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Characteristics of cyclist collisions in Ireland: Analysis of a self-reported survey

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ABSTRACT

As both a utility mode of transport and recreational activity, cycling has well-known health, environmental, and economic benefits. For these reasons it has been encouraged in many countries, including the Republic of Ireland. However, with increasing popularity there have been concurrent increases in road traffic related cyclist injuries. This study aims to characterise cyclist collisions, which are known to be underreported in Police statistics.

For data collection, a survey addressing collisions was distributed to cyclists across the country in 2018. Univariable testing was used to identify differences in collision factors and injury outcomes for cyclist collisions with motorised vehicles, and those where a motorised vehicle is not involved as a collision partner i.e. single cyclist, cyclist-pedestrian, or cyclist-cyclist collisions. Furthermore, binary logistic regression modelling was used to clarify biasing factors for Police reporting of collisions.

The largest proportion of collisions was between cyclists and motorised vehicles (56%), followed by single cyclist collisions (29%), collisions with other cyclists (8%), and pedestrians (7%). The odds of Police reporting for collisions with motorised vehicles in this study was 20 times greater than single cyclist collisions, 10 times greater than cyclist-cyclist collisions, and 4 times greater than collisions with pedestrians. The odds of Police reporting of serious injury collisions was 7 times greater than minor injury collisions. There were several differences in road, environmental, and human factors, and injury patterns between cyclist-motorised vehicle collisions and non-motorised vehicle collisions.

The findings of this study indicate that greater attention should be paid to the following underreported collision types: 1) those that do not involve collisions with motorised vehicles (single cyclist collisions in particular), which have been shown to have differing collision characteristics to motorised vehicle collisions, and 2) less severe injuries, which have been shown to be a substantial contributor to the cyclist safety problem. Furthermore, surveys have been shown to be a valuable mechanism for investigation of lower severity cyclist injuries, which are largely unrecorded in Police or hospital data.

1. Introduction

1.1. Popularity of cycling in the Republic of Ireland

Due to its numerous health, environmental, and economic benefits (Dutch Cycling Embassy, 2018), cycling has been encouraged throughout Europe (Department of Transport, 2009; European Commission, 1999). Historically, pre-1960s Dublin (the capital city of the Republic of Ireland) was anecdotally described as having the 3rd highest bicycle usage of European cities, after Amsterdam and Copenhagen (Hanna, 2015). More recently it was estimated via survey that 12% of Europeans cycle every day, with substantial variability between countries; from 1% in Malta to 43% in the Netherlands (European Commission, 2013). In the Republic of Ireland (hereinafter Ireland) only 5% of respondents stated that they cycle every day, ranking 22nd overall (ibid.). As a mode of transport to/from work, school, or college, the Irish government had set a targeted increase in modal share from less than 2% in 2009 to 10% by 2020 (Department of Transport, 2009). The popularity of cycling has increased in recent years, though it is not likely that the target has been reached, as there had been only a modest increase up to 3% in 2016 (Central Statistics Office, 2016).

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1.2. Irish road safety trends

A key factor affecting the uptake of cycling is safety; perceived risks have been shown to deter the uptake of cycling in Dublin (Lawson et al., 2013). Moreover, with increased uptake there is also the increased responsibility on road safety stakeholders to ensure a safe cycling environment. The European Cyclists' Federation aims to both double cycling popularity across the EU, and halve the rates of cyclist fatalities and serious injuries by 2030 (European Cyclists' Federation, 2017). Road safety in Ireland has been improving, and in 2011 Ireland was awarded the 'Road Safety PIN Award' by the European Transport Safety Council for sustained successful strategies in reducing road deaths (European Transport Safety Council, 2011). The year 2018 was an all-time low for road traffic fatalities in Ireland (Road Safety Authority, 2018a), leading to Ireland again being awarded the PIN award and ranked the 2nd safest country in the EU, with 30 fatalities per million population (European Transport Safety Council, 2019). However, the modal share of cyclist injuries has been increasing substantially in Irish Police reported collision data: between 2005 and 2015, their share of all minor injuries increased from 3% to 11%, and their share of all serious injuries increased from 2% to 19% (Road Safety Authority, 2018b, 2007).

