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Injury by design: A thematic networks and system dynamics analysis of work-related musculoskeletal disorders in tram drivers

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ABSTRACT

Tram driving is a safety critical task where work-related musculoskeletal disorders (WRMSDs) and injuries are associated with interacting occupational design factors over time. These interactions then carry implications for workforce retention, public safety, workplace relations and supports. To better understand such interactions, this study used thematic networks and system dynamics (causal loop diagrams) analysis with the aim to unearth a global theme underscoring occurrence of WRMSDs, and describe the factors influencing the system dynamics of WRMSD occurrence in tram drivers. Building on earlier work focused on occupational participation, secondary analysis of driver interviews ($n = 13$) and driving observations ($n = 11$) produced thematic network and causal loop models of risk factors that highlighted an *Injury by Design* problem structure as a global theme. Research targeting organisational culture, human factors, and design standards is needed to minimise WRMSDs risk in tram drivers.

1. Introduction

In many corners of the globe, tram (i.e., light rail) systems are undergoing a 'remarkable renaissance' (International Association of Public Transport, 2019), and being celebrated for their economic (e.g., urban renewal, land value uplift, scalability, ease of use), social (e.g., connectivity, accessibility, preference) and environmental (e.g., reduced emissions, sustainability, mixed modality) benefits (Australasian Railway Association, 2021). Like many surface transportation sectors, the tram system features inherent risks associated with operating in population-dense mixed-traffic environments (Naznin et al., 2017). As an occupation, driving trams is thus cognitively demanding where in addition to the physical operation of the tram, the driver must engage heavily with external monitoring and awareness-maintaining activities (Naweed and Balakrishnan 2014)—aspects of performance that are compounded by human limitations (e.g., delayed reaction time, reduced situation awareness, elevated fatigue) which increase injury risk (Chapman et al., 2019; Dorrian et al., 2006).

Driving rail vehicles is a safety critical task, particularly when moving passengers, and is associated with various chronic metabolic health disorders, frequently ascribed to the design of the job (Naweed et al., 2017b). Work-related musculoskeletal disorders (WRMSDs) and related injuries are a rising problem within and across the rail driving workplace (Nathanael and Marmaras 2018; Office of Rail and Road 2014) and include shoulder, wrist, forearm, back and neck strains, and muscle disorders leading to pain and discomfort. In Australia, WRMSDs comprising injury to the upper and lower body and limbs, and including conditions such as non-specific low back pain, neck pain and carpal tunnel syndrome account for 40% of injury and disease reported by rail drivers in compensation claims (Monash Insurance Work and Health Group, 2018).

The physical risk factors that cause damage and microfailure to musculoskeletal tissues are well-established. Factors include exposure to tasks that involve: high rates of repetition; high force demands; awkward postures; and long duration (Gallagher and Heberger 2013; Hoogendoorn et al., 1999). However, WRMSDs are also compounded by psychosocial factors (Bovenzi 2015), though the mechanisms for this are more complex (Fox et al., 2020). Tram driving features repetitive movements, vibration and muscular stress and a complex psychosocial environment (Naweed and Moody 2015). Importantly, tram driving is also an imposed seating environment where good seat design is needed to overcome sit-slouching postures, as a risk factor for WRMSDs (Black et al., 2012). Given tram systems are growing but rail is facing workforce retention issues everywhere (Australasian Railway Association, 2018;

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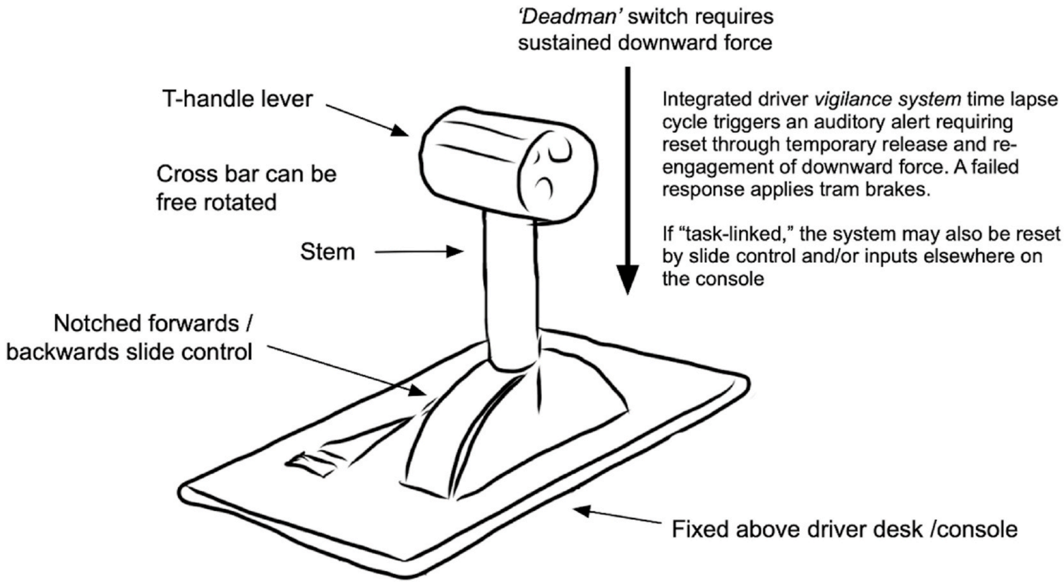

Fig. 1. Illustration of a generic Master Controller design used on tram vehicles.

Fender 2019; Hendry 2019), there is a pressing need to reduce occurrence of WRMSDs to promote rail workforce retention.

In comparison to other health issues (e.g., obstructive sleep apnoea), WRMSDs have a tendency to be treated as a less significant issue, even though they reduce worker health and wellbeing which invariably impacts public safety. They also tend to be treated as a local/individual health issue, but the impact of injured drivers extends to the broader system where it creates implications for re-rostering, balancing of spare shifts, and a reliance on the availability of the rest of the limited workforce (Naweed et al., 2020). WRMSDs also tend to be attributed to physical ergonomics explanations for causation and remediation. For example, Naweed et al. (2020) describe a case where the physical design of the Master Controller—the primary interface for controlling and adjusting the speed and velocity of a rail vehicle—was attributed by the tram organisation as the primary cause of WRMSDs in its driver population. However, WRMSDs are a symptom of broader systems issues that may indeed be associated with equipment design, but also arise from a complex interaction of different factors over time. As a case in point, the Master Controller (see Fig. 1) is the epitome of complexity in that it is not only used by the driver to exert control on vehicle speed, but *it* uses these inputs to evaluate the driver's own physical (deadman device) and cognitive (vigilance device) capacity, and therefore, the Master Controller can also be considered to control the driver. The driver and the Master Controller therefore function as a joint cognitive system (Hollnagel and Woods 2005).

