Australasian Transport Research Forum 2023 Proceedings
29 November – 1 December, Perth, Australia
Publication website: http://www.atrf.info

Cyclist safety around trams: Melbourne case study

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Abstract

Trams and tram tracks present a particular hazard to cyclists. Bicycle wheels wedging or slipping on tram tracks often result in a cyclist falling and sustaining serious injuries. Previous research focused on cyclists who presented to hospital with little attention given to cyclists' experiences on roads with trams and tram tracks. This case study of Melbourne, Victoria reports the first survey of cyclists' experiences with tram- and tram-track related crashes and incidents. In total, 287 cyclists responded to the survey about their experiences over the last five years. One in five had been involved in at least one crash involving tram tracks and almost half (43%) reported being involved in at least one tram-related incident in the last five years. The majority of incidents involved skidding on the tram track (track-skid, 70%). Half of all incidents (50%) involved a combination of track skidding and wet conditions. Almost one in four incidents involved the bicycle tyre being stuck in the tram track (track-wedging, 24%). No collisions with trams were reported. These findings contrast with Victorian hospital data for injured cyclists. While track skidding was a common experience among survey participants, it was a lower proportion of hospital presentations (11%) with higher proportions involved in crashes following track-wedging (85%) or a crash with a tram (4%).

Some tram operators are exploring the use of rubber inserts that fill the groove in tram tracks to reduce the likelihood of track-wedge incidents. However, the efficacy of the rubber inserts is still unclear as the tram track rail head remains exposed. Findings suggest that in Melbourne, tram tracks are a hazard for cyclists. Greater segregation and separation between cyclists and tram tracks are needed to create safe spaces to cycle that meet the current government road safety policy (Safe System) principles.

1. Introduction

Light Rail Transit (LRT) operating in mixed traffic may increase road safety risks to other road users, including cyclists. Previous studies have reported cyclist crashes involving tram tracks are of particular concern (Cameron et al. 2001; Deunk et al. 2014; Teschke et al. 2016; Maempel et al. 2018; Leune et al. 2021) with crash outcomes including upper limb fractures, dislocations, the need for surgical intervention and death (Deunk et al. 2014; Leune et al. 2021).

Despite the potential severity of tram-related cyclist crashes, in previous studies, tram-related crashes were typically a subset. Little is known about cyclists who often ride around trams and tram tracks, their experience and frequency of tram-related incidents including unreported injuries and close-calls and the contributing factors.

Some tram operators are already installing primary countermeasures, such as rubberised products that fill the groove in tram tracks with the intention of preventing the bicycle tyre from entering the groove and being wedged (SRF News 2019; Railway Gazette 2022). However, the efficacy of these products are yet to be determined and it is not known if such interventions will bring tram networks into alignment with the Safe System principle of eliminating all serious injury and fatal crashes.

The study includes the first known survey of cyclists about their experience of tram-related crashes and incidents. The rest of this paper is structured as follows: the next section briefly reviews the research literature. Study methodology is outlined in Section 3. Section 4 presents the results, which are discussed in Section 5 prior to a brief conclusion in Section 6.

2. Research context

For two decades, the Safe System has underpinned road safety policy in Australia. The approach is based on the underlying principles that: human error is inevitable; the consequences of such errors should not be serious injury or death; and that road designers and managers (rather than road users) have the primary responsibility for maintaining safety (PIARC 2015; Lyndon & Turner 2017; Turner & Lyon 2017; Morgan et al. 2018). Yet in the literature of cyclist and tram-related crashes that were reviewed, only two studies mentioned the Vision Zero and/or Safe System framework (Teschke et al. 2016; Utriainen et al. 2023).

Cyclists and pedestrians are vulnerable road users due to their lack of crash protection. There is already much literature about pedestrian safety around trams (Korve et al. 2001; Unger et al. 2002; Cleghorn et al. 2009; Currie et al. 2011; Kruszyna & Rychlewski 2013; Naznin, Currie, Logan, et al. 2015; Naznin, Currie, Sarvi, et al. 2015; Weber et al. 2015; Fontaine et al. 2016; Naznin, Currie & Logan 2016a, 2016b; Naznin, Currie, Logan, et al. 2016b, 2016a; Maître 2017; Naznin et al. 2017, 2018; Tubis et al. 2019). However, cyclists generally travel faster than pedestrians, which might increase the importance of a smooth and consistent surface. Cyclists also often have to ride amongst other vehicles for some or all of most trips. (Natalizio et al. 2017; Taylor et al. 2017). Sharing a roadway with trams, which weigh up to 50 tonnes (Choo & Yarra Trams 2020), may be particularly hazardous to cyclists. Serious injury and fatality in the event of a crash involving cyclists and heavy vehicles can occur at speeds from 15km/hr (Hillier 2022). This is roughly equivalent to the average timetabled tram speed in Melbourne (including stops and traffic)(Currie & Shalaby 2007).

