Transportation Research Part F: Psychology and Behaviour 106 (2024) 169–178

Contents lists available at ScienceDirect

Transportation Research Part F: Psychology and Behaviour

journal homepage: www.elsevier.com/locate/trf

The proportions of severe and less severe bicycle crashes and how to avoid them

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ARTICLE INFO

Keywords:
Bicycle crashes
Proportion of injuries
Prediction of crashes

ABSTRACT

Background: In collaboration with a bicycle airbag helmet company, data were collected to help explain events where head protections are deployed. The head protection records activations continuously, and when a head protection is deployed, this information is sent to the company. The company invited affected cyclists to (i) participate in a web survey, and (ii) share their data with researchers. The first aim of the study was to investigate the proportions between different severities of crashes, i.e., how many crashes with serious injuries occur for every crash with minor injuries, while the second aim was to predict when bicycle crashes will occur. **Method:** A total of 196 cyclists completed the web survey. Participants were 20–76 years old (mean age 46 years) and consisted of 125 women and 55 men. The cyclists were highly educated, and 73 percent had completed a university or college education. In addition, head protection data were collected from 355 other cyclists, of which 264 had their helmet deployed. **Results:** One of the 182 (included events) cyclists ended up in hospital care. The data collected indicated the proportions of cyclists who needed hospital care (1 = severe injuries), cyclists with injuries (15), slight injures (85) and cyclists who could continue as before (81 = no injuries). The head protection data confirmed the web survey findings, but also demonstrated that the head protection, on journeys that ended with head protection deployment, had a higher degree of activations before the event) compared to journeys where it was not deployed. Furthermore, on trips made after deployment, the head protection had lower levels of activations, which can be understood as the cyclists adapting their behavior by, for example, riding more carefully (but not slower). **Conclusion:** This study highlights the proportions of events leading to minor injuries versus hospitalization. Activation measures (head protection conditions) can predict when events will occur, and cyclists will adjust their behavior accordingly following events.

1. Introduction

Cycling crashes are one of the traffic safety issues that need to be addressed if political targets on accident reductions will be reached (cf. EC-EU Road Safety Policy Framework 2021–2030, 2019; Report on the EU Road Safety Policy Framework, 2021). In Europe, there were 19 450 cycling fatalities between 2010 and 2018 (Adminaité-Fodor & Jost, 2020). Cycling crashes is the most common traffic accident type in Sweden (Rizzi et al., 2020), with over 23 000 cyclists seeking care at emergency hospitals every year

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https://doi.org/10.1016/j.trf.2024.07.027
Received 13 May 2024; Received in revised form 26 June 2024; Accepted 28 July 2024
Available online 17 August 2024

(MSB, 2013) and Eriksson et al. (2022), showed that 138 cyclists died during the six-year period from 2014 to 2019. Utriainen, et al., 2022, shows that the share of bicycle injuries caused by single bicycle crashes, i.e., falls and impacts not involving contact with another road user, varies between 52 per cent and 85 per cent and the contributing factors for these cases are for example unsafe riding speeds or actions, distractions such as traffic pressures, inadequate infrastructure, and adverse road or weather conditions. The most common locations were crashes on street or road sections, followed by street or road crossings.

The results above are mostly based on extracts from databases. The Swedish Transport Administration's in-depth database of fatal road accidents, and the STRADA (Swedish Traffic Accident Data Acquisition) register of (i) police-reported traffic accidents with personal injuries, and (ii) hospital-reported data on traffic-injured individuals who sought care. But, cycling collisions are under-reported in Sweden and internationally (Gildea et al., 2021; Rizzi et al., 2013; Shinar et al., 2018; Watson et al., 2015). Less severe injuries in particular are underreported but are important to investigate due to frequency, and because injuries, perceived risks discourage cycling (Aldred and Crosweller, 2015; Sanders, 2015). Aldred and Crosweller (2015) present what they phrase the "normality" of near misses. In their study approximately one in four (of 1532) respondents rated that they (in their every diary day) experienced a very scary incident. Aldred and Crosweller (2015) conclude that the prevention of near misses reduces injuries and will improve the cycling experience. Sanders (2015) also argue for the perceived risk as a barrier for cycling. Sanders, 2015 conclude that "targeting road user behaviors and roadway designs associated with these near misses could mitigate perceived and actual traffic risk for bicyclists, …". The strength of the analysis on near misses or near crash events is not only the high frequency. Near-crash events involve a manoeuvre by the driver and are events that otherwise would have led to a crash under similar circumstances. Near-crash events are evasive maneuvers for collision avoidance, which are more frequent than real crashes and have similar characteristics to real crashes (Guo et al., 2010; Shinar, 2017). Guo et al, 2010, also showed that it was a positive relationship between the frequency of contributing factors for crashes and near-crashes. They also showed that the combination of crash and near-crash data underestimates the risk of contributing factors compared to using crash data alone. However, the accuracy of the assessment will increase. The authors conclude that it allows investigators to identify true high-risk behaviors while qualitatively assessing potential biases (Guo et al., 2010). Hence, near crash events can reveal information on how to avoid crashes. Second, near crashes reduce the cycling experience.