While systems approaches (e.g., Rasmussen 1997) for articulating the interrelationships of different systems components in WRMSDs are on the rise (e.g., Goode et al., 2019; McCormack et al., 2021), application of such approaches for WRMSD prevention in rail are rare, and finding research with real-world examples of WRMSD occurrence in rail driving couched as a systems issue is a challenge. In the absence of this, single-factor explanations for causation abound and attract assignment of blame—particularly in highly regulated systems (Waring 2005; Wolff 2006), meaning that the propensity for this within rail is high (Clarke 1998). Too often, attempts to research the cause, understand its prevalence, and publish learnings on WRMSDs in rail are also constrained by non-disclosure agreements, privacy issues around workers' compensation insurance claims, and engagement with consultants/non-research agencies.

As mentioned previously, the Naweed et al. (2020) study describes the case of a tram organisation where a large proportion of the tram driver workforce were either off work or on light duty (i.e., performing office tasks) from WRMSDs. Specifically, this mixed-methods study examined driving behaviours through the lens of the Person-Environment-Occupation-Performance (PEOP) model (Christiansen and Baum 2005), which proposes that intrinsic (person), extrinsic (environmental), and occupation (task) factors interact to produce the person's occupational performance. The study revealed a range of injury predisposing factors linked with WRMSDs with themes deductively mapped on the PEOP model to produce a broad picture of factors contributing to WRMSD occurrence in tram driving. However, what the ergonomics literature in the context of WRMSDs in rail is currently missing is an exploratory analysis of factors that have been derived inductively (i.e., without preformulating categories) and a central metaphor or theme that better conveys the nature of WRMSDs. Importantly, the literature is also missing an account of the causal dynamics and feedbacks driving the behaviours surrounding WRMSDs.

Various approaches and frameworks for mapping and analysing system dynamics abound, including connection circles (Quaden et al., 2006), STAMP (Salmon et al., 2016), and causal loop diagrams (Comrie et al., 2019). Causal loop diagrams offer a practical methodology for generating system dynamics analyses and have been used prevalently to depict and identify the feedback loops driving system behaviours (Sterman 2000). Application of this approach is underpinned theoretically by the key idea that all system behaviour is fundamentally influenced by interacting positive and negative loops (Sterman 2000). As well as being used for systems analyses purposes (Comrie et al., 2019), this makes them very useful for capturing causal dynamics, communicating the feedbacks driving certain behaviours, and informing system dynamics models which can then simulate behaviour over time (Sterman 2000). As a simplistic and generic example, Fig. 2 illustrates the effect of both physical and psychological strain on WRMSDs. This is presented as a 'reinforcing loop,' where increased physical/psychological strain means more WRMSDs, which means more physical/psychological strain. To counter this, good design is illustrated as a 'balancing loop' in that physical/psychological strain increases the need for good design within the worker's job and the environment, which once implemented, decreases in physical/psychological strain (all else being equal).

Identifying a central theme underlying WRMSD in tram driving and exploring the systems dynamics will not only add further to our understanding of the problem, but it may also: (1) encourage more buy-in

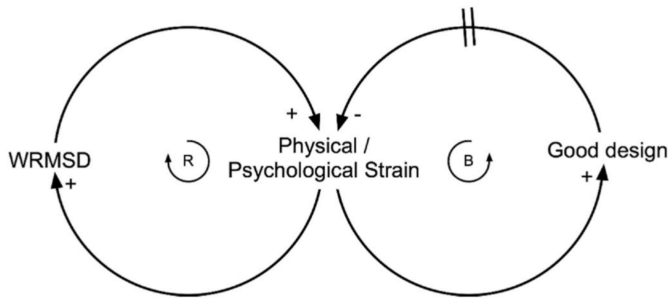

Fig. 2. Simple causal loop diagram in the context of WRMSD and good design. Links with a positive polarity (+) refer to an effect in the same direction (e.g., if the cause increases, the effect increases, and if the cause decreases, the effect decreases also). Links with a negative polarity (−) refer to an effect in the opposite direction (e.g., if the cause increases the effect decreases, and if the cause decreases the effect increases). Delay marks indicated by "||" on the good design and physical/psychological strain link, indicate that it takes time for this effect to occur, in this case, there may be a number of incremental changes or trials involved in the design of system elements before it reduces strain.

and recognition from organisations of WRMSDs in their employees as a systems issue (therefore needing a systems as opposed to an individual-level focus); (2) inform the development of systems models which can simulate behaviour over time; and (3) identify potential factors that can be explored in further research in a more deliberative manner.

1.1. Aims & objectives

The aim of this study was to identify the theme(s) governing WRMSDs in the context of tram driving, and explore the causal dynamics and feedbacks underpinning system behaviours. The objective was to conduct a secondary data analysis, primarily using qualitative data collected from Naweed et al. (2020) to answer the following research questions:

RQ1. What theme(s) describes the occurrence of WRMSDs among tram drivers?

RQ2. What factors underpin the system dynamics around the occurrence of WRMSDs among tram drivers?

2. Methods

2.1. Study design

A secondary analysis research methodology is a useful way of investigating new questions on rich and unique archival qualitative data (Corti et al., 2006), particularly when the topic is a sensitive one involving a difficult to access population (Long-Sutehall et al., 2011).

In this study, a robust secondary analysis was performed on archival data collected from an Australian tram organisation. This included one-to-one interviews, focus groups, and driving observations.[1] Prior to the study, the cause of WRMSDs was attributed solely to the physical design of the Master Controller, namely the downward force requirements (see Fig. 1). So unwavering was this belief that the tram organisation was developing a business case to remove and substitute the Master Controller with an alternative proprietary design. The nature of the issue created sensitivities for the organisation, and intergroup tensions among the driver population.

Building on findings reported by Naweed et al. (2020), the present study re-analysed the interview, focus group and *in situ* observational data using thematic networks analysis (Attride-Stirling 2001), a sensitive tool to identify recurrent patterns, multiple meanings, and unearth a global theme governing perspectives on WRMSDs. This process was supported by initial and focused coding (Charmaz 2006). These findings were then analysed using causal loop diagramming (Sterman 2000) in order to make the systems dynamics clearer, identify factors underpinning behaviour, and produce a more holistic picture of the various parts and their interactions. Causal loop diagramming has been used in many contexts, including rail, to research system dynamics in areas such as passenger safety (Jia and Wang 2016) and accidents (Fan et al., 2015). Fig. 3 illustrates the overall research design. The next sections summarise the details substantive to the qualitative data analysed in this study.