In addition, tram tracks have the potential to be a serious hazard to cyclists, even when trams are not present. Bicycle tyres may slip on the metal surface, especially when wet. As well, embedded tram tracks typically have a grooved rail to provide space for the tram wheel flanges (Jones 2004). These grooves are a similar width to many bicycle tyres, which can easily become wedged causing a cyclist to fall and in some cases being launched at speed over the handlebars.

While typically, tram-related cyclist crashes were subsections of studies of all cyclist crash types, five recent studies have focused on tram-related cyclist crashes. Findings suggest that tram-related crashes are different to other cyclist crashes because they:

- are becoming more frequent and tending to consume more emergency department resources than other cyclist crash type (Gerber et al. 2021);
- tend to result in fractures and dislocations, absence from work (Leune et al. 2021); and “a sizeable minority” of people subsequently giving up cycling (Maempel et al. 2018, p. 649);
- represent a public health issue (Teschke et al. 2016; Smith et al. 2023); and
- need to be further investigated by researchers so that practitioners might know how to better address this issue (Teschke et al. 2016; Gerber et al. 2021; Smith et al. 2023).

Over the last two decades, research into tram-related cyclist safety has been largely informed by hospital records, interviews or police reports. However, such data sets underreport cyclist crashes, especially for crashes with low injury severity or involve cyclist-only (Gildea et al. 2021), which might be typical for many tram track-related incidents.

Some studies used additional data sources including interviews with cyclists post-crash (Teschke et al. 2016; Maempel et al. 2018), workers at bike shops (Teschke et al. 2016) and tram operators (Marti et al. 2016) and measuring the width of tyres (Teschke et al. 2016). However, most of the tram-related cyclist safety literature is data-driven with limited engagement with cyclists who did not seek hospital treatment.

In analysing tram-related cycling crashes, previous studies focused on the interaction between cyclists and the tram tracks (Deunk et al. 2014; Teschke et al. 2016; Gerber et al. 2021; Smith et al. 2023). A statistically significant association was reported for the presence of tram tracks and cyclist crashes. Other relevant crash factors included: cyclists being forced to cross onto tracks because of parked, parking or general traffic; bicycle type (hybrid or racing), lack of rider experience and cyclists who ride less often, gender (being female), sites with a lack of cycling facilities, crossing the track at an angle less than 90 degrees, and having to turn across track. Tram-involved cyclist crashes tended to occur at hotspots (Leune et al. 2021; Smith et al. 2023), suggesting that resolving issues at a few sites may generate large improvements to overall safety.

Consequences of tram-related cyclist crashes identified in the literature suggest that current practices and conditions are not Safe System compliant. Outcomes for cyclists from tram-related crashes include fatalities and injury requiring hospitalisation including head injuries, fractures and dislocations (Cameron et al. 2001; Deunk et al. 2014; Weber et al. 2015; Marti et al. 2016; Marti et al. 2017; Maempel et al. 2018; Gerber et al. 2021; Leune et al. 2021; Smith et al. 2023).

Countermeasures suggested in the research literature include hook turns (two-stage turns) as an effective way to cross tram tracks 90 degrees (Teschke et al. 2016; Maempel et al. 2018). The potential for rubber inserts fitted into the rail groove to prevent wedging incidents was also suggested but it was unclear whether these will do much to prevent slip/skid-related crashes as the metal rail head remains exposed. Other countermeasures included separation or segregation[1] which may be the only way to fully eliminate the risk of track-slip/skid crashes. However, the research literature has not considered how various countermeasures fit into the Safe System framework nor the treatment hierarchy of Primary and Supporting Treatments[2].

Public education directed at cyclists was also suggested. Specifically addressing the danger of trams and track to cyclists, selecting wide bike tyres and choosing routes to avoid tram tracks.