One major objective for the development of advanced rider assistance systems (ARAS) is to help the cyclist to avoid crashes (c.f. Andersson et al, 2024). One approach towards a development of ARAS is to understand risky behaviors better (de Hartog et al., 2010). For instance, Usache et al, (2022) present a three factor model (violations, errors and positive behaviors) that reveal a distinction between risky behaviors. Furthermore, Möller et al., 2024 showed that especially electrical (e-bikers) versus conventional bikers (c-bikers) self-reported lower rates of traffic violations. However, Ma et al., 2019, showed an 8.2 times higher crash numbers for e-bikers than c-bikers. E-biking is now the main mode for daily commuting in China. Janstrup et al., 2023 showed the higher risk for e-bikers for the Danish context as well. In the present study risky behavior will only be studied by the proportion of different helmet conditions and bicycling speed (see method section for details). The logic is that cyclist that reveal a riskier behavior will end up in an unwanted event more often. The developed ARAS could warn or intervene, i.e., reducing crashes.

Based on conflict theory results (Hydén, 1987), it is shown that there are more less serious crashes for every serious crash, i.e., that there are more minor crashes than serious crashes. The current study aimed to clarify these proportional values for cycling, i.e., the proportions of the varying severities. The prediction based on conflict theory (for the car drivers) is nevertheless that the proportion of less serious crashes is higher than the proportion of severe crashes. The specific proportions, on the other hand, is more difficult to predict. The data collection on cycling events that might, or might not, end up in an injury is difficult to obtain due to the under-reporting of crashes (Gildea et al., 2021; Rizzi et al., 2013; Shinar et al., 2018; Watson et al., 2015) and that events that do not end up in an injury would nevertheless not be reported. However, a head protection company have developed an airbag helmet for cycling (called head protection for now on). The head protection deploys when the activations are powerful enough (based on cyclist head "shaking" movements). When the head protection deployment occurs, the company is contacted (see Method section 2.2 and 2.3, for details). The cyclist who experienced a deployment of the head protection can be contacted, creating a unique possibility for data collection. The head protection can also provide cycling data collected continuously. The head protection recordings made it possible to collect two data samples (see Method section 2.2 and 2.3, for details) used to understand the proportions of severe and less severe bicycle crashes and how to avoid them.

1.1. Definition of an crash, injury, and event

In this study, the term 'event' was used when a head protection was deployed. The deployment of the head protection could result in an crash but also of a near miss or incident. An crash is here defined as a cyclist being injured in some way, regardless of whether the cyclist needed medical care or not (damaged material is not included though). In near crashes and incidents, on the other hand, no person is injured.

1.2. Aims

The first aim is to investigate the proportions between different severities of crashes, i.e., how many severe crashes occur for every less severe crash with minor injuries and how frequent events without injuries are. The second aim is to understand how to prevent a bicycle crash to occur by the use of head protection data.

2. Materials and methods

2.1. Overview of the project

The complete project, which focused on understanding bicycling crashes, contained several data collection methods, i.e., web survey, interviews, and head protection data collection. The current paper focuses on the head protection data investigation and only some data from the web survey is included, i.e., where it is directly related to the head protection data and the purpose of this study. Two data samples have been analysed. One data sample of head protection data recordings and is henceforth called the head protection study (section 2.3). The second sample is from participants that have experienced an event and participated in a web based survey (section 2.2).

2.2. The survey

2.2.1. Participants

The head protection company sent out at least 266 invitations (to cyclists whose head protections had deployed) to participate in the web survey. A total of 220 responses were received (83 % of the 266 and not the same participants as in head protection data recordings (25 cyclist overlapped). The data for those who did not complete their name and address (22 cyclists) were excluded, to avoid duplicates. In some cases, it was evident that the same individual started the survey more than once with the aim of describing the same event, but without completing the survey. This left 198 responses for analysis from 196 cyclists; 2 cyclists described 2 unique events each. The response rate based on the number of cyclists was therefore 74 percent (196 out of 266). Information on bicycle type (conventional or electrical) was included, but 14 of the 196 used other types of bikes, leaving 182 events to be analyzed (including 2 cyclists with 2 events). As a token of appreciation, the cyclists were offered the choice between three lottery tickets or a movie ticket (approximately 9 Euro in value).

The 180 cyclists (participants) were 20–76 years old (mean age 46 years) and consisted of 125 women (70 percent) and 55 men (women and men were in the same age). The cyclists were highly educated, and 73 percent had completed a university or college education. Roughly half of the cyclists rode a conventional bike (85 cyclists) while roughly half (95 cyclists) rode an electrical bike.