2.2. Participants & recruitment

A total of 13 drivers were recruited through an organisational contact to participate in interviews and a focus group. Of these, 10 (3 female, 7 male; 4 with WRMSDs, 6 uninjured) took part in one-to-one interviews ($n = 10$), and a further 3 (1 female, 2 male, all identifying as having WRMSDs) took part in a focus group. All participants ($N = 13$) were informed of the purpose of the research and provided informed consent. There was no pre-requisite for a specific WRMSD type as every driver that was placed on light duties had injuries that were relevant to the task.

For observations of driving, a total of 11 drivers participated (9 male, 2 female; 5 injured, 6 uninjured). Ten of these participants were also involved in the interviews/focus groups.[2]

The gender of participants was determined through self-selection. There is a tendency toward higher proportions of male drivers in the rail industry generally, including tram driving (18% female gender share, Australian Government National Skills Commission, 2021). This was reflected in the study participants, given the cohort of drivers accessible to the researchers.

Note that to preserve the anonymity of participants, some demographic data (e.g., age) were not collected. Ethical approval for the study was obtained from CQUniversity (Approval No. H17/09-168).

2.3. Procedure

2.3.1. Interviews and focus group

The semi-structured protocol covered six broad topics, including:

1. Confirmation of current injury status;
2. Work history, tram driving experience, current shift patterns;
3. Vehicle perspectives, cab layout, design features;
4. Driving considerations, behavioural patterns, skills and habits;
5. Injury considerations, perspectives of prevention, avoidance, and management; and
6. Driver observations and reflections.

Data were collected within the passenger saloon of a stabled tram at a depot. Conducting the interviews in this manner (i.e., within the cab environment) provided shared reference points for discussion, explanation and interpretation of behaviours, and improved accuracy of data. The third step of the protocol was undertaken within the cab itself, allowing participants to demonstrate their views. Interviews ran for ~60 min, and the focus group, ~90 min.

2.3.2. Observations

Observations of driving were conducted around the working driver

[1] Note: An online, anonymous psychosocial survey was also completed by drivers at the tram organisation. While this survey was part of the broader archival dataset, it was not reanalysed for the purposes of this study.

[2] Note: A total of 43 drivers from the same tram organisation completed the online, anonymous psychosocial survey. Survey data were not reanalysed for the purposes of this study, however, full sample demographics, and methodology for the survey can be found in Naweed et al. (2020).

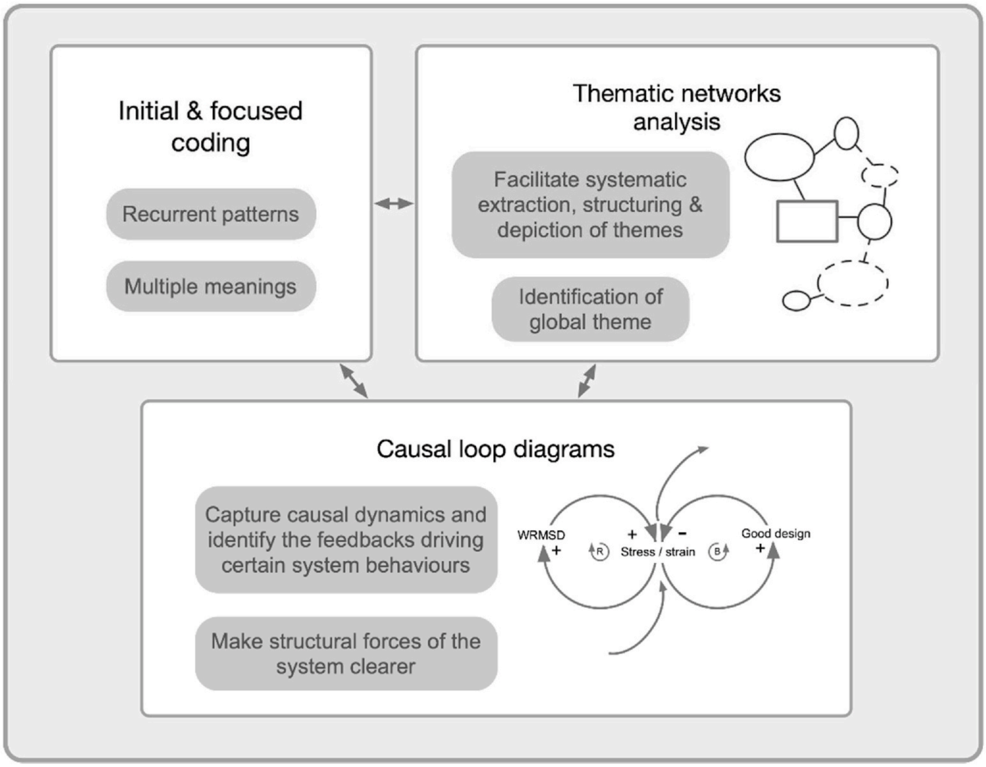

Fig. 3. Research design showing the tools used to conduct the secondary analysis in the study.

roster on outward and/or return trips and recorded using two GoPro cameras: one overhead facing down the body, and a second on the front console facing the left side (see Fig. 4). The participant and researchers entered the tram at an exchange point near the main depot. The participant relieved the current driver in a routine handover (~20 sec). As cameras could not be installed during this exchange, researchers installed cameras (using quick-release suction mounts) at the next passenger stop. Install location and timing was rehearsed in a stabled tram, and took ~15 sec. Cameras were linked via Bluetooth to a tablet, allowing researchers to view the feed and verify sight lines. Six drivers each completed a full trip in a single direction, and five drivers completed a full trip plus a turnaround and return (i.e., 2 trips). Equipment was removed and at the end of a full trip, and reinstalled at the opposite end if the participant was also completing a turnaround journey.

Researchers remained within the passenger saloon while cameras were recording, however, for participants completing a recorded full trip in a single direction (i.e., six drivers) observations were also conducted *in situ*. On these trips, a researcher accompanied the driver within the cab (in a small pull-out seat) over the course of the trip. These observations comprised informal discussion with participants to expand on any points covered in interviews/the focus group. The vigilance cycle for the Master Controller was also tested to determine time elapse before the alert.

Fig. 4. View inside the driver-cab as observed through cameras mounted on the console facing the driver from the side (left photo), and down the driver's body from the top (right photo). A side-mounted camera can be viewed in the top camera view. Note the radio button built into the footpedal in the right photo.

Table 1
Organising and basic themes with example focused and initial codes (note: ID-tags for data units used to derive example initial codes show both participant number and injury status (U = uninjured; I = injured).