1.3. Cyclist safety analysis and underreporting

Evidently, increased efforts should be made to reduce the occurrence of injuries to cyclists. In Ireland, much of the analysis performed on Police reported data has focused on frequencies of cyclist collisions for various collision factors (e.g. environmental, road, human, and vehicle factors) (Road Safety Authority, 2020, 2014, 2010). One study has taken a multivariable statistical approach, highlighting relationships between collision factors (e.g. speed limits, cyclist age, and lighting conditions) and injury severity (Short and Caulfield, 2014). However, although Police data is the most complete source for road traffic collision data in Ireland, limited detail is available for analysis (e.g. information on injuries to individual body regions, collision configuration, helmet and bicycle light use are not available to researchers). Furthermore, it is well documented that cycling collisions are underreported in Police data both internationally (Department for Transport, 2017; International Transport Forum, 2013; Madsen et al., 2018; Rizzi et al., 2013; Shinar et al., 2018; Watson et al., 2015) and in Ireland (Bedford et al., 2011; Foley et al., 2016; Short and Caulfield, 2014). Less severe cyclist collisions have lower odds of being reported to the Police (de Geus et al., 2012; International Transport Forum, 2013; Salifu and Ackaah, 2012; Shinar et al., 2018). Since injurious collisions are much more frequent than fatal ones, their underrepresentation is a significant shortcoming in the assessment of the national burden of cycling injuries. The effects of less severe collisions are also non-trivial, for example, Hours et al. (2013) found that close to half of those who experience a minor injury in a road traffic collision (MAIS1 or MAIS2) still experience regular pain after a year. Due to their non-inclusion in Police or hospital statistics, non-injurious collisions are not commonly investigated, however, recent studies have demonstrated how near misses have negative effects on perceived safety and cycling participation (Aldred and Crosweller, 2015; Sanders, 2015), which in turn may have adverse effects on cyclist safety via the 'safety in numbers' effect (Elvik and Bjørnskau, 2017).

It is known that the vast majority of cyclist collisions in Irish Police statistics are with motorised vehicles, and fewer than 10% are single cyclist collisions (Road Safety Authority, 2020, 2014). However, internationally it is known that collisions where a motorised vehicle is not involved as a collision partner i.e. single cyclist, cyclist-pedestrian or cyclist-cyclist collisions have lower odds of being reported to the Police (International Transport Forum, 2013; Rizzi et al., 2013; Shinar et al., 2018). The biased nature of cyclist collision reporting has clear implications for policy makers and road safety researchers, who generally rely on Police data to determine road safety priorities.

1.4. Self-reported collision data

A major challenge with understanding the overall burden of cycling collisions in Ireland and internationally therefore relates to a substantial proportion of missing data. One approach used to address this is to combine existing injury datasets, for example, collisions in hospital and Police data are systematically linked in Sweden. However, since all existing datasets lack completeness, a common approach has been to use self-reported surveys to gain a greater understanding of cycling collisions not present in Police, hospital, or insurance data (e.g. Madsen et al. (2018), and Shinar et al. (2018)). Madsen et al. (2018) found that roughly ¾ of self-reported collisions in their study were not reported to the Police nor an insurance institution by the cyclist, and did not result in a hospital/GP visit; indicating their low likelihood of appearing in Police, insurance, or hospital statistics. The self-reported nature of these surveys has challenges, but they are a valuable mechanism for assessment of otherwise unobserved cases and unrecorded information. They have identified rates and biasing factors for underreporting (Shinar et al., 2018), established collision factors for various cyclist cohorts (e.g. age groups, bicycle types), as well as categorised general collision mechanisms for underreported collision types (e.g. infrastructural design, slipping, lane departure, loss of balance, and risky behaviour) (Boele-Vos et al., 2017; Engbers et al., 2018; Heesch et al., 2011; Hertach et al., 2018; Schepers and Wolt, 2012; Tyréns, 2013; Useche et al., 2019).

1.5. Study aims

There is a large body of international research into the factors that contribute to both the occurrence and severity of cyclist collisions, and their associated prevention strategies (e.g. Simms and Wood (2009), and Elvik et al. (2009)), however, given the large disparity in cycling rates and cycling environments between countries it is unclear how applicable international findings are to the Irish context. Accordingly, the overall aim of this study is to use an online survey to investigate cyclist collisions in Ireland, and inform future prevention priorities. Specifically, in this study we: 1) investigate the factors biasing the reporting of cyclist collisions, informing further investigation into collision types that are least represented in Police statistics, and 2) compare collision characteristics and injury outcomes for motorised vehicle collisions and non-motorised vehicle collisions (which have lower odds of being reported to the Police).

2. Methods

2.1. Survey design and dissemination

The online survey was designed following an extensive literature review, a focus group session, and survey trialling to collect collision information from a target population of adult cyclists (>18) in Ireland who had been involved in a collision(s) in the past five years (as per Hollingworth et al. (2015), and Useche et al. (2019)). The survey seeks collision details under the headings of road factors, environmental factors, and human factors, as well as outcome details such as Police reporting, injury severity, and hospital attendance. Behavioural and attitudinal information was collected for cyclists who had not been involved in a collision, where cyclists were defined as people who had cycled on a public road in the previous 12 months. However, this paper only contains information relating to the collisions. Behavioural and attitudinal information was only sought for those not involved in collisions to limit each individual's response time (and hence increase response numbers). Injury severities were coded as ‘minor’ or ‘serious’ according to the definitions used in Police statistics in Ireland and the UK (see Table A1).

A flowchart of the survey showing a bifurcation section, a collisions pipeline, and a behaviours & attitudes pipeline is shown in Fig. A1. Respondents were directed to the collisions pipeline if they had a collision since the 1st of January 2013. Cyclists were directed to enter their most recent collisions. A link to the full survey questionnaire is available here: https://kevgildea.github.io/.