2.2.2. Survey data

The web survey contained several questions related to the event (40 questions with several alternative answers). Questions regarding the context of the event, the cyclist's understanding of the event, explanations for the event, and the consequences of the event were included. Consequences of the event (injuries) were analysed in this work. All cyclists answered questions about their degree of injury sustained in the event and how this will affect them in the future. The main question analysed here was the consequences of the deployment event. Four categories were used. No injuries, injury but minor – do not to seek medical care, injuries and needed to seek medical care, and finally injuries needed hospitalization

Fig. 1. A deployed Hövding bicycle airbag helmet. Image published with permission of Hövding (cropped).

2.3. The head protection study

2.3.1. Participants

The company sent VTI (the Swedish National Road and Transport Research Institute) head protection data from an additional 355 cyclists over a roughly 2.5-year period. Data was collected by the "head protection system" continuously as soon as the head protection was used. Of these 355, we were able to identify 264 cyclists who experienced the head protection being deployed (only 25 cyclists also participated in the survey). Processing was performed to enable analysis of the head protection data. The head protection company delivered a total of 64,814 files (from 264 cyclists) in so-called 'json' format. The data cover the period 2019/10/20 to 2022/06/30. The data files do not contain any information about the cyclist, e.g., gender, age, bicycling experience.

2.3.2. Head protection specifications

The head protection is for cyclists and consists of an airbag inside a collar worn around the neck (see Fig. 1). When the cyclist straps on the head protection system, the cyclist's movement pattern is recorded and is by blue tooth connected to the cyclist mobile phone. If it the movement pattern (head shakings) deviates from a normal movement pattern (sufficiently strong activations), the airbag deploys in less than 0.1 s. Cyclists with version 3 of the head protection, which was launched on the market in autumn 2019, is equipped with Bluetooth, and can register data in a mobile application. The user can choose to share bicycling data with the company and opt for a message to be sent to the company and a relative when the head protection deploys. The head protection is intended for use when bicycling in urban environments and on country roads, not for extreme bicycling, such as off-road or BMX bicycling.

When a head protection was deployed, an automatic message was sent to the company; the user (cyclist) then received an e-mail from the company with an invitation to answer a web survey constructed by VTI. In the e-mail, there was a direct link to the web survey. The online survey was available for one year from January 2021 through January 2022.

2.3.3. Head protection data

The data collected consisted of, among other things, GPS (Global Positioning System) coordinates, times, and the head protection's reported "condition". The coordinates come from the mobile phone, and are updated, with large variations, on average every 3 s. Using these data, the cyclists' speeds were calculated. The head protection "condition", based on how much the head protection shakes, has four modes, which have been termed here as "calm", "worried", "irritated", and "angry". The helmet conditions do not describe the cyclists' modes, only how much the helmet shakes. When the shaking becomes greater than that which defines an "angry" condition, the head protection deploys. The frequency and accuracy of data collection is affected by several aspects, such as the user's mobile phone type, and their phone's signal (reception) strength at that moment. The data quality thus varies between cyclists but also within cyclists (from occasion to occasion).

2.3.4. Data processing

The number of trips per head protection user varies from only 1 trip for seven cyclists to 1,728 trips for the user who cycled most often. A total of 226 json files were duplicates and therefore excluded from the analysis. The 10 trips where the head protection had been used abroad were also excluded from the analysis. The amount of data for Stockholm's inner city (number of trips and event locations) is illustrated as an example, in Fig. 2, below.

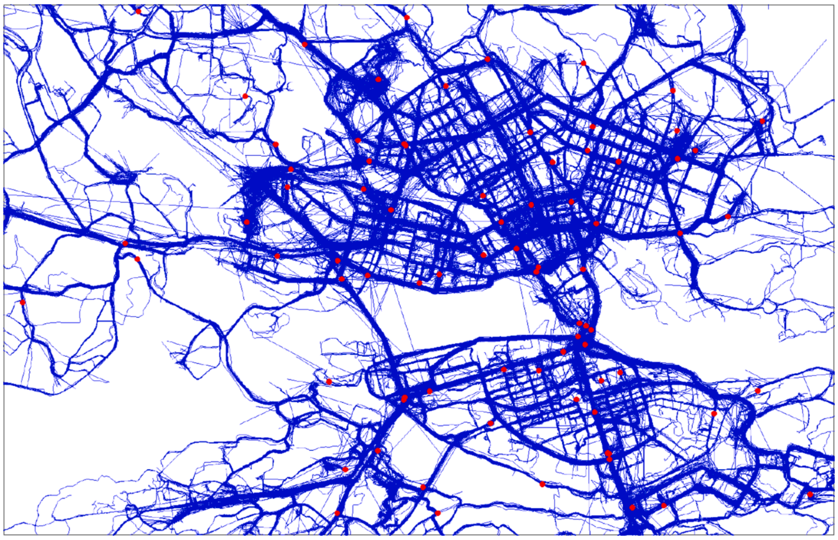

Fig. 2. All trips made (in blue) and all events that occurred (red dots) for the inner city of Stockholm. Thicker lines indicate more trips. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

The data in the json files consist of coordinates in the WGS 84 format (World Geodetic System 1984; three-dimensional coordinate reference frame for establishing latitude, longitude, and height), as well as the associated time indication and information about the "condition" of the head protection. In the analysis, the coordinates have been converted to the SWEREF 99 TM coordinate system, and from these and the time indications, the speeds of the cyclists were calculated. The quality of the GPS data was mostly good, but occasionally obviously incorrect positions were recorded, leading to unreasonably high speeds. In this study, speeds above 50 km/h were considered incorrect coordinate information, and therefore excluded from further analyses.