Organising theme(s)	Basic theme(s)	Example focused code(s)	Example initial code(s)
The driver-cab is not designed to fit the human	The seat does not serve the human body	The seat is a risk factor for back injury	The adjustability of the seat is very limited (D01U; D04I) The lumbar support in driver's seat is inadequate (D05U) The seat slumps the body forward (D14I; D09I)
	The footrest does not promote rest	The driver's body is always in a state of misalignment	Avoidance of accidental activation of radio pedal creates stress (D01U; D04I) Radio pedal promotes off-centre posture and increases driver discomfort (D11U; D12U)
	Using the master controller feels unnatural	The deadman switch is making us sick	Sustained force on deadman can only be alleviated for a few seconds when driving (D14I; D09I) Deadman causes discomfort, wrist fatigue, and injury (D08I; D07I)
The job promotes anxiety and acute stress response	Something really stressful will happen every day	Sources of stress in tram driving are ubiquitous	The stress associated with public safety and time pressure is extremely high (D08I) Vigilance alerts can be stressing (D01U) Stress is associated with driver focus (D05U; D09I)
	We are detached from our body and mind	Attentional demand creates a sense of detachment	Attentional demand limits considerations to posture and movement (D02U) Stress and anxiety contributes to sensory saturation or high stimulation (from visual, auditory, kinaesthetic cues) (D07I; D08I)
	The shift/roster pattern is reducing wellbeing	Shift and roster design is becoming a juggling act	Shifts are hampered by inconsistent patterns, rostering effects, time pressure (D05U; D06I) Shifts are needing to change in response to the structure of job role for injured drivers (D04I; D07I)
Identifying yourself as injured is stigmatising	Injured drivers feel intrinsically ashamed	Injured drivers feel labelled and defective for who they are Injuries have low visibility because drivers do not want to deal with them openly	Treatment experiences of other drivers producing avoidant behaviours (D14I) Organisation-contracted physician is judgmental (D08I; D14I) Injured drivers are afraid to speak up about an injury (D09I; D07I; D14I)
	Uninjured drivers have no empathy	Uninjured drivers believe that an MSD injury is not a genuine injury	Injured drivers are not pulling their weight (D11U; D02U Tram driving is not so physically taxing that it would induce injury (D11U) Uninjured drivers have no lived experience and are very selfish (D04I)
	Some drivers are predisposed towards WRMSDs	Prior injury may increase susceptibility/aggravate new injury	Inherent desire to not let any prior injury be detected during medical screening (D03I) Prior injuries may affect employment (D05U) Prior injury status is not always detected by medical assessments (D03I; D05U)
Concerns are minimised by an unsupportive organisation	WRMSDs impact the wellbeing of the uninjured too	Accommodations being made for the injured encroaching on the wellbeing and job satisfaction of the uninjured	Team spirit is being compromised because uninjured drivers are covering the work of injured drivers but being paid the same wage (D03I) Being on "stand by" now means doing nothing (D12U) Injured drivers satisfied to perform light duties via spare shifts (D04I)
	Driver wellbeing is not being prioritised	Uninjured feeling reduced autonomy and increased uncertainty at work	Time constraints during driver handover forcing rapid adjustment from settings from previous driver (D05U) Better treatment for injury can be obtained through a private doctor (D08I)
	Drivers must compensate for bad design themselves	Drivers try to work around the limitations of the seat, cab and master controller Drivers used strategies to compensate for system design flaws impacting their wellbeing	Drivers use personal portable lumbar supports (D04I) Swapping shifts with other drivers helps accommodate injury effects (D07I) Drivers position right foot on edge of console or cross it to compensate for off-centre posture promoted by radio pedal (D01U) Driver forearm, wrist, grip and finger positioning deliberately alternated to compensate for pressure of using MC with deadman switch (D11U; D03I)

2.4. Data analysis

In this secondary analysis, thematic networks analysis (Attride-Stirling 2001) was used to uncover the central theme, and causal loop diagramming was conducted to build a more cohesive picture of the systems dynamics in the process. Data analysis was undertaken using three steps:

Step 1. Initial coding and focused coding of entire data set;

Step 2. Thematic networks construction; and

Step 3. Development of a causal loop diagram.

Step 1 involved close reading of the interview and focus group transcripts, and the notes taken during *in situ* observations for salient perspectives, attitudes and behaviours. These were used to develop initial codes which were then extracted and added into OmniGraffle visual communication software (build 7.18.4, v. 204.11.0). Each code was compared with previous codes and collapsed into succinct categories to form focused codes. Saturation was reached when data no longer yielded anything new and all concepts were fully explored and understood (Charmaz 2006). The number of participants in the study allowed data to be examined to the point of saturation (Francis et al., 2010).

In Step 2 codes were refined to interpret and visualise relationships. This involved abstracting and re-abstracting focused codes into clusters of basic themes. These basic themes were then compared, grouped and summarised, to form broader organising themes. Through network construction and refinement, a global theme was eventually distilled, illustrating the representative relationships and interconnections between themes (Attride-Stirling 2001). Rather than take a reductive approach, the central theme branched outwards to describe phenomena, effectively orienting the aim of the research but not limiting the analysis.

In Step 3, interacting networks were modelled in VensimPLE (ver. 8.1.0), using the relationships and interconnections conveyed within the thematic network. The boundary for analysis of systems dynamics was established as an exploration of the positive and negative causal feedback loops associated with participant perceptions of WRMSD cause and effect. Each link and polarity in the causal loop diagram were iteratively refined and systematically cross-checked against the data inputs.

2.5. *Trustworthiness & rigour*

A single researcher with 15 years of experience in rail human factors and systems thinking (AN) conducted the thematic networks and systems dynamics analysis. Remaining researchers (LB, JT, CU) refined and verified the thematic networks analysis through crosschecks, and reviewed the nodes and relationships of the systems dynamics analysis, confirming and/or modifying and removing any if they were considered inappropriate. For the observations, video footage of the behaviours being coded in addition to the limited range of potential behaviours (given cabin and role job constraints) reduced any ambiguity about how drivers were moving (i.e., direction, duration).

3. Results

3.1. *Thematic networks analysis*

During initial coding, themes related to person-job fit and the nuances of tram driving emerged and more entrenched risk factors for WRMSDs became apparent. These culminated in a global theme of *Injury by Design*. Table 1 shows example initial codes extracted from the data, example abstracted focused codes, the basic theme groupings, and the four organising themes.