Overall, this review of the literature suggests there are gaps in tram-related cyclist-safety research related to a lack of: Safe-System-informed studies; studies of non-European systems; and engagement with all cyclists, not just those who have presented to hospital or otherwise reported a crash.

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[1] Separation and segregation may sometimes be used interchangeably, but are different. Separation provides cyclists with space on the road away from embedded tram tracks. Segregation is a physical barrier that makes it impossible for cyclists to ride near or on tram tracks (e.g. ballast or grass track, kerbing or a cyclist path distinct from the roadway).

[2] Primary Treatments contribute to the elimination of serious injury and fatal crashes. Supporting Treatments may reduce the likelihood of a serious injury or fatal crash, but not eliminate it. Woolley et al. (2018) gives examples of audio-tactile linemarking, which might alert a distracted driver and reduce the likelihood of a crash versus wire rope safety barrier, which will limit the consequences of a crash in the event that the driver of an errant vehicle does not recover prior to leaving the roadway.

3. Methodology

This study used a case research approach to examine cyclist experiences across the Melbourne tram network. An important issue in case-based research is the duality criterion, in that the study needs to be grounded within the context of the case, yet seek findings that are generalisable to other places (Ketokivi & Choi 2014).

Melbourne is an ideal location to examine safety in relation to trams and tram tracks with the largest street-running tram network in the world. The majority of tram tracks in Melbourne operate in mixed traffic (75% of 250 kilometres of double track)(Currie & Shalaby 2007). While Australia is an emerging cycling country with fewer people cycling than in established cycling countries, Melbourne has a growing cycling culture with cyclists accounting for 16 percent of all vehicle movements into the city in the morning peak (16%)(City of Melbourne, n.d.). Using Melbourne as a case study also expands the research attention on tram-related cyclist crashes beyond Europe. Notably, bicycle helmets are mandatory in Australia, however, it is anticipated that this will have limited impact on the experiences of cyclists and tram tracks and is not likely to affect the generalisability of the study findings.

3.1. Primary data: Cyclist survey

The study involved a survey targeted at people who cycle on streets with trams[3], administered through an online platform (Qualtrics). Participants were recruited online (i.e. Facebook, Instagram) via inner city bicycle user groups, so respondents may be more likely to be frequent and experienced riders with an interest in improving cycling safety. The survey was active from 1 August to 5 September 2022.

Data analysis included univariate descriptive statistics with chi-square tests conducted to test relationships between categorical variables. A binary logistic regression model was also constructed to examine the association between contributing variables for cyclist involvement in tram-related incidents.

3.2. Secondary data: hospital data

The Victorian Injury Surveillance Unit (VISU) at Monash University collects data from government and hospital records to track deaths, admissions to hospital and people attending emergency departments. Data from this source was also reviewed as part of the case study.

4. Survey Results

4.1. Crash involvement in the last five years

287 responses were included for analysis[4]. Cyclists were asked about their experience of all types of crashes in the last five years and reported 477 crashes. Approximately two-thirds (n=195, 68%) of respondents reported involvement in a crash while cycling in the last five years (Table 1). Approximately one in five respondents (n=61, 21%) reported at least one crash involving tram tracks. A chi-square test showed a significant relationship between reported crash frequency and type[5] ($\chi2(12, n=2{,}009) = 233.78, p<.001$). Falls was the most frequently reported crash type (n=143, 50%).

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[3] Generally, located within the central city and inner suburbs, but extending some 15 to 20 kilometres from the Central Business District (CBD) for some tram routes.

[4] 403 responses were received including 300 completed surveys. After exclusions (infrequent cyclists on inner Melbourne roads (a few times a year), n=13), the final sample size was 287.

[5] Frequency categories were condensed to 0, <5 and 5 or more to meet the assumptions of the chi-square test that less than 20% of cells have expected frequencies lower than 5.