All analyses were conducted in Matlab software. Each trip has a locality determination (in addition to the coordinates themselves) in the form of a text string in json data. From this, roughly 13,000 trips were made in Stockholm, just under 10,500 in Malmö, and roughly 5,600 in Gothenburg. Analyzing the head protection data, via the coordinates and the trips per county, the high representation of the metropolitan regions was even more striking. Out of a total of about 64,500 trips, about 23,500 were made in Stockholm County, just under 18,000 in Skåne County (where Malmö is situated), a little over 10,000 in Västra Götaland County (where Gothenburg is situated), and a total of about 13,000 trips in the country's other counties.

2.3.5. Trip categorization

Two independent raters categorized all places where the head protection deployed. As a basis for the categorization, the travel stretch length assessed was approximately **200 m** before and up to the event, and this route was laid out in Google Maps with both a map and a satellite background. If there was uncertainty or disagreement between raters, the location was inspected via Google Street View, which usually brought clarity to the type of location (also referred to as the 'event context') at which the head protection deployed. In total, the number of events (head protection deployments) amounted to 273, in which the 264 cyclists were involved. The event locations were combined into three main categories shown below, including 247 trip categorizations (out of 273).

- Road stretch (n = 52)
- Bicycle lane/bicycle field (n = 61)
- Complex situations (n = 134): intersection with road, cycle path, cycle lane, cycle crossing/cycle passage, pedestrian crossing, circulation area, entrance or exit, square or shared space, parking

2.3.6. Travel speed and head protection condition

As a basis for the speed measurement used in the analyses, the travel stretch length assessed was approximately **200 m** before and up to the event, and this stretch was laid out in Google Maps with both a map and a satellite background, as used for categorization. The average travel speeds were calculated across all trips recorded for the three main categories of location type, for *before*, *during* and *after* the event (200 m before the event and up to the event location). The participant had to cycle at least five times on a specific stretch registered to be included in the database analyzed (for before the event and after the event, the during trip was only happening once). If participant 'x' experienced an event in location 'y', the speed measures before, during, and after this event were calculated for 200 m up to the 'y' location. The cyclist had to cycle the same stretch after an event at least 5 times to be included in the analysis.

The head protection conditions were registered continuously (for the complete stretch) and logged in the cloud (organized by the helmet company and delivered to VTI). Four conditions depending on the characteristic of the head "shaking" detected. The condition categories were proportion of "calm", "worried", "irritated", and "angry" (an increase from calm to angry symbolize a more bumpier cycling condition). The proportion of the condition was based on the complete stretch before an event at location 'y', i.e., not only the 200 m as for the speed value used in the analysis. But it had to be the same stretch at all times to be included in the analysis.

2.3.7. Statistical considerations

All analyses presented were conducted with SPSS version 28 statistical software, using an alpha level of 0.05. Mixed ANOVAS was computed. The dependent measures were speed km/h or proportion of head protection condition ("calm", "worried", "irritated", and "angry"). The independent measures were Context location (Road stretch, Bicycle lane/bicycle field or Complex situations/Intersections) and Time (Before, During and After the event). Context location was a between-participant variable and Time was a within-participant variable. If main effects or interaction effects were obtained pairwise comparisons were performed and Bonferroni corrections were used to control for multiple testing.

3. Results

3.1. Web survey data

The web survey responses reporting the degree of injury sustained by cyclists in connection with 182 events where their head protections were deployed are presented in Table 2. One participant was so seriously injured that he was hospitalized, 15 cyclists needed to seek medical care but were able to go home later that day, and 85 cyclists were mildly injured and did not need to seek care. In total, 81 cyclists escaped the event completely unharmed.

3.2. Head protection data – Locations

First, the different locations of the events were identified based on GPS data. Fig. 2 shows all the trips made and events that occurred in Stockholm inner city, as an example. As can be seen, there are no simple overlaps (of events), even if specific areas are overrepresented. The events were thus widely spread over a large part of Stockholm, and occurred rather often at crossings, and in complex situations compared to stretches of road; there were no unique black spots. A thick blue line indicates a large number of cycling trips and a thin line indicate fewer trips.

3.3. Head protection data – Time of day

Fig. 3 shows all registered trips distributed over the course of a day, where red and blue bars represent weekdays and holidays respectively. The distribution per day of the week is roughly 11,000 trips per weekday and approximately 4,000 per holiday. From this information, it seems reasonable to conclude that a significant portion of (air bag) head protection cyclists are commuters.