The basic themes represented the processes through which injury by design was found to exert an influence on WRMSDs. These included: the seat does not serve the human body, the footrest does not promote rest, using the master controller feels unnatural, something really stressful will happen every day, we are detached from our body and mind, the shift/roster pattern is reducing wellbeing, injured drivers feel intrinsically ashamed, uninjured drivers have no empathy, some drivers are predisposed towards WRMSDs, WRMSD injury impacts the wellbeing of the uninjured too, driver wellbeing is not being prioritised, and drivers must compensate for bad design themselves. The basic themes were grouped into four organising themes: *the driver-cab is not designed to fit the human; the job promotes anxiety and acute stress response; identifying yourself as injured is stigmatising*; and *concerns are minimised by an unsupportive organisation.* The network of global, organising, and basic themes is shown in Fig. 5.

3.1.1. *The cab is not designed to fit the human*

The design of the cab was primarily described in terms of its poor fit with the human body. Both injured and uninjured drivers noted discomfort, and at times, physical strain and pain in response to constrained posture related to poor cab design.

The lumbar support was considered inadequate by both driver groups (i.e., injured and uninjured). Injured drivers considered access to controls on the front console as an injury risk factor when height and seat positioning meant repetitive reaching/leaning. The seat itself was implicated in driver discomfort and physical strain. Both injured and uninjured drivers mentioned the "hardness" of the seat which led to discomfort. Injured drivers noted the limited adjustability of the seat impacted the availability of arm and wrist support and caused excessive strain on the shoulder.

The location of the footrest relative to the seat position increased postural discomfort during driving. A radio pedal built into the footrest (see Fig. 4) induced stress and a state of constant alertness (to avoid unintentional activation) among both injured and uninjured drivers. The positioning of the radio pedal promoted an off-centre posture so that the body was typically misaligned when seated.

The 'deadman' switch built into the Master Controller required constant vertical depression of the stem. When combined with acceleration/braking control, injured drivers reported discomfort from maintaining downward force. For some, the effects of this on their posture were compounded by the lengthy height of the controller stem. Most drivers noted that the 'deadman' downward force requirements caused wrist and shoulder discomfort or fatigue at best, and at worst, injury. A lack of fit between drivers' arms and the armrests was considered to cause a significant amount of discomfort to the arms and wrists, and at times, the left armrest was reportedly not used at all. In these cases, the driver's elbows were frequently unsupported though with pressure applied to the 'deadman' carried by the forearm and wrist.

3.1.2. *The job promotes anxiety & acute stress response*

Driver handover at the exchange point was considered high pressured because the time for such a midway stop had not been factored into the static timetable. This meant drivers typically started a shift mindful of accruing delay minutes. Consequently, there was little opportunity to adjust the seat from the settings used by the previous driver, meaning some attempted rapid adjustment while driving while others waited until a suitable time. Both driver groups mentioned a tendency to slump until the seat was adjusted to their satisfaction, only becoming aware of slumping when they felt pain.

Turning attention away from inside the cab to external cues (e.g., signals, pedestrians), was felt to create a sense of detachment from one's own body, limiting attention to postures/movements that potentially preceded/exacerbated injury. The unpredictability of the mixed-traffic environment meant drivers remained constantly on high alert, scanning pedestrian body language and other vehicles (via turn indicators/ vehicle movement) to discern intention and anticipate risks. The attentional shifting between safety and time pressure induced stress, and was felt to influence health; of note is that in other rail research, this has been shown to not only increase stress, but the propensity for risk-taking behaviour (Naweed and Rainbird, 2015). In addition to the visual (pedestrians, passengers, road and tram signals) and kinaesthetic (tram movement/vibration) cues, the auditory cues (e.g., 'wheel squeal') reduced comfort. The alert from the vigilance mechanism promoted anxiety, and was therefore felt to require regular pre-emptive deactivation/reset via depression/movement of the Master Controller.

Shift constraints related to shift coverage and consistency, fatigue, rostering, time pressure and changes in job role (in response to WRMSDs), reduced driver wellbeing such that both injured and uninjured driver groups described shift structure as a risk factor for occupational injury. For the injured, this was related to the ability to consistently adhere to their modified shift patterns, which was reduced for some given fluctuating in injury-related pain.

3.1.3. *Identifying yourself as injured is stigmatising*

Some drivers were predisposed towards WRMSDs as a result of prior injuries sustained through their personal lives or pre-employment. Medical assessments were thus considered problematic, because divulging a previous injury was considered to affect employment opportunities. However, revealing injury whether pre- or post-employment was also felt to be stigmatising, with some not wanting to

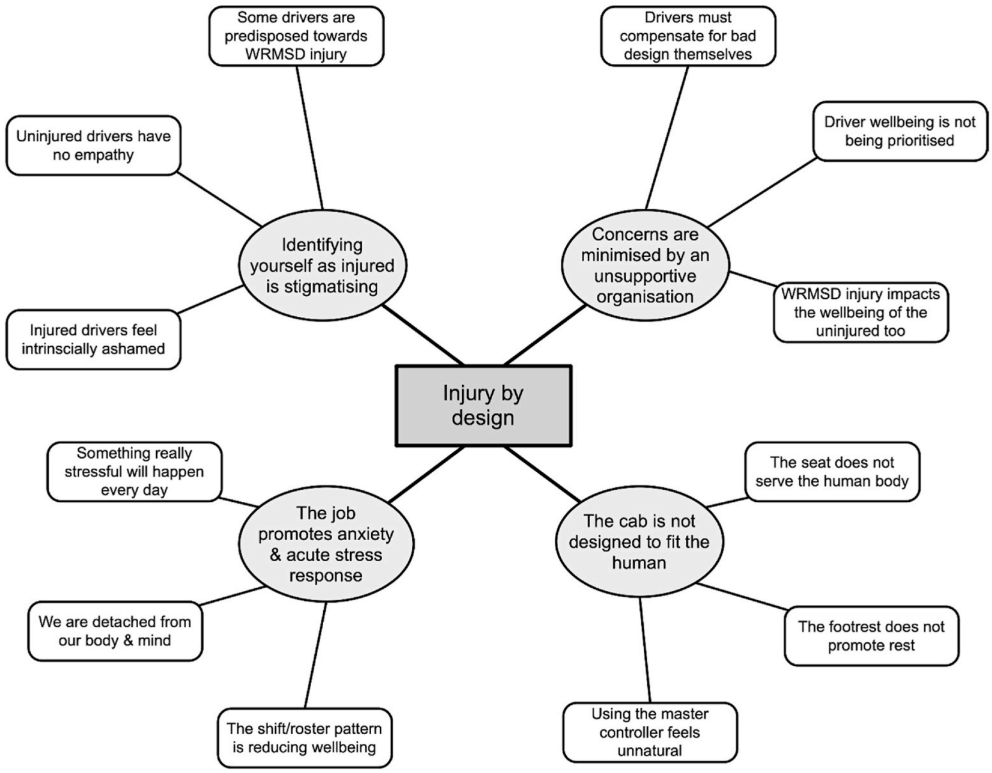

Fig. 5. Thematic network: *Injury by design* in WRMSDs related to tram driving.

openly deal with organisational requirements. Injured drivers thus felt WRMSDs were more prevalent than was known.