The survey was open March 24th - August 2nd, 2018. Dissemination was via mailing lists of several cycling organisations, employers, and universities, and was also circulated through social media. In an effort to reduce sampling bias, the study was advertised simply as a cyclist safety survey. Ethical approval for the survey and focus group were provided by the Trinity College Dublin Faculty of Health Sciences Ethics Committee.

2.2. Data cleaning

Three techniques were applied to identify invalid responses as either ‘inconsistent’, ‘wrong turns’, or ‘substantially incomplete’, similar to methods used in Hertach et al. (2018). Within the survey are groups of two or more questions with mutually exclusive answers, which should be answered in a certain pattern. Cases deviating from these expected patterns were excluded (e.g. the respondent selects that the collision occurred both on the ‘Weekend’ and on ‘Wednesday’). Since the survey uses piping, and directs respondents based on their responses to certain questions, some respondents made errors and were sent to an inappropriate page. These erroneous responses were excluded. Responses may be considered ‘substantially incomplete’ if the respondent did not engage with the survey sufficiently, as these respondents may leave many questions unanswered. Such responses were excluded from the survey. Respondents were also excluded if they were under 18 years old or if their collision had occurred outside of the Republic of Ireland. For further details see Fig. A1. Collisions were also examined for miscoded collision types (according to the definitions in Table A1).

2.3. Statistical analysis

All statistical analyses were carried out using IBM SPSS 26.0. Significance was taken at a level of $p < 0.05$. Respondents had the option of entering multiple collision events. Accordingly, we included only the primary collision when performing statistical tests (i.e. Chi-square tests, Fisher’s tests, T-tests, and logistic regression modelling) so as not to violate the assumption of independence of observations. A total of 78 collisions which were respondent’s 2nd, 3rd, or 4th collisions were excluded from these tests.

2.3.1. Univariable analysis

For categorical variables, Chi-square testing was used to identify significant differences between two groups: 1) motorised vehicle collisions versus non-motorised vehicle collisions, and 2) injury patterns for the different collision types. Fisher’s exact test was applied in cases where more than 20% of cells had expected frequencies < 5. For the continuous variable age, an independent-samples *t*-test was used to compare the means between the groups.

2.3.2. Multivariable analysis

Binary logistic regression modelling was used to establish the effects of various collision details on whether a collision was reported to the Police:

$$p = P(Y = 1 | X = x_1, \ldots, X_i = x_i) = \frac{e^{\beta_0 + \beta_1 x_1 \ldots + \beta_i x_i}}{1 + e^{\beta_0 + \beta_1 x_1 \ldots + \beta_i x_i}}, \quad (1)$$

where the dependent variable Y takes two values (1, 0), β_i are the coefficients estimated using the method of maximum likelihood and x_i are the predictor variables. This can be rearranged as:

$$OR = \frac{p}{1 - p} = e^{\beta_0 + \beta_1 x_1 \ldots + \beta_i x_i}, \quad (2)$$

where *OR* is the odds ratio used to estimate the change in outcome per unit increase in the corresponding predictor variable, while keeping remaining variables fixed.

Many questionnaire studies handle missing data by performing listwise deletion: simply using cases with fully populated responses and discarding cases with missing values. However, the distribution of missing values may not be random. Rubin (1976) describes three types of missing data: missing completely at random (MCAR), missing at random (MAR), and missing not at random (MNAR). Since we do not have access to unobserved data, neither MAR nor MNAR can be tested, however MCAR can be tested using Little’s multivariate test (Little and Schenker, 1995). We applied a method called multiple imputation, which fills missing data with plausible values (Rubin, 1987). This method is commonly used in analysis of data which has a degree of missingness as it has been shown to yield more accurate results than listwise deletion for MNAR and MAR data, and improvements in statistical power for MCAR data (Lall, 2016).

2.4. Data descriptions and summary of methodological approach

There were 3,904 respondents to the survey. A total of 860 fully completed collisions were available for analysis, along with a further 562 partially completed collision cases where the respondent exited the survey prior to completion (giving a total of 1,422 collision cases) (see Fig. A1). In section 3.1, collision characteristics of collisions with motorised vehicles vs. collisions not with motorised vehicles are compared. In section 3.2, injury outcomes are compared between collision types (for the 564 collisions involving injuries). In section 3.3, Police reporting biasing factors were investigated for all collision cases, and Police reporting/hospital attendance were further investigated for injurious cases (Fig. 1).

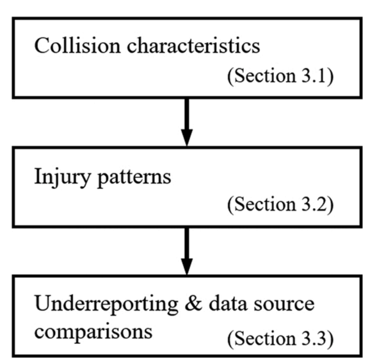

Fig. 1. The methodological approach used in this study.