3.4. Head protection data − trip speed

In the first analysis, the average travel speeds of cyclists on trips were analyzed (i) before, (ii) during and (iii) after the head protection triggered (see Table 1). Only 137 (of 248) cyclists with sufficient data are included here; 111 cyclists had no recorded trips after the incident or it was impossible to specify their context. The results, based on a mixed analysis of variance (ANOVA) (3 × event contexts and 3 × time periods), revealed that the average trip speed was the same regardless of whether the data were collected before, during, or after the head protection was activated. This means that the cyclists cycled at the same average speed on all times analyzed. In addition, there was no difference between the different event context types. This means that the average trip speed (200 m before − up to the location) was the same regardless of whether the event occurred on a road stretch, at an intersection (complex situation) or on a bicycle lane/field. There was no significant interaction effect either. This means that the speeds of each trip were similar regardless of the time period or the event context.

When only the data for the time periods (i) before and (ii) during an event were examined, all 248 cyclists could be included in the analysis. The analysis revealed no significant main effects for average trip speed or event location. However, there was a significant interaction ($F(2, 242) = 3.33$, $p < 0.05$, MSE=9.6) (see Fig. 4). The only significant pairwise comparison was found for before and during the trip for the intersection/complex situations category. This means that the speed was lower for intersections/complex situations on the occasions when the head protection was deployed than on the trips that the cyclists made prior to the head protection being deployed (on the same location).

3.5. Head protection data – Activation condition

The head protection system communicates continuously the condition of the head protection (i.e., “calm”, “worried”, “irritated”, and “angry”). The analyses of head protection condition assessed whether the trip that resulted in head protection deployment was equivalent to trips that did not. For each trip, it was determined what percentage of the time (dependent variable) the head protection was in the various four conditions (see Table 2). The trip when the head protection was deployed was then compared with the person’s other trips when no event occurred. Four mixed ANOVAs (one for each head protection condition) were carried out, i.e., a 3 (time period; before, during and after the event) and 3 (location type; road stretch, bicycle lane/field, intersection) mixed ANOVA was computed. The location type was a between-participant variable since the unwanted event occurred at a specific location.

For the “calm” condition, the ANOVA showed that the head protection had a lower percentage of calm (main effect) when the event occurred ($F(2, 304) = 44.38$, $p < 0.01$, MSE=0.06). That means that there were calmer trips both before and after the trip, compared to trips when the event occurred. There was no significant difference between the time periods of before and after the trip.

For the condition “worried”, there was a significant difference between the time periods ($F(2, 304) = 11.34$, $p < 0.01$, MSE=0.01). This effect of time period revealed that the head protection was in a less worried condition on the trips *after* an event had occurred. The

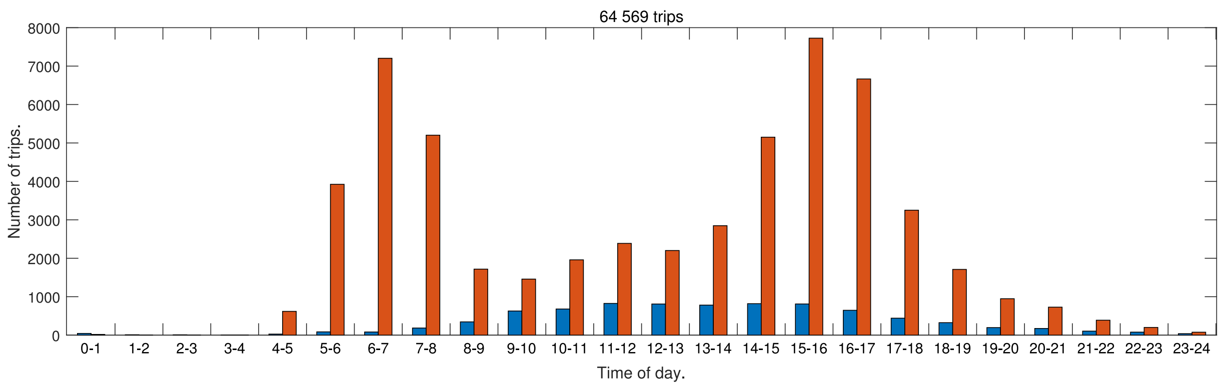

Fig. 3. Distribution of trips made according to hour of day for the 355 cyclists, from 2019 to 10-20 to 2022–06-30, where red and blue bars represent weekdays and holidays respectively. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

Table 1
Average travel speed (for a stretch of 200 m in total) before an event and number of cyclists according to event time period (before, during or after the event) and location (event context). SD=standard deviation.