Most injured drivers perceived their engagement with the organisation-contracted physician as a negative experience, opted to minimise or avoid engagement with this process, and sought health services (even for minor complaints) from independent physicians. Drivers were aware of the negative treatment experiences and job modifications of other injured drivers and sought to avoid being labelled as 'injured' and deter perceived negative outcomes for themselves.

Injury likelihood was discussed in relation to body size/frame, with perceptions that larger frames reduced injury likelihood. Self-management of health and injury prevention by uninjured drivers was characterised through a sense of control over personal health and comfort, with injured drivers perceiving that they managed their own health and injury susceptibility proactively. Uninjured drivers viewed that tram driving tasks were not physically taxing enough to cause injury, did not consider the WRMSDs ailing injured drivers as a genuine injury, and suggested that injured drivers were not doing their fair share of work. While feeling defective for their injuries, injured drivers perceived uninjured drivers had no lived experience of an injury and should not pass any comments or judgment on the matter.

3.1.4. *Concerns are minimised by an unsupportive organisation*

Most drivers identified a good overall safety culture within their organisation but felt that individual concerns were deprioritised or minimised. Uninjured drivers perceived injured drivers to be exploiting provisions made in the safety culture. For example, the uninjured perceived the injured to be using all the 'rest shifts' which meant that the uninjured could not access these opportunities for downtime. Injured drivers were also perceived by the uninjured to be paid the same as them to do nothing. Intergroup tensions were evident and reinforced by each group sharing their views within their own enclaves; there was little communication with the opposing group. The injured were satisfied with their ability to perform light duties but felt their injury was being invalidated, but the uninjured felt reduced autonomy (freedom from external control), increased uncertainty, and that the lack of rest shifts could increase their own propensity to sustain a WRMSD. Thus, the accommodations being made for the injured were felt to encroach on their own wellbeing. In the perceived absence of external support, drivers felt like they had to compensate for system design flaws and protect themselves against injury. Many drivers alternated their hand-grips on the Master Controller to compensate for the static load demands of the 'deadman' switch. Such alternations reportedly reduced the amount of time that pressure was experienced in any one arm and wrist posture, and was thus a direct strategy to protect against injury. To alleviate back pressure and compensate for lack of lumbar support, drivers shifted seat position multiple times per shift, and fell into a habit of gradually leaning forward over the course of a shift, while others utilised portable lumbar supports. Stretching took place both before and during shifts to further alleviate stiffness and pressure on the driver's back, and drivers positioned the seat to sit at a level angle and work around the radio pedal in the footrest.

3.2. *System dynamics analysis*

Fig. 6 illustrates three key interacting nodes established within the causal loop diagram. Given that high perceived stress is related to increases in muscle tension (Larsman et al., 2013), psychosocial stressors impede healing (Faucett 2005). Also, given the findings of the thematic networks analysis, the relationship between psychological strain/stress and WRMSD is depicted as a reinforcing feedback loop where more psychological strain/stress leads to more chance of a WRMSD, and a WRMSD leads to more psychological strain/stress. The first balancing loop in this dynamic was established based on the thematic networks analysis, which identified that WRMSD led to a change in the job role/shift structure of those affected, therefore more occurrence of WRMSD means more change in job role/shift structure, which ostensibly decreases WRMSD. The second balancing loop is derived from the survey-based findings reported in Naweed et al. (2020), which revealed a link with interpersonal support, where more supports were found to be

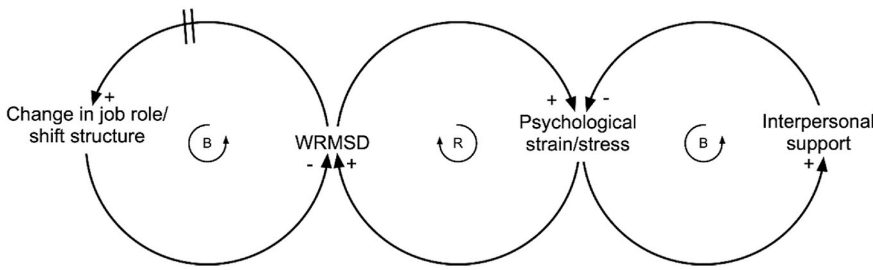

Fig. 6. Simple causal loop diagram in the context of WRMSD and psychological strain/stress with interpersonal support and change in job role/shift structure presented as balancing loops. Links with a positive polarity (+) refer to an effect in the same direction (e.g., if the cause increases, the effect increases, and if the cause decreases, the effect decreases also). Links with a negative polarity (−) refer to an effect in the opposite direction (e.g., if the cause increases the effect decreases, and if the cause decreases the effect increases). Delay marks indicated by "||" on the WRMSD and change in job role/structure link indicate that it takes time for this effect to occur, in this case, there may be a medical or risk assessment process to determine exposure to the stressor.

protective against WRMSD in this tram driver population. This was diagrammed as psychological strain/stress increasing the need for interpersonal support, with interpersonal support, in turn, having the effect of reducing psychological strain/stress.

Building on the key nodes, Fig. 7 illustrates the full network of interacting relationships. Physical strain/postural discomfort also emerges as a key interacting node showing how this effect/cause acts in concert with psychological strain/stress to give rise to WRMSDs. Here, a direct causal link is also reflected in the form of high alertness (from external cues) increasing psychological strain/stress, but also reducing body awareness, which increases physical strain. As a central node, physical strain/postural discomfort is intensified through poor fit with various aspects of the environment by virtue of poor/awkward design. In some design cases, such as the radio button, this created maladaptive behaviours where unintentional activation of this button creates a problematic balancing loop to reduce psychological strain/stress by avoiding using the footrest. However, this behaviour is also driven by the need to balance the ensuing increases in accidental "emergency" calls to traffic control.

The full causal loop diagram reflects the interacting effect between WRMSDs, work intensity and interpersonal support reported in Naweed et al. (2020). Here, high work intensity (speed of operations, tram turnaround times), which also gives rise to time pressure, are both reflected as problematic feedback loops for interpersonal support and psychological strain/stress—thus high work intensity and reduced interpersonal support increase the likelihood of WRMSDs. However, the availability of interpersonal support is negatively impacted by the effect of two other interacting key nodes: Job satisfaction/wellbeing of the driver population, and stigma. The former is substantially (albeit indirectly) causally linked through unintentional impacts of reduced autonomy and increased uncertainty brought on from changes in job role/shift structure, with this effect reinforced by further constraints on shift work. Change in job role/shift structure means change to the number of laps or shifts that injured drivers feel capable of achieving before experiencing discomfort or pain. Managing this also corresponds with sense of purpose for the injured, but also increases constraints to the shifts of uninjured drivers, which increases fatigue/sleep disruption, all of which affects job satisfaction/wellbeing. Importantly, disrupted sleep/fatigue also increases WRMSD through its negative impact on healing and recovery.