Table 1: Cyclist crashes in the last five years by frequency and crash type

Crash type	None	Fewer than 5	5-10	11-20	21-50	>50	Total
Fall	50.2% (144)	46.7% (134)	3.1% (9)	-	-	-	100% (287)
Road defects	63.8% (183)	27.2% (78)	3.8% (11)	1.7% (5)	1.0% (3)	2.4% (7)	100% (287)
Involved motor vehicle	71.1% (204)	26.8% (77)	2.1% (6)	-	-	-	100% (287)
Tram tracks	78.7% (226)	19.9% (57)	1.4% (4)	-	-	-	100% (287)
Infrastructure	86.1% (247)	12.5% (36)	1.0% (3)	-	0.3% (1)	-	100% (287)
Involved pedestrian	90.6% (260)	9.1% (26)	-	-	0.3% (1)	-	100% (287)
Other	86.1% (247)	12.2% (35)	0.7% (2)	0.3% (1)	0.3% (1)	0.3% (1)	100% (287)

The survey also asked about the outcomes of each participant's most serious crash of each type (Table 2). A chi-square test showed a significant relationship between crash type and injury level for the most serious crash experienced by participants in the last five years across crashes involving tram tracks, motor vehicles, falls and road defects[6] ($\chi2(12, N=391)=45.67$, $p<.001$).

Table 2: Most serious outcome of each cyclist crash type in the last five years

Crash type	Not injured	Injured, no treatment	Minor medical treatment	Attended hospital	Admitted to hospital	Total
Fall	23.1% (33)	41.3% (59)	20.3% (29)	11.2% (16)	4.2% (6)	100% (143)
Tram tracks	24.6% (15)	45.9% (28)	16.4% (10)	3.3% (2)	9.8% (6)	100% (61)
Vs motor vehicle	27.7% (23)	22.9% (19)	28.9% (24)	14.5% (12)	6.0% (5)	100% (83)
Infrastructure	37.5% (15)	32.5% (13)	22.5% (9)	5.0% (2)	2.5% (1)	100% (40)
Road defect	51.9% (54)	26.9% (28)	14.4% (15)	4.8% (5)	1.9% (2)	100% (104)
Vs ped	63.0% (17)	18.5% (5)	14.8% (4)	3.7% (1)	-	100% (27)
Other	32.5% (13)	27.5% (11)	22.5% (9)	15.0% (6)	2.5% (1)	100% (40)

4.2. Tram-related incident involvement

Participants were asked how many tram-related incidents they had been involved in during the last 5 years. In total, 410 incidents were reported. Almost half (n=123, 43%) had been involved in at least one tram-related incident (Table 3). Chi-square tests showed significant associations between involvement in at least one tram-related incident in the last five years and: age (18-35 years) (p=0.014); the number of years cycled (p <0.001), including if they had cycled regularly for less than 10 years (p=0.004); and the amount of cycling each participant does on roads with tram tracks (p=0.034), including if more than 20% of their cycling was on roads with tracks (p=0.009).

[6] Crashes involving infrastructure, pedestrians and Other, were excluded from the chi-square test due to small numbers. These categories did not meet the requirement of 20% of expected frequencies less than 5 assumption.

Table 3: Characteristics of cyclists' involvement in at least one tram-related incident in the last five years

Characteristic	n	Overall n=287[1]	> 0 tram-related incidents No n=164[1]	Yes n=123[1]	p-value[2]
Age	287				0.2
18-24		20 (7.0%)	10 (6.1%)	10 (8.1%)	**0.014**[3]
25-34		72 (25%)	33 (20%)	39 (32%)	
35-44		93 (32%)	57 (35%)	36 (29%)	
45-54		68 (24%)	43 (26%)	25 (20%)	
55+		34 (12%)	21 (13%)	13 (11%)	
Gender	287				0.3
Man		208 (72%)	119 (73%)	89 (72%)	
Woman		70 (24%)	42 (26%)	28 (23%)	
Other/prefer not to say		9 (3.1%)	3 (1.8%)	6 (4.9%)	
Income	287				>0.9
Less than $34,999		14 (4.9%)	9 (5.5%)	5 (4.1%)	
$35,000 to $49,999		15 (5.2%)	9 (5.5%)	6 (4.9%)	
$50,000 to $74,999		32 (11%)	18 (11%)	14 (11%)	
$75,000 to $99,999		45 (16%)	24 (15%)	21 (17%)	
$100k to $149,999		78 (27%)	48 (29%)	30 (24%)	
$150,000+		61 (21%)	33 (20%)	28 (23%)	
Prefer not to say		42 (15%)	23 (14%)	19 (15%)	
Years regularly cycling	287				**<0.001**
Less than 3 years		34 (12%)	23 (14%)	11 (8.9%)	
3-5 years		23 (8.0%)	7 (4.3%)	16 (13%)	**0.004**[5]
5-10 years		49 (17%)	19 (12%)	30 (24%)	
10+ years		181 (63%)	115 (70%)	66 (54%)	
Inner Melbourne cycling frequency	287				>0.9
Somewhat infrequently (few trips a month)		26 (9.1%)	14 (8.5%)	12 (9.8%)	
Occasionally (1-2/week)		52 (18%)	32 (20%)	20 (16%)	
Frequently(4-5/week)		124 (43%)	70 (43%)	54 (44%)	
Very frequently (2+/day)		85 (30%)	48 (29%)	37 (30%)	
Main reason for cycling	273				0.5
Work		161 (59%)	86 (56%)	75 (63%)	
School/college		9 (3.3%)	5 (3.2%)	4 (3.4%)	
Local trips, shopping		46 (17%)	26 (17%)	20 (17%)	
Recreation/health		57 (21%)	37 (24%)	20 (17%)	
Unknown		14	10	4	
% of cycling with track	281				**0.034**
0-20%		146 (52%)	93 (59%)	53 (43%)	
21-40%		87 (31%)	42 (27%)	45 (37%)	
41-60%		30 (11%)	17 (11%)	13 (11%)	
61-80%		9 (3.2%)	2 (1.3%)	7 (5.7%)	**0.009**[8]
81-100%		9 (3.2%)	4 (2.5%)	5 (4.1%)	
Unknown		6	6	0	