Time period	Context	Mean trip speed (km/h)	SD	*n*
Before	Road stretch	17.74	2.42	32
	Bicycle lane/bicycle field	18.53	2.72	33
	Intersection/complex situation	18.33	3.66	91
	Total	18.25	3.25	156
During	Road stretch	18.41	4.44	32
	Bicycle lane/bicycle field	18.74	4.34	33
	Intersection/complex situation	17.51	5.25	91
	Total	17.96	4.91	156
After	Road stretch	17.99	3.14	32
	Bicycle lane/bicycle field	18.45	2.63	33
	Intersection/complex situation	18.17	3.79	91
	Total	18.19	3.43	156

Table 2
Average proportion of head protection activation (calm, worried, irritated, and angry) before, during or after the event for all locations (event context). SD=standard deviation (in parenthesis).

Time period	**Event context**	**Proportion Calm**	**Proportion Worried**	**Proportion Irritated**	**Proportion Angry**	**n**
Before the event	Road stretch	0.989 (0.02)	0.0089 (0.01056)	0.002337 (4.43×10^{-3})	0.70×10^{-5} (2.98×10^{-5})	32
	Bicycle lane/bicycle field	0.892 (0.13)	0.0177 (0.02124)	0.003788 (8.06×10^{-3})	3.4×10^{-5} (1.74×10^{-4})	33
	Intersection/complex situation	0.993 (0.02)	0.0134 (0.01898)	0.003559 (8.78×10^{-3})	1.10×10^{-5} (5.17×10^{-5})	91
	Total	0.979 (0.07)	0.0135 (0.01835)	0.003364 (7.87×10^{-3})	1.60×10^{-5} (9.61×10^{-5})	156
During the event	Road stretch	0.913 (0.03)	0.0104 (0.02340)	0.002347 (6.53×10^{-3})	1.95×10^{-2} (1.06×10^{-1})	32
	Bicycle lane/bicycle field	0.992 (0.13)	0.0265 (0.04502)	0.007197 (2.08×10^{-2})	2.70×10^{-4} (1.68×10^{-3})	33
	Intersection/complex situation	0.983 (0.01)	0.0133 (0.02589)	0.006092 (1.98×10^{-2})	2.07×10^{-4} (1.32×10^{-3})	91
	Total	0.933 (0.06)	0.0160 (0.03179)	0.005597 (1.82×10^{-2})	4.19×10^{-3} (4.82×10^{-2})	156
After the event	Road stretch	0.992 (0.02)	0.0066 (0.01069)	0.000583 (1.00×10^{-3})	0.69×10^{-5} (0.81×10^{-5})	32
	Bicycle lane/bicycle field	0.989 (0.13)	0.0065 (0.01047)	0.001600 (3.56×10^{-3})	3.12×10^{-5} (1.51×10^{-4})	33
	Intersection/complex situation	0.892 (0.02)	0.0070 (0.01390)	0.001280 (3.37×10^{-3})	1.01×10^{-5} (4.48×10^{-5})	91
	Total	0.993 (0.07)	0.0068 (0.01242)	0.001217 (3.09×10^{-3})	1.39×10^{-5} (5.97×10^{-5})	156

interaction effect was also significant ($F(4, 304) = 2.7$, $p < 0.03$, MSE=0.01) (see Fig. 5). The pairwise comparisons revealed that the head protection had a higher proportion of "worried" state *during* incidents that occurred on a bicycle lane/field compared to trips *before* and *after* the event. Pairwise comparisons also showed a significant difference between the *before* and *after* time periods for those who had an event on a bicycle lane/field (see Fig. 5).

The analysis for "irritated" revealed a significant effect of time period ($F(2, 304) = 5.4$, $p < 0.01$, MSE=0.01). Pairwise comparisons revealed that, on trips after the event, head protections were in a less irritated condition than trips both before and during the event. This means that there was no difference in the percentage of irritated head protection conditions for the trips before and during the event, but that the head protection was not in as irritated a state on the trips that occurred after the events.

Regarding "angry" conditions, no significant main or interaction effects were obtained, either for time period or for location type, although there was a tendency for an effect of time, whereby the head protection was more often in an angry condition during an event.

4. Discussion

4.1. Proportion of severities

The first aim was to investigate the proportions between different severities of crashes, i.e., how many crashes with serious injuries occur for every crash with minor injuries. The results revealed that 1 cyclist was hospitalized, 15 contacted primary or emergency hospitals for care, 85 had grazes or small wounds, and 81 were not injured at all. A total of 16 cyclist (the person who was hospitalized