3. Results

3.1. Collision characteristics

Of the 1,030 collisions for which the collision partner was specified, the largest proportion of collisions was between cyclists and motorised vehicles (MVC) (55.9%), followed by single cyclist collisions (SCC) (29.0%), collisions with other cyclists (CCC) (7.9%) and pedestrians (CPC) (7.2%). Tables 1–3 show the distributions of the various characteristics in two groups: 1) cyclist collisions with motorised vehicles and 2) cyclist collisions with anything other than a motorised vehicle (i.e. single cyclist collisions, collisions with pedestrians, or with other cyclists).

Comparisons of road factors are shown in Table 1. Chi-square statistics were used for inter-group comparisons, and odds ratios were calculated. The speed limits on roads differ between collision groups:

Table 1
Road factors for collisions with and without the involvement of motorised vehicles.

	Motorised vehicle collisions		Non-motorised vehicle collisions		Overall	
	No.	%	No.	%	No.	%
Speed limit (km/h)* **						
30	126	26.8%	93	28.4%	219	27.4%
50	281	59.8%	166	50.6%	447	56.0%
60	34	7.2%	12	3.7%	46	5.8%
80	25	5.3%	43	13.1%	68	8.5%
100	4	0.9%	14	4.3%	18	2.3%
Total	470	100.0%	328	100.0%	798	100.0%
Cycling facility **						
Segregated lane	5	0.9%	8	1.9%	13	1.3%
Dedicated on road lane	151	27.4%	90	21.4%	241	24.8%
Combined cycle/bus lane	78	14.2%	42	10.0%	120	12.3%
Contraflow lane	7	1.3%	0	0.0%	7	0.7%
No facility	310	56.3%	281	66.7%	591	60.8%
Total	551	100.0%	421	100.0%	972	100.0%
Using cycling facility[a]						
Yes	221	92.1%	129	92.1%	350	92.1%
No	19	7.9%	11	7.9%	30	7.9%
Total	240	100.0%	140	100.0%	380	100.0%
Road curve* **						
Straight	516	89.9%	338	75.4%	854	83.6%
Bending	54	9.4%	86	19.2%	140	13.7%
Sharp Bends	4	0.7%	24	5.4%	28	2.7%
Total	574	100.0%	448	100.0%	1022	100.0%
Road incline*						
Flat	506	88.2%	373	83.3%	879	86.0%
Uphill	27	4.7%	18	4.0%	45	4.4%
Downhill	37	6.4%	53	11.8%	90	8.8%
Hillcrest	4	0.7%	4	0.9%	8	0.8%
Total	574	100.0%	448	100.0%	1022	100.0%
Junction type* **						
T Junction	112	19.5%	44	9.8%	156	15.3%
Y Junction	19	3.3%	16	3.6%	35	3.4%
Other Junction	82	14.3%	36	8.0%	118	11.5%
Roundabout	34	5.9%	11	2.5%	45	4.4%
Entrance	42	7.3%	16	3.6%	58	5.7%
Not at Junction	285	49.7%	325	72.5%	610	59.7%
Total	574	100.0%	448	100.0%	1022	100.0%
Road type* **						
Cyclist-Pedestrian Area	11	2.0%	42	9.5%	53	5.3%
Dual Carriageway	24	4.3%	7	1.6%	31	3.1%
Footpath/Pedestrianised	0	0.0%	5	1.1%	5	0.5%
Greenway	0	0.0%	3	0.7%	3	0.3%
Housing Estate	11	2.0%	7	1.6%	18	1.8%
One-way	61	10.8%	84	19.0%	145	14.4%
Private road	0	0.0%	4	0.9%	4	0.4%
Two-way	456	81.0%	290	65.6%	746	74.2%
Total	563	100.0%	442	100.0%	1005	100.0%

a: for collisions where there was cycling infrastructure available to be used, *significant at the 5% level, **significant at the 1% level ***significant at the 0.1% level

Table 2
Environmental factors for collisions with and without the involvement of motorised vehicles.