Notes: 1. n (%); 2 Fisher's exact test or Pearson's Chi-squared test; 3. p = 0.01 and p = 0.014 for 18-34 vs 35+; 4. p = 0.006 for 18-44 vs 45+; 5. p<0.001 and p = 0.004 for less than 10 years vs 10+; 6. p=0.01 for very frequently vs others; 7. p = 0.019 for work and school/college combined vs other.

Binary logistic regression modelling was used to further explore these relationships (age was excluded to improve model fit). The binary logistic regression model shown in Table 4 was statistically significant $\chi^2(df=5, n=281)=24.69$, $p<0.001$, Pseudo-R^2 (Cragg-Uhler)=0.11 and (McFadden)=0.06. Model coefficients indicated that likelihood of being involved in a tram-related incident increased with the proportion of the time cyclists cycled on roads with tram tracks. Compared to riding on roads with tram tracks for 0-20% of the time, 21-40% increased the likelihood to 1.8 times more likely (p=0.037) and 61-80% increased the likelihood to 5.8 times more likely (p=0.042). Cycling experience, that is regular cycling over time, was also a factor in crash involvement with less experienced cyclists (3-5 years) 2.6 times more likely (p=0.019) to be in a crash than people with more experience (5-10 years) and 3.4 times more likely (p=0.014) than people with over a decade of regular cycling experience.

Table 4: Logistic regression results, involvement in at least one tram-related incident in the last 5 years

Characteristic	OR[1]	95% CI[1]	p-value
Years regularly cycling			
10+ years	—	—	
5-10 years	2.57	1.34, 5.04	**0.005**
3-5 years	3.35	1.32, 9.28	**0.014**
Less than 3 years	0.8	0.33, 1.81	0.6
Share of cycling with track			
0-20%	—	—	
21-40%	1.81	1.04, 3.16	**0.037**
41-60%	1.44	0.62, 3.25	0.4
61-80%	5.75	1.22, 41.8	**0.042**
81-100%	2	0.48, 8.76	0.3

[1] OR = Odds Ratio, CI = Confidence Interval. Null deviance = 385; Null df = 280; Log-likelihood = -180; AIC = 372; BIC = 394; Deviance = 360; Residual df = 275; No. Obs. = 281

4.3 Types of tram-related incidents

Table 5 presents responses for the types of tram-related incidents participants were involved in and what they considered were associated factors. Skidding on the tracks was the most frequently reported tram-related incident (71%). Of all events, half (55%) were skid incidents on slippery and/or wet road conditions and a quarter involved track wedging (25%). No collisions with trams were reported, while collisions with tram passengers or stops and other types of tram-related incidents were 5% of incidents.