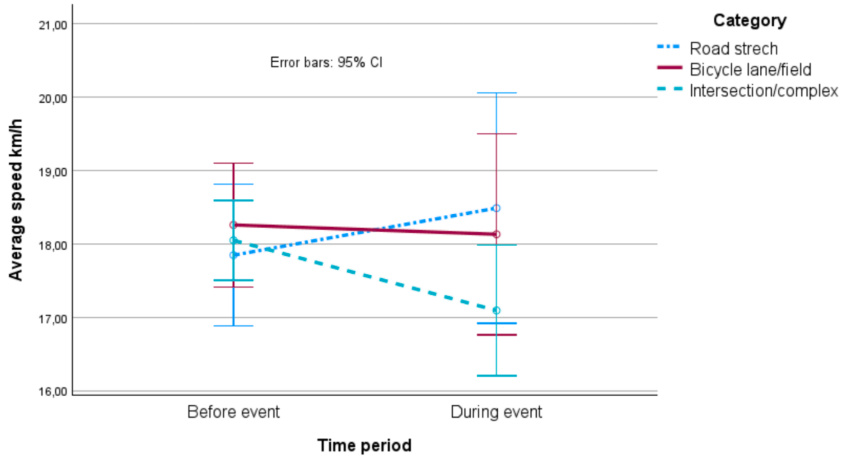

Fig. 4. Mean trip speeds for different event locations, for before and during the event. The error bars indicate 95 percent confidence intervals.

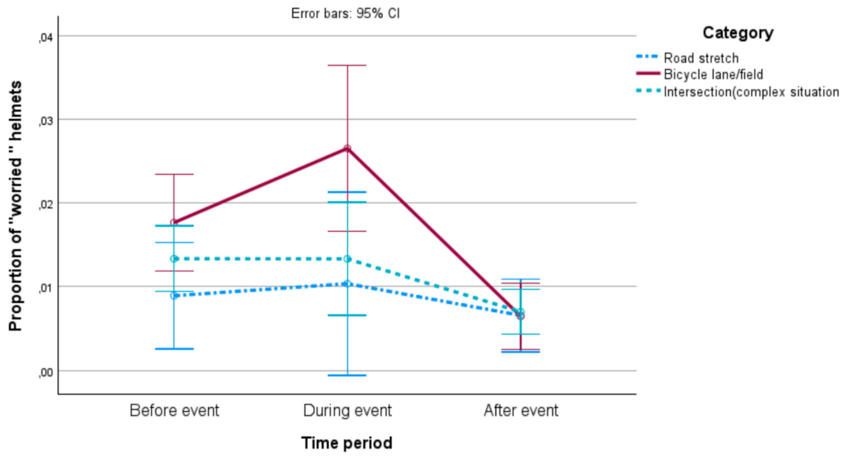

Fig. 5. Interaction between "worried" head protections and the time period and location of the event. the error bars indicate 95 percent confidence intervals.

and the 15 cyclists who sought hospital care) could have been registered in STRADA if they had visited an emergency hospital. If they, on the other hand, visited primary healthcare, they would not be included in any accident statistics. The 85 cyclists with grazes or small wounds are not included in the accident statistics either. This is the first attempt (to the authors knowledge) to establish the proportions of different degrees of bicycling crash severity, and the results should be interpreted with caution, especially as only one cyclist was hospitalized and the total sample of 182 events. According to the terminology used by Myhrmann et al. (2021): 1 cyclist was severely injured, 100 (15 + 85) were slightly injured and 81 had no injuries. Future studies will reveal if the obtained values are close to valid, similar to the original work on car crashes (Hydén, 1987; Svensson, 1998). Based on our findings, 0.5 percent of cyclists in an incident are hospitalized, 8 percent who experience an event will require primary care or emergency hospital services, 47 percent will be hurt but not require primary care, and 45 percent will not be physically injured at all when cyclist experience an event. The sample size of events and the consequences in terms of injuries are rather small and we should not overemphasis the relation between severe and less severe injuries. The data do, however, indicate a form of under reporting (Gildea et al., 2021; Rizzi et al., 2013; Shinar et al., 2018; Watson et al., 2015). Approximately 47 per cent was slightly injured and will not be registered in databases that rely on police reported or emergency hospitals reported events.

4.2. Crash predictions

The second aim was to predict when bicycle crashes will occur. The results revealed that increased bicycling speed (compared to the cyclists' normal speed) is associated with the occurrence of an unwanted event but only on road stretches, but above all, the reduction of speed (compensation for ice/slippery roads?) for trips that resulted in an event at intersections/in complex situations, was not compensatory enough. A reduction to slower than normal bicycling speeds still resulted in an unwanted event. The interpretation of the interaction between time period and location type (event context) is difficult. The likely interpretation is that something has already occurred (at least 200 m before the location of the event) that caused the cyclist to reduce their speed in relation to their own normal speed for the same familiar stretch. The cyclist had reduced their speed, but this reduction was not enough to avoid an unwanted event, especially events that occur in complex situations/intersections. This suggests that cyclists have an understanding about the situation but overestimate their abilities at intersections and in complex situations. Indeed, self-estimated ability is related to risky behavior (cf. Anderséns et al., 2024; McIlroy, et al., 2022). It is assumed that cyclists who experience an event and hurt themselves understand that the head protection has benefited them, i.e., the outcome could have been much worse. In studies investigating why bicycle crashes occur, Peterson, et al., (1995) suggested that it is the cyclist's own insight about how vulnerable they are that is important. They found no effects of either age or gender with regard to risky behavior; rather, it was the individual's perception of how vulnerable they were as a cyclist that made the difference. In a self-report study, McIlroy, et al., (2022) showed that cyclists' self-reported bicycling behavior was not related to self-reported crash involvement. Awareness of vulnerability and self-estimated ability are not the same thing, and it seems that the awareness of vulnerability provides a better explanation for why bicycle crashes occur than how capable the cyclist believes they are.