	Motorised vehicle collisions		Non-motorised vehicle collisions		Overall	
	No.	%	No.	%	No.	%
Day* **						
Weekday	483	84.9%	321	72.1%	804	79.3%
Weekend	86	15.1%	124	27.9%	210	20.7%
Total	569	100.0%	445	100.0%	1014	100.0%
Time						
00:00-06:00	11	1.9%	11	2.5%	22	2.2%
06:00-12:00	277	48.5%	215	48.9%	492	48.7%
12:00-18:00	190	33.3%	138	31.4%	328	32.4%
18:00-00:00	93	16.3%	76	17.3%	169	16.7%
Total	571	100.0%	440	100.0%	1011	100.0%
Urban/rural (opinion) * **						
Urban	527	93.1%	359	80.5%	886	87.5%
Rural	39	6.9%	87	19.5%	126	12.5%
Total	566	100.0%	446	100.0%	1012	100.0%
Traffic conditions* **						
No Traffic	29	5.1%	70	15.7%	99	9.7%
Light Traffic	150	26.3%	185	41.4%	335	32.9%
Moderate Traffic	221	38.7%	120	26.8%	341	33.5%
Heavy Traffic	171	29.9%	72	16.1%	243	23.9%
Total	571	100.0%	447	100.0%	1018	100.0%
Weather conditions* **						
Dry	486	86.0%	307	70.9%	793	79.5%
Wet	71	12.6%	88	20.3%	159	15.9%
Windy	0	0.0%	5	1.2%	5	0.5%
Foggy	0	0.0%	2	0.5%	2	0.2%
Snowy/Icy	2	0.4%	20	4.6%	22	2.2%
Multiple	6	1.1%	11	2.5%	17	1.7%
Total	565	100.0%	433	100.0%	998	100.0%
Road conditions* **						
Dry	485	84.9%	281	63.1%	766	75.4%
Wet	81	14.2%	112	25.2%	193	19.0%
Frost/Ice	3	0.5%	22	4.9%	25	2.5%
Gravel	1	0.2%	8	1.8%	9	0.9%
Oil	0	0.0%	9	2.0%	9	0.9%
Other	0	0.0%	6	1.3%	6	0.6%
Multiple	1	0.2%	7	1.6%	8	0.8%
Total	571	100.0%	445	100.0%	1016	100.0%
Light conditions* **						
Dark, no street lighting	0	0.0%	3	0.7%	3	0.3%
Dark, poorly-lit	3	0.5%	20	4.5%	23	2.3%
Dark, well-lit	55	9.6%	41	9.2%	96	9.4%
Dusk	38	6.7%	10	2.2%	48	4.7%
Daylight, poor visibility	16	2.8%	19	4.3%	35	3.4%
Daylight, good visibility	455	79.7%	353	79.1%	808	79.4%
Daylight, low sun	4	0.7%	0	0.0%	4	0.4%
Total	571	100.0%	446	100.0%	1017	100.0%

*significant at the 5% level, **significant at the 1% level ***significant at the 0.1% level

collisions in environments with speed limits of 60 km/h or less had higher odds of being with motorised vehicles (OR 3.3, 95% CI:2.0–5.3). Collisions on roads without cycling facilities had lower odds of being with motorised vehicles (OR 0.6, 95% CI:0.5–0.8), however, for those who stated they were using the cycling facility (if available) there was no significant difference between groups (OR 1.3, 95% CI:0.6–2.9). Collisions on bending roads had lower odds of being with motorised vehicles (OR 0.3, 95% CI:0.2–0.5), similarly for collisions on roads with downhill gradients (OR 0.5, 95% CI:0.3–0.9). Collisions at junctions had higher odds of being with motorised vehicles (OR 2.7, 95% CI:2.0–3.5).

Comparisons of environmental factors are shown in Table 2. Chi-square statistics were used for inter-group comparisons, and odds ratios were calculated. Collisions on weekdays had higher odds of being with motorised vehicles (OR 2.3, 95% CI:1.7–3.1), as were collisions in environments flagged as urban by the respondent (OR 3.3, 95% CI:2.2–5.0). Collisions in no/light traffic had lower odds of being with motorised vehicles (OR 0.3, 95% CI:0.3–0.4), as were collisions in inclement weather (OR 0.4, 95% CI:0.3–0.6), or on hazardous road surfaces (i.e. not dry) (OR 0.3, 95% CI:0.2–0.4).

Comparisons of human factors are shown in Table 3. For categorical variables, Chi-square statistics and Fisher's exact test (where applicable) were used for inter-group comparisons, and odds ratios were calculated.

Table 3
Human factors for collisions with and without the involvement of motorised vehicles.

	Motorised vehicle collisions		Non-motorised vehicle collisions		Overall	
	Median	IQR [a]	Median	IQR [a]	Median	IQR [a]
Age (years)	37	26-45	38	26.75-46	37	26-46
	No.	%	No.	%	No.	%
Sex*						
Female	147	27.3%	138	33.3%	285	29.9%
Male	392	72.7%	276	66.7%	668	70.1%
Total	539	100.0%	414	100.0%	953	100.0%
Familiarity with the location* **						
Not Familiar	7	1.2%	43	9.6%	50	4.9%
Familiar	566	98.8%	405	90.4%	971	95.1%
Total	573	100.0%	448	100.0%	1021	100.0%
Helmet use						
No	107	18.8%	91	20.2%	198	19.4%
Yes	463	81.2%	360	79.8%	823	80.6%
Total	570	100.0%	451	100.0%	1021	100.0%
High-vis apparel use [b]						
No	17	17.7%	16	21.9%	33	19.5%
Yes	79	82.3%	57	78.1%	136	80.5%
Total	96	100.0%	73	100.0%	169	100.0%
Bicycle light use [b]						
Front and Rear	89	92.7%	70	94.6%	159	93.5%
Rear	3	3.1%	2	2.7%	5	2.9%
Front	1	1.0%	2	2.7%	3	1.8%
None	3	3.1%	0	0.0%	3	1.8%
Total	96	100.0%	74	100.0%	170	100.0%
Alcohol use						
No	567	99.0%	441	98.2%	1008	98.6%
Yes	6	1.0%	8	1.8%	14	1.4%
Total	573	100.0%	449	100.0%	1022	100.0%
Mobile Phone use						
No	567	99.1%	448	99.3%	1015	99.2%
Yes	5	0.9%	3	0.7%	8	0.8%
Total	572	100.0%	451	100.0%	1023	100.0%
Earphones use***						
No	518	90.6%	425	94.2%	943	92.2%
Yes	54	9.4%	26	5.8%	80	7.8%
Total	572	100.0%	451	100.0%	1023	100.0%
Trip purpose***						
Commuting/Utility/Work	448	78.0%	289	64.2%	737	72.0%
Leisure/Training/Racing	126	22.0%	161	35.8%	287	28.0%
Total	574	100.0%	450	100.0%	1024	100.0%
Bicycle type*						
Road bicycle	362	63.1%	313	69.2%	675	65.8%
Hybrid bicycle	172	30.0%	111	24.6%	283	27.6%
Mountain bicycle	40	7.0%	28	6.2%	68	6.6%
Total	574	100.0%	452	100.0%	1026	100.0%
Cyclist speed (km/h)***						
0	13	2.3%	2	0.5%	15	1.5%
0-10	148	26.0%	118	26.6%	266	26.3%
10-20	250	43.9%	145	32.7%	395	39.0%
20-30	129	22.6%	126	28.4%	255	25.2%
30-40	24	4.2%	40	9.0%	64	6.3%
40-50	6	1.1%	8	1.8%	14	1.4%
50+	0	0.0%	4	0.9%	4	0.4%
Total	570	100.0%	443	100.0%	1013	100.0%