Table 5: Cyclist and tram-related incidents: incident types and associated factors

	Participant-reported associated factor				
	Slippery and/or	Swerved to avoid a:			
Incident type	**wet road**	**car door**	**pedestrian**	**Other**	**Total**
Track-skid	51.7% (198)	9.7% (37)	1.6% (6)	7.8% (30)	70.8% (271)
Track-wedge	5.0% (19)	6.5% (25)	1.8% (7)	10.7% (41)	24.0% (92)
Collision with tram passenger/pedestrian	-	1.6% (6)	1.0% (4)	0.3% (1)	2.9% (11)
Collision with tram stop	-	-	0.3% (1)	-	0.3% (1)
Collision with tram	-	-	-	-	0.0% (0)
Other	1.0% (4)	0.5% (2)	-	0.5% (2)	2.1% (8)
Total	57.7% (221)	18.3% (70)	4.7% (18)	19.3% (74)	100% (383)[7]

[7] There were some inconsistencies in the total number of tram-related incidents reported when participants were subsequently asked to identify contributing factors. This appears to be in part due to respondents estimating the number of incidents they had been involved in over the past five years, and hence sometimes rounding numbers.

4.4 Comparing track-skid and track-wedge incidents

Table 6 compares participant-reported factors for track-skid and -wedge incidents. A chi-square test returned a significant relationship between whether an incident involved wedging or skidding and the factor identified by the survey participant as related to the incident ($\chi2(3, n=363)=83.89$, $p<0.001$). Participants identified that 73% of track-skid incidents involved slippery/wet road, compared to only 21% of the track-wedge incidents

Table 6: Cyclist and tram-related incidents: track wedge and track skid incidents

Incident type	Slippery and/or wet road	Swerved to avoid a: car door	Swerved to avoid a: pedestrian	Other	Total
Track-skid	73.1% (198)	13.7% (37)	2.2% (6)	11.1% (30)	100% (271)
Track-wedge	20.7% (19)	27.2% (25)	7.6% (7)	44.6% (41)	100% (92)

Participants were also asked about the outcomes of their most serious tram-related incidents. Table 7 shows responses for track-skid and -wedge incidents[8]. A chi-square test showed significant relationships between the outcome of the most serious incident of each type and whether a tram-related incident involved wedging in or skidding on the track ($\chi2(2, n=153)=7.70$, $p=0.021$)[9]. The results suggest more serious outcomes for track-wedge incidents, with 55% of survey participants involved in at least one track-wedge in the last five years reporting that their most serious incident of this type resulted in an injury. This compares to only 34% for track-skid incidents.

Table 7: Outcomes of most serious track-skids and -wedges, by survey participant

Incident type	Admitted to hospital	Attended hospital	Minor medical treatment	Injured, no treatment	Not injured	Total
Track-skid	2.2% (2)	0.0% (0)	6.6% (6)	25.3% (23)	65.9% (60)	100% (91)
Track-wedge	4.8% (3)	3.2% (2)	12.9% (8)	33.9% (21)	45.2% (28)	100% (62)

5. Victorian Injury Surveillance Unit (VISU) data

Table 8 summarises the tram-related bicycle crashes recorded by the Victorian Injury Surveillance Unit (VISU).

Table 8 Hospital presentations related to tram-related cyclist crashes. Source: VISU.

Type	Wedge	Slip/skid	Tram vs bike	Collision with stop or barrier	Total
Crashes (2006 to 2021)	748	98	34	<5	~885
Per year	49.9	6.5	2.3	<0.3	~60
Per week	1.0	<0.1	<0.1	~0	~1.2
Share	85%	11%	4%	<1%	100%

On average, 60 tram-related cyclist crashes per year were recorded by VISU. That is, crashes that resulted in presentation to a hospital emergency department. Of particular note, the majority (85%) of recorded crashes, an average of almost one per week, were attributed to bicycle tyres being wedged in the tram tracks. Slip/skid related crashes and crashes involving cyclists and trams resulting in presentation to hospital average only 6.5 and 2.3 per year respectively. The VISU dataset also records a crash type that does not appear in the research

[8] Other tram-incident types excluded due to small number of survey participants involved in these incidents.
[9] Admission and attendance at hospital, and minor medical treatment combined to meet test assumptions.

literature: cyclist crashes into tram stops and related infrastructure, but these crash types were infrequent[10].

6. Discussion and conclusions

This paper presents, to our knowledge, the first survey of cyclists about their experience of tram-related crashes and incidents. This contrasts to previous research, which mostly used hospital and crash data, and interviews of cyclists who have presented to hospital emergency rooms. In general, the findings of this study appear consistent with previous research that suggests that track-related crashes are a key issue in cyclist safety around trams.

