agree a little	Agree strongly
Is Talkative					
Is Depressed, Blue					
Is Reserved					
Is relaxed, handles stress well					
Is full of energy					
Can be tense					
Generates a lot of enthusiasm					
Worries a lot					
Tends to be quiet					
Is emotionally stable, not easily upset					
Has an assertive personality					
Can be moody					
Is sometimes shy, inhibited					
Remains calm in tense situations					
Is outgoing, sociable					
Gets nervous easily					

13. Please read each statement and choose the response which indicates how much the statement applied to you over the last week. There are no right or wrong answers. Do not spend too much time on any statement.

	Did not apply to me at all	Applied to me to some degree or some of the time	Applied to me a considerable degree or a good part of the time	Applied to me very much or most of the time
I find it hard to wind down				
I was aware of dryness of my mouth				
I couldn't seem to experience any positive feeling at all				
I experienced breathing difficulty (e.g. excessively rapid breathing, breathlessness in the absence of physical exertion)				
I found it difficult to work up the initiative to do things				
I tended to over-react to situations				
I experienced trembling (e.g. in the hands)				
I felt I was using a lot of nervous energy				
I was worried about situations in which I might panic and make a fool of myself				
I felt that I had nothing to look forward to				
I found myself getting agitated				
I found it difficult to relax				
I felt down-hearted and blue				
I was intolerant of anything that kept me from getting on with what I was doing				
I felt I was close to panic				

	Did not apply to me at all	Applied to me to some degree or some of the time	Applied to me a considerable degree or a good part of the time	Applied to me very much or most of the time
I was unable to become enthusiastic about anything				
I felt I wasn't worth much as a person				
I felt that I was rather touchy				
I was aware of the action of my heart in the absence of physical exertion (e.g. sense of heart rate increase, heart missing a beat)				
I felt scared without any good reason				
I felt that life was meaningless				

14. The following questions relate to your usual sleep habits during the past week only. Your answers should indicate the most accurate reply for the majority of the days and nights in the past week. Please answer all questions.

During the past week, at what hour have you usually gone to bed? (24 hour clock) ___________

During the past week, how long (in minutes) has it taken you to fall asleep each night? __________

During the past week, at what hour have you usually gotten up in the morning? _____________

How many hours of actual sleep did you get last night? (This may be different than the hours you spend in bed) ______________

During the past week, how often have you had trouble sleeping because you………

	Not during the past week	Less than once a week	Once or twice a week	Three or more times a week
Cannot get to sleep within 30 minutes				
Wake up in the middle of the night or early morning				
Have to get up to use the bathroom				
Cannot breathe comfortably				
Cough or snore loudly				
Feel too cold				
Feel too hot				
Have bad dreams				
Have pain				
Other reasons (Please Describe, including how often you have had trouble sleeping because of this reason(s))				

	Not during the past week	Less than once a week	Once or twice a week	Three or more times a week
During the past week, how often have you taken medicine (prescribed or "over the counter") to help you sleep?				
During the past week, how often have you had trouble staying awake while driving, eating meals, or engaging in social activity?				

15. During the past week, how much of a problem has it been for you to keep enough enthusiasm to get things done?

[ ] No problem at all [ ] Only a very slight problem [ ] Somewhat of a problem

[ ] A very big problem

16. During the past week, how would you rate your sleep quality overall?

[ ] Very good [ ] Fairly good [ ] Fairly bad [ ] Very bad

17. Below are a number of statements addressing individual reactions to noise. After reading each statement, please choose the response that best represents your level of agreement with the statement. For each item, use the following scale.

	Strongly disagree	Disagree	Neutral	Agree	Strongly agree
I wouldn’t mind living on a noisy street if the apartment I had was nice.					
I am more aware of noise than I used to be.					
No one should mind much if someone turns up his or her stereo full blast once in a while.					
At movies, whispering and crinkling candy wrappers disturb me.					
I am easily awakened by noise.					
If it’s noisy where I am studying, I try to close the door or window or move someplace else.					
I get annoyed when my neighbours are noisy.					
I get used to most noises without much difficulty.					
It would matter to me if an apartment I was interested in renting were located across from a fire station.					
Sometimes noises get on my nerves and get me irritated.					
Even music I normally like will bother me if I’m trying to concentrate.					
It wouldn’t bother me to hear the sounds of everyday living from neighbours (footsteps, running water, etc.).					
When I want to be alone, it disturbs me to hear outside noises.					
I’m good at concentrating no matter what is going on around me.					

	Strongly disagree	Disagree	Neutral	Agree	Strongly agree
In a library, I don't mind if people carry on conversation if they do it quietly.					
There are often times when I want complete silence.					
Motorcycles ought to be required to have bigger mufflers.					
I find it hard to relax in a place that's noisy.					
I get mad at people who make noise that keeps me from falling asleep or getting work done.					
I wouldn't mind living in an apartment with thin walls.					
I am sensitive to noise.					

18. Do you hear train horns when inside your home?

[ ] Yes [ ] No

19. On a typical day, how often do you hear train horns when inside your home during the day (4AM-6PM)?

[ ] Less than 5 times [ ] 5-10 times [ ] 11-20 times [ ] Over 20 times

20. On a typical night, how often do you hear train horns when inside your home during the night (6PM-4AM)?

[ ] Less than 5 times [ ] 5-10 times [ ] 11-20 times [ ] Over 20 times

21. Thinking about the last 12 months or so, when you are at home, how much does the train horn bother, disturb or annoy you?

[ ] Not at all [ ] Slightly [ ] Moderately [ ] Very much [ ] Extremely

22. For the below train horn acoustic characteristics, please indicate the extent to which they are noticeable (and/or disturbing) to you?

	Not at all	Slightly	Moderately	Very much	Extremely
Tonality					
Loudness					
Sharpness					

23. Do you hear railway-related sound (excluding train horns) when inside your home?

[ ] Yes [ ] No

24. On a typical day, h ow often do you hear railway-related sound (excluding train horns) when inside your home during the day (4AM - 6PM)?

[ ] Less than 5 times [ ] 5-10 times [ ] 11-20 times [ ] Over 20 times

25. On a typical night, how often do you hear railway-related sound (excluding train horns) when inside your home during the night (6PM - 4AM)?

[ ] Less than 5 times [ ] 5-10 times [ ] 11-20 times [ ] Over 20 times

26. Thinking about the last 12 months or so, when you are at home, how much does railway-related sound (excluding train horns) bother, disturb or annoy you?

[ ] Not at all [ ] Slightly [ ]Moderately [ ] Very much [ ]Extremely