a: Interquartile range b: for collisions in dusk or dark conditions, *significant at the 5% level, **significant at the 1% level ***significant at the 0.1% level

For the continuous variable (age), an independent-samples *t*-test was performed. There was no significant difference in respondent age for collisions with motorised vehicles (M = 37, SD = 11.7) and collisions without motorised vehicles (M = 38, SD = 12.4), t (938) = -1.84, p = 0.07. Collisions involving male cyclists had slightly higher odds of being with motorised vehicles (OR 1.3, 95% CI:1.0–1.8). Collisions in unfamiliar locations had much lower odds of being with motorised vehicles (OR 0.1, 95% CI:0.1–0.3). There was no significant difference in use of helmets (OR 0.9, 95% CI:0.6–1.2), or high visibility equipment (OR 0.9, 95% CI:0.4–2.1) and bicycle lights (during dusk/dark conditions) (p = 0.28) between groups. Reporting of alcohol use or mobile phone use on the part of the cyclist was extremely low (<2%), and there were no significant differences between groups; p = 0.26, and p = 1.0, respectively. Cyclists reported earphone usage was also low (8%), however cyclists wearing earphones had higher odds of being in collisions with motorised vehicles (OR 1.6, 95% CI:1.0–2.7). Cyclists travelling for commuting/utility/work purposes had higher odds of being in collisions with motorised vehicles (OR 2.1, 95% CI:1.6–2.9), as were cyclists using hybrid/mountain bicycles (OR 1.3, 95% CI:1.0–1.7). Collisions involving cyclists travelling at speeds of 20 km/h and over had lower odds of being with motorised vehicles (OR 0.5, 95% CI:0.4–0.7).

3.2. Injury patterns

In Fig. 2, injury patterns and overall injury severities are presented for each collision type. For overall injury severities, 977 cases were available for analysis (i.e. Minor, Serious, or no injury), and for the analysis of injury patterns, 564 cases were available for analysis (i.e. injury occurrence for each body region). Chi-square statistics were used for inter-group comparisons, and odds ratios were calculated. Approximately 70% of respondents sustained injuries to the upper and lower limbs, 48% to the torso, 37% to the head and 14% to the neck. Injuries ranged from minor bruises and abrasions to fractures and severe internal injuries. Single cyclist collisions had the highest level of injury occurrence (73% involved injuries); compared to collisions with vehicles, the odds of injury occurrence for single cyclist collisions were almost 3 times greater (OR 2.8, 95% CI:2.0–3.9). Collisions with other cyclists also had high odds compared to collisions with vehicles (OR 1.8, 95% CI:1.1–3.1). Collisions with pedestrians had the lowest levels of both overall injury occurrence (46%) and serious injury occurrence (7%).

Injury patterns were generally similar across all collision types, though those involving pedestrians had lower injury levels for all body regions. Injuries to the upper and lower extremities dominate, with injuries to these regions in over 70% of cases (except for collisions with pedestrians). Single cyclist collisions and motorised vehicle collisions had similar levels of head injury.