Reduced job satisfaction and wellbeing of the driver population as a whole drives stigma around WRMSDs and being labelled "injured", which has the effect of reducing interpersonal communication and "team spirit" within the work culture, and the availability of interpersonal support over time. The need for a supportive organisation/workplace culture is therefore represented as a balancing feedback loop, which can reduce WRMSDs as a stigmatising issue over time and also increase the job satisfaction/wellbeing of the driver population. In the absence of this, stigma remains unchecked, and continues to drive a reluctance to divulge of injuries to the organisation, which further reinforces the stigma and drives the negative cycle loop. Based on thematic network findings, the stigma node is also influenced by engagement practices with the organisation-contracted physician, and pre-employment risk, where injuries are not reported to increase chances of passing medical screening.

The vigilance system features into the context of tram driver WRMSD systems dynamics indirectly as part of the milieu of awkward/poor Master Controller design impacting on psychological strain/stress. However, as reported in Naweed et al. (2020), the vigilance system has a direct relationship with psychological strain/stress in that the auditory alert was considered stress-inducing, and injured drivers were found, through driver behaviour frequencies, to reset the system significantly more than uninjured drivers. This relationship has been depicted as a balancing loop where more experience of psychological strain/stress leads to more pre-emptive resetting of the vigilance system, which then has the effect of reducing psychological strain/stress. This loop has potential to be maladaptive if it is an indirect cause as opposed to a symptom of WRMSDs. Most drivers interviewed were not able to accurately describe the timing cycle of the vigilance cycle—this was identified to be 30 sec from observations. Of particular note, drivers interviewed were also unaware that the vigilance system had been altered to become task-linked two years prior. This meant that release and re-engagement of downward force was not the only means of resetting the system. As lack of knowledge or understanding of adjustment to the vigilance cycle (i.e., change to "task linked" resetting – see Fig. 1) was a finding, support provision of this is a reflection of a supportive organisational culture and therefore represents another balancing loop.

4. Discussion

Using secondary data analysis methodology, this investigation aimed to: (i) identify the theme(s) describing the occurrence of WRMSDs among tram drivers, and (ii) investigate the factors underpinning the system dynamics around occurrence of WRMSDs in this group. To achieve this, the data were analysed with thematic networks analysis (Attride-Stirling 2001) and system dynamics analysis using causal loop diagramming (Sterman 2000). The thematic network analysis identified a global theme of *Injury by Design* for WRMSDs. Bringing in a previous research finding of the importance of the role of personal support in protecting against WRMSD in this tram driver population, the causal loop diagramming clarified the systems dynamics, and produced a more holistic picture of factors related to the occurrence of WRMSDs and their interactions. This identified both the positive and negative loops that surround WRMSDs related to psychological strain/stress, change in job role and shift structure, job satisfaction and wellbeing among this population, stigma associated with WRMSDs and organisational culture, as well as the role of personal supports.

Many of the 'design' issues substantive to the central theme underlying WRMSDs among tram drivers were elucidated in the Results, but of particular note is how the organisation arranged the job role and shifts and the impact this had on job design. Advantageously, shifts were designed in a way that allowed for the existence of spare shifts, so that drivers in need (e.g., because of injury) could take a spare shift to rest