In the last five years, a fifth (21%) of cyclists had been involved in at least one tram track-related crash. This is fewer than the proportion of cyclists reported crashes relating to falls (50%), road defects (36%) or collisions with motor vehicles (29%). However, half of survey respondents (52%) reported cycling on roads with tram tracks for 0-20% of their cycling, which might suggest that tram track-related crash rates are high given that most cycling occurs on roads without tracks.

Tram and tram track-related crashes, like all cycling crashes, are relatively rare events. But incidents that might have had similar outcomes to crashes if not for chance, evasive action or otherwise, are much more prevalent. This is part why this study asked respondents about all tram-related incidents, not just actual crash events. The findings about which factors are more common amongst cyclists involved in at least one tram-related incident in the last five years are consistent with what might be expected: cyclists riding on roads with tram tracks more often and less experienced cyclists[11] are more likely to have been involved in a tram-related incident.

No survey respondent reported being involved in a collision with a tram in the last five years. This may be a positive from a Safe System perspective, as it might be expected that tram-related cyclist crashes would be especially likely to result in serious injury or fatality. However, this result is at odds with the VISU data, which indicated that around 4% of presentations at hospitals that are tram-and-bike related involve collisions between a tram and a cyclist. It may be that cyclists who had been involved in a tram-related crash were not recruited in this survey because they are no longer active, as Maempel et al. (2018) reported some cyclists do not resume cycling after a tram-related crash.

The findings of this survey suggest that track-skid incidents are more common than track-wedge incidents. This is in contrast to the emphasis in much of the previous research literature on track wedging being a larger issue than skidding. This may in part be explained by the differing outcomes, with track wedging appearing to be more likely to result in injury. The VISU data similarly suggests that track wedging results in more hospital visits (85%) than track skids (11%), which also appears consistent with Maempel et al. (2018)[12].

Results from the survey suggest that track skidding is associated primarily with wet conditions, consistent with expectations as wet road conditions is a contributing factor in cyclist tram-related crashes (Teschke et al. 2016; Maempel et al. 2018; Leune et al. 2021). This might

[10] For privacy reasons the VISU does not release exact crash numbers for categories with fewer than 5, so as not to allow the identification of individuals.

[11] Except for cyclists who have cycled regularly for 0-3 years, but this would appear likely to be because these cyclists have had less time to be involved in a tram-related incident.

[12] In their study of 191 cyclists presenting to emergency services in Edinburgh and West Lothian, 142 had been involved in crashes related to track-wedging, while only 32 related to track-skidding.

suggest that education or encouragement campaigns might be targeted towards avoiding track skids with an emphasis on being especially cautious when conditions are wet.

This study is the first to survey cyclists' experiences with tram-related incidents, in contrast to previous studies based on crash and hospital data or post-crash interviews. While this study provides new insights, further research is needed to maximise safety outcomes for cyclists. Qualitative methods will further our understanding of the types of tram-related incidents cyclists experience and how these might be reduced. In addition, refinement of the survey instrument and application in other cities will also provide greater insights. Adding a geographic component into the survey, to ask respondents where they have been involved in incidents / crashes or which locations they find particularly hazardous might also be considered in future research. Further, respondents to this survey were recruited through bicycle user groups and may not be representative of all cyclist types (e.g. commuter, commercial delivery riders, e-bike riders). While the model presented in this paper provide some indication of which factors may be important, the explanatory power appears low; with R^2 values less than 0.11. A larger and more representative sample might provide additional findings about cyclist safety in relation to trams.

The importance of gaining a better understanding of track-skid incident types is also suggested by the findings of this study, as cyclists reported these incidents at a higher frequency than track-wedge incidents. Study findings support previous research that track-wedge incidents more frequently result in serious road trauma and presentation to hospital than track-skid incidents. While this might appear to support the use of rubber track inserts as a Primary Treatment, the results of this study suggest that track-skid incidents also have the potential to result in hospital presentation. Likewise, the VISU data showed that track skids, crashes between cyclists and trams and cyclist collisions with tram stops also result in serious injury. It is unclear if rubber track inserts reduce the consequences of these crash types. Action required to meet the Safe System principles suggest practitioners focus on separation, segregation, shifting crossing angles to 90 degrees (including hook turns for cyclists) and other countermeasures that prevent the likelihood of tram-related cyclist crashes, not just track wedging.

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