3.3. Underreporting biases

Table 4 shows the results of a binary logistic regression with Police reporting as the dependent variable and age, sex, location (county Dublin/outside county Dublin), locus familiarity, setting (urban/rural), day (weekend/weekday), time of day, trip purpose, collision type and injury severity as independent variables (see Table A2). The Variance Inflation Factor (VIF) was found to be <10 for all variables, suggesting that the level of multicollinearity is not problematic. The continuous variable age was found to be linearly related to the logit of the dependent variable via the Box-Tidwell procedure, with p > 0.05. Information was missing for one or more variables for 565 cases (40%). The null hypothesis for Little's test (that the missing data is MCAR) was not rejected with p > 0.05, suggesting that multiple imputation will work well. Multiple (30) imputations were performed, as recommended by White et al. (2011). Only location, collision type, and injury severity were found to be significant, see Table A2. Since in this study we are concerned with effect estimation, both significant and insignificant variables were included in the final model i.e. inclusion of insignificant variables increases the likelihood that the confidence interval for the effect of interest has the stated coverage (Harrell, 2015). The model was statistically significant, $\chi^2(15) = 211.922$, $p < 0.0001$. The model explained 37.1% (Nagelkerke R^2) of the variance in Police reporting and correctly classified 87% of cases. The area under the Receiver Operating Characteristic (ROC) curve was 0.840 (95% CI: 0.803–0.876) (considered an excellent level of discrimination according to Hosmer et al. (2013)), with a corresponding Gini coefficient of 0.680 (95% CI: 0.606–0.752). Five outliers (0.4% of cases) were found, indicated by an absolute value of standardised residual greater than 2.5 in the regression output, with values ranging between 2.7 and 3.0. These cases were investigated and were retained as there was no obvious reason for

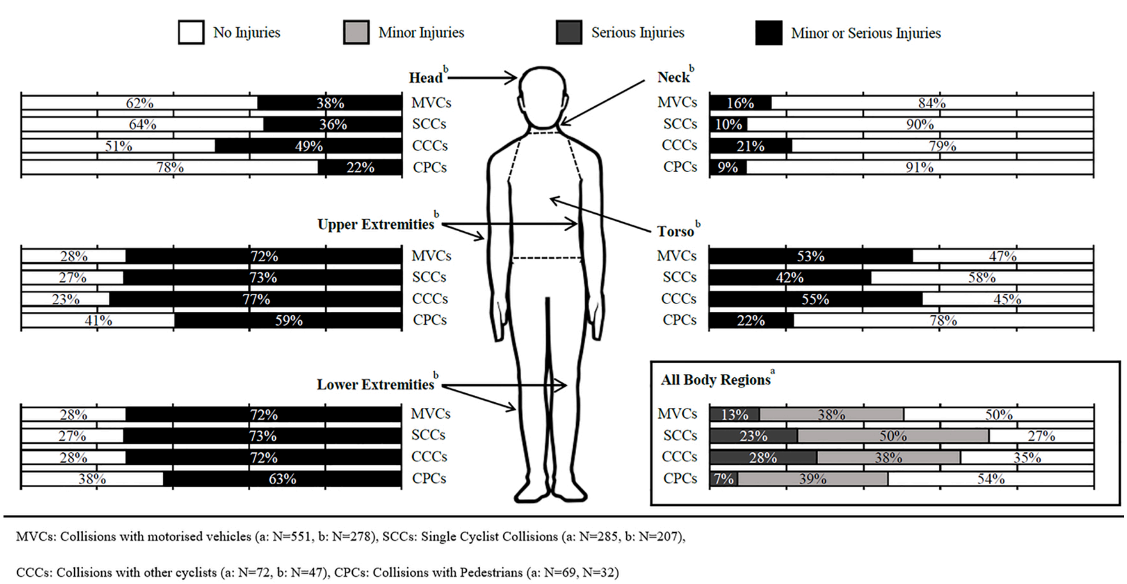

Fig. 2. Injury patterns for injured cyclists, overall and for each collision type.

Table 4
Underreporting of collisions to the Police.

	Reporting to the Police						Univariable Analysis		Multivariable Analysis	
	Not reported		Reported		Total					
	No.	%	No.	%	No.	%	OR	95% CI	OR[a]	95% CI
County										
Rest of Ireland	173	78.3%	48	21.7%	221	100.0%	1.665**	(1.134 – 2.444)	2.226**	(1.234 – 4.017)
County Dublin	679	85.9%	111	14.1%	790	100.0%	ref	ref	ref	ref
Total	852	84.3%	159	15.7%	1011	100.0%				
Collision type										
Cyclist-Motorised Vehicle (MVC)	434	75.7%	139	24.3%	573	100.0%	ref	ref	ref	ref
Single Cyclist (SCC)	280	96.2%	11	3.8%	291	100.0%	0.133***	(0.070 – 0.251)	0.050***	(0.024 – 0.105)
Cyclist-Cyclist (CCC)	74	92.5%	6	7.5%	80	100.0%	0.261***	(0.111 – 0.613)	0.102***	(0.036 – 0.292)
Cyclist-Pedestrian (CPC)	69	93.2%	5	6.8%	74	100.0%	0.241***	(0.095 – 0.611)	0.243**	(0.087 – 0.676)
Total	857	84.2%	161	15.8%	1018	100.0%				
Injury severity										
No Injury	379	92.7%	30	7.3%	409	100.0%	0.104***	(0.063 – 0.173)	0.041***	(0.022 - 0.076)
Minor	340	84.8%	61	15.2%	401	100.0%	0.410***	(0.253 – 0.662)	0.143***	(0.084 - 0.246)
Serious	93	58.5%	66	41.5%	159	100.0%	ref	ref	ref	ref
Total	812	83.8%	157	16.2%	969	100.0%				

a: multivariable odds ratios calculated by binary logistic regression, *significant at the 5% level, **significant at the 1% level ***significant at the 0.1% level