4.3. Adaptation and learning effects

The results also revealed that the proportion of head protections in "worried" conditions was higher when a cyclist experienced an event on a bicycle lane/field. Furthermore, these results demonstrate that cyclists do not ride slower after an event but generally ride more smoothly. The explanation for these results may reflect a form of adaptation. The cyclist might also refrain from bicycling because they anticipate it will be a shaky, dangerous trip; that is, the cyclist cycles at their usual speed but avoids days, times or environments that will likely give a shaky ride. Regardless of the explanation, the cyclist exhibits adaptation over time. The unwanted event probably taught the cyclist something, but not to slow down enough on specific locations. The experience of having had an event seems to have had an effect in the present study. If this is an effect of perceived risk (Sanders, 2015) is however not possible to conclude on the basis of collected data. However, the findings for the analyses of degree of head protection activations are still interesting. The proportion of "worried" head protections decrease as an effect of experiencing an event. The cyclist seems to: (i) cycle more calmly, (ii) take routes that do not result in a worried head protection condition, or (iii) refrain from bicycling. The degree of activation of the head protection system predicts whether an event will occur (based on speed or head protection conditions measures) – particularly an event on a bicycle lane/field or intersection/complex situations. Different measures for different locations. This information could be used to communicate the increased likelihood for head protection deployment to the cyclist whilst they are riding, i.e., an ARAS.

4.4. E-bikers versus c-bikers

Conventional cycle riders experienced an unwanted event as often as an electrical cycle rider (and injured as often). We only know on a general level that 45 per cent of head protection cyclist use electrical bicycles. Women use this head protection more often. To many confounding variables exit for analysing bicycle type in a reliable and valid way in this study. Earlier studies (see Möller et al., 2024, for example) have revealed straightforward results, but the lack of a sufficient base-line for e-biker use in this sample, prevent valid conclusions in this study.

4.5. Study limitations and future work

This study has a number of limitations, and the results should be interpreted with caution. One limitation is that we, due to technical problems, only had data from the head protection as well as from the web survey from a very small number of cyclists (25 cyclist was participating in the survey and included in the 264 helmet data). A second limitation is that the studied group is specific and is not representative of all cyclists (commuters). This is confirmed by a survey carried out by the head protection company in which 300 head protection cyclists were included. It revealed that most of the head protection cyclists were women (approximately 70 percent) and approaching middle-age (35–55 years). Many lived in big cities, commuted to work and 45 percent used electric bicycles according to this survey. Sixty-eight percent of the web survey cyclists were women, suggesting that women have crashes as often as men. However, this could just as well be explained by an increased willingness to participate in studies. We do not have any data on violations or errors or positive behavior that could be related to crashes (c.f. Möller et al., 2024; Useche et al., 2022) that suggest a between group variance of interest, i.e., some bicyclists are more violation prone than others. The present work has revealed that within-participant behavior can predict crashes. Speculatively, it might be the case that it is the bicyclist that is not violation prone that end up in crashes when they violate.

5. Conclusions

The present study presents the proportions of severe injuries, light injuries, and no injuries for bicycle events. There was 1 severely injured cyclist for every 100 lightly injured cyclists. It is problematic to compare these results with those based on extracts from databases, see for example, Eriksson et al. (2022), where 20 percent of those injured were seriously injured, from 2014 to 2019. Our study suggests that cyclists' experience of an event has both objective (more smooth bicycling rides) and subjective consequences. It is unclear whether this insight is due to an understanding of vulnerability or calibrated ability. Finally, it was found that unwanted events could be predicted by the activations captured by the head protection during bicycling; this information could be used to inform the cyclist i.e., develop an ARAS that inform or warn the bicyclist.

CRediT authorship contribution statement

Jan Andersson: Writing – original draft, Visualization, Validation, Resources, Project administration, Methodology, Investigation, Funding acquisition, Formal analysis, Conceptualization. **Henriette Wallén Warner:** Writing – original draft. **Per Henriksson:** Writing – review & editing, Methodology, Data curation. **Peter Andrén:** Writing – original draft, Visualization, Data curation. **Christina Stave:** Writing – review & editing, Investigation, Conceptualization.

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.

Data availability

Data will be made available on request.

Acknowledgement

First of all, we would like to thank all participants. Second, we would like to thank the head protection company sharing their data without any financial or whatsoever restrictions.

The project was funded by The Foundation Länsförsäkringsgruppen's Research and Development Fund.

Ethical approval was given by EPN (Dnr 2020-05019).

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