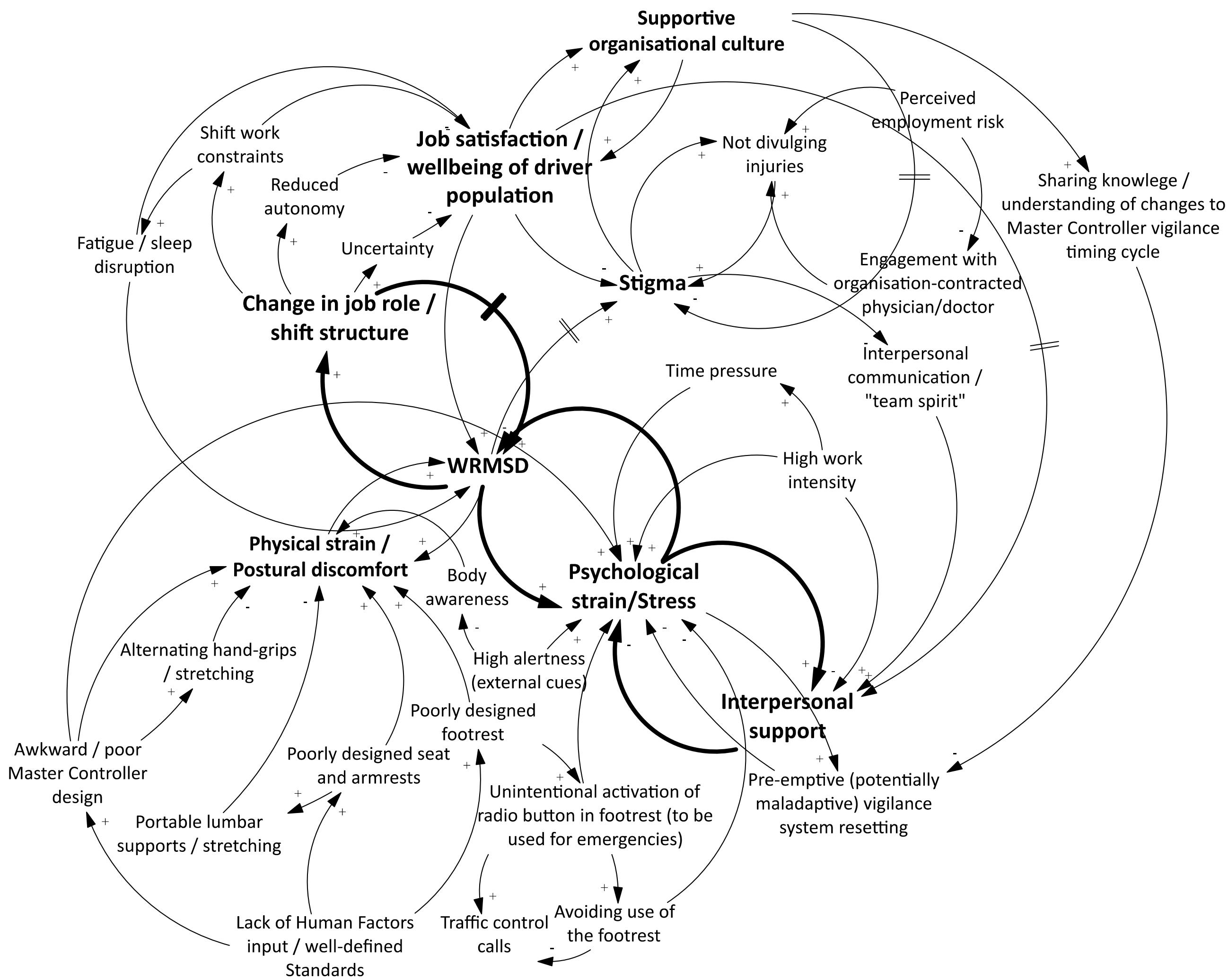

Fig. 7. Full causal loop diagram of WRMSD in tram driving reflecting findings from thematic networks analysis and previously published research (Naweed et al., 2020). Links with a positive polarity (+) refer to an effect in the same direction (e.g., if the cause increases, the effect increases, and if the cause decreases, the effect decreases also). Links with a negative polarity (−) refer to an effect in the opposite direction (e.g., if the cause increases the effect decreases, and if the cause decreases the effect increases).). Delay marks indicated by "||" on links indicate that it takes time for this effect to occur.

and prepare for their next one. However, this created resentments among the uninjured staff who felt they could not access spare shifts to recuperate and ended up clocking more hours on the job for the same wage. The uncertainly of which shifts may be spare or may need filling also created the potential for psychological strain/stress among both groups as drivers could not always be sure of work commitments, and therefore commitments at home. As illustrated in Fig. 7, change in job role/shift structure produced uncertainties and consequences across all loops.

The job was designed so that at the start of every shift, drivers had no opportunity to manage the design of the cabin to fit them, due to the rapid changeover cycle. It was highlighted that many drivers eventually modified their seat, posture and foot positioning while driving, however, this gives rise to the implication associated with the additional cognitive workload of performing these adjustments while driving. The impact of distractions and cognitive load on tram drivers has been documented on both tram drivers (Naweed et al., 2017a) as well as those driving in road vehicles (Engström et al., 2017). As demonstrated within heavy rail environments (Naweed and Balakrishnan 2014), tram drivers must also engage heavily with external monitoring and awareness-maintaining activities which are compounded by human limitations (Chapman et al., 2019). Thus, the need to make seat and body adjustments gives rise to distraction, creating potential for serious negative consequences on driving performance among tram drivers and safety more broadly. Driving while engaging in non-driving-related tasks has been linked with elevated risk in rail driving modes (Naweed 2013).

4.1. Future research to promote positive change

A number of features of the causal loop diagram identified in this study may be targeted for investigation in future research to promote positive change. The two most noteworthy are the organisational culture, which serves as a balancing loop for a number of key links, and human factors input/well-defined technical and/or occupational Standards, which drive a lot of the injury-causing links seen in the physical aspects of design. Few studies have concurrently investigated organisational culture and the views and behaviours of management alongside an understanding of injury occurrence among rail drivers. Management plays a pivotal role in: selecting cabin design; implementation of support programs to assist workers to manage the physical demands of a shift work role with physically taxing requirements; setting the tone for team spirit; defining job roles and designing the shift structure; supporting optimal sleep hygiene among their shift workers; and, engaging and working with the company physician. Research to further investigate how management can be better informed and supported to do their job well (and not only well-intentioned) has clear potential to mitigate WRMSD risk among workers. Ineffective relationships between injured drivers and the organisation and externally contracted medical supports were found. This aspect of organisational culture and management was an element of our research that warrants its own focused (sociological) research. This is because the social dynamics of the workplace, and those associated with medical assessments, are likely to influence the nature and extent of further occupational risks, extending beyond WRMSDs.

Research to test, develop and implement evidence-based Standards is urgently required to support workers in their daily job performance, and ultimately, should reduce the occurrence of WRMSDs. Standards need to specify optimal designs for the cabin as a whole unit, focussing on specific areas identified through this study as problematic, including the armrest, seat (lumbar support), footrest/radio button, and the Master Controller. Opportunities have not yet been explored to determine how digital health interventions (Murray et al., 2016) could be introduced in this environment to support workers self-monitor and manage their physical and psychological stressors *in-situ*, to minimise the development of WRMSDs or manage ongoing injuries.

Injured drivers were not observed to use the mitigating strategies that the uninjured drivers used to prevent discomfort and strain (e.g., adjustment to posture, stretching). Potential education gaps around this were identified in the systems dynamics analysis, and it may also be the case that some injured drivers were predisposed to engage with the task a certain way. At an individual level, future research may look to identify specific injury mitigating strategies that can be communicated with such groups, for example in the form of a 'Brief Intervention' for role occupational hygiene for WRMSD Risk.

While the ratio of male to female participants was broadly representative of numbers in the rail industry, they were unequal. There are active efforts to address this imbalance in the industry in Australia (Sexton, 2021). As this is addressed across the industry, the proportion of female and nonbinary drivers will likely shift and be reflected in injury prevalence figures for non-stratified samples in future work.

Finally, automotive research is showing that 'fidgets' (i.e., the number of small movements/posture adjustments) within a driving seat correlate with subjective discomfort (Sammonds et al., 2017). While the tram driving context has a very different and unique context, some consideration may be given here to future research.

5. Conclusion

A global theme of *Injury by Design* was found to underscore the occurrence of work-related musculoskeletal disorders in a large tram driver population in this study. The intersections between injury and "design" were multifaceted with factors interacting in complex ways to shape system behaviour. As well as physical and functional design issues from a myriad of in-cab artefacts and prostheses that created problems of fit with the driver, this included much broader structural design issues such as poorly calibrated/consideration of driver handover in timetabling, and the backdrop of perennial design issues created by rostering and shiftwork. Importantly, higher-concept organisational design elements were critically implicated, such as well-intentioned reactions from the organisation to change job role/shift structure. In the absence of a culture that could balance the negative effects of job change, stigma, and Master Controller interface knowledge gaps, this contributed deleteriously to WRMSD recovery.

The analysis in this study contributes to a growing understanding of injury occurrence among rail drivers and the importance of the role of systems thinking in dealing with occupational injury. This study offers three key improvements to implementation of injury mitigation strategies in rail contexts: 1) A detailed model to guide the practicalities of injury-related job design interventions, 2) a clear demonstration that such models can be created via unobtrusive and highly structured observation, and 3) support for enhancing the models by drivers' described experience. With these accurate models, rail organisations will be better equipped to counteract injury risk within their unique organisational needs.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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