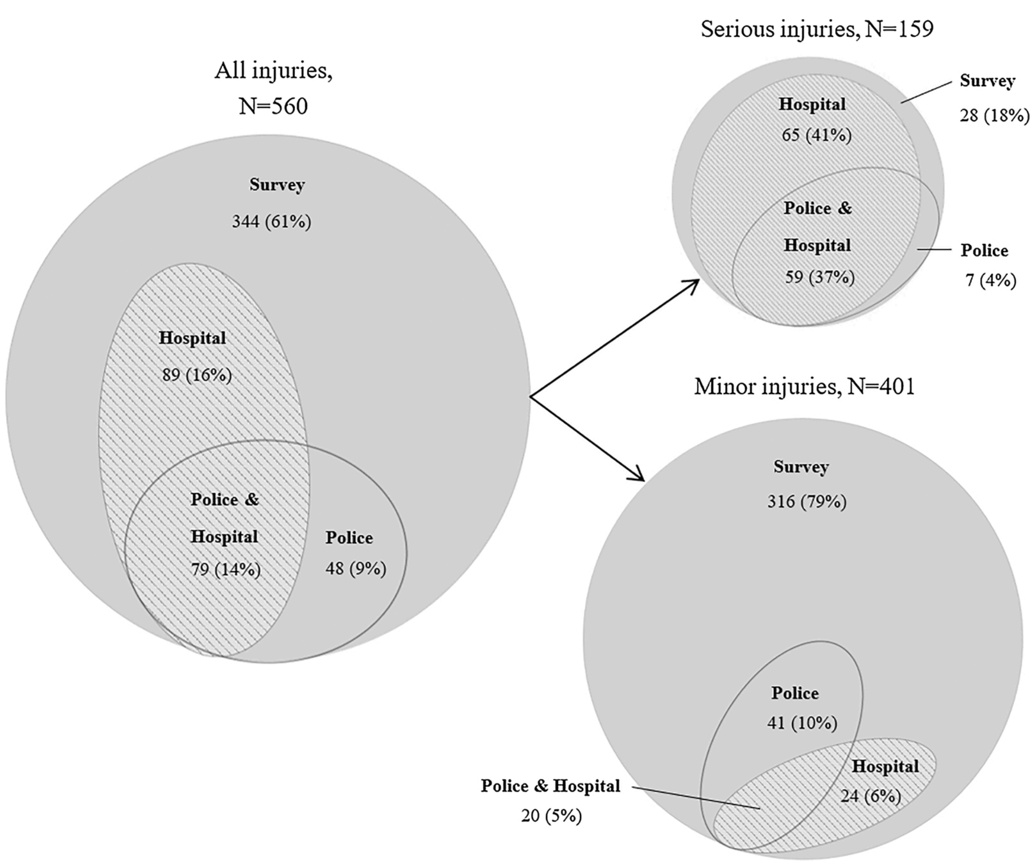

Fig. 3. Reporting of injurious collisions to the Police and hospital attendance, represented as a proportional area Euler Diagram (generated using the approach by Micallef and Rodgers (2014)).

removal, and their presence had low influence on the model, as indicated by Cook's distance values between 0.32 and 0.54, and Leverage values between 0.006 and 0.012.

The findings show that the odds of Police reporting for collisions outside of county Dublin was 2.2 times greater than those in county Dublin. The odds of Police reporting for collisions between cyclists and motorised vehicles were the highest; 20.0 times greater than single cyclist collisions, 9.8 times greater than cyclist-cyclist collisions, and 4.1 times greater than collisions with pedestrians. The odds of Police reporting for serious injury collisions were the highest; 7.0 times greater than minor injuries, and 24.4 times greater than non-injurious collisions.

A cross comparison of Police reporting and hospital attendance for collisions involving injuries is shown in Fig. 3. For 4 injurious collisions no indications of Police reporting, or hospital attendance were given (N = 560). Overall, only 23% were reported to the Police, and 30% resulted in a hospital attendance. Only 14% of collisions were both reported to the Police and resulted in a hospital attendance, and 61% were neither reported to the Police nor resulted in a hospital attendance. A large proportion of serious injuries (82%) resulted in either hospital attendance or Police reporting, compared to only 21% of minor injuries.

4. Discussion

This paper presents findings of the first self-reported survey of cycling collisions in Ireland. With details of over 1,000 cycling collisions, the results demonstrate this approach is effective at augmenting our understanding by providing detail for cases not seen in Police or hospital data.

4.1. Underreporting biases

These survey results provide further evidence that cycling collisions are substantially underreported: only 23% of collisions with injuries were coded as having been reported to the Police, and only 30% reported a hospital attendance. Bedford et al. (2011); Short and Caulfield (2014), and Foley et al. (2016) previously presented analyses of Police and hospital data, implying underreporting in an Irish context, and our findings provide further evidence through the addition of survey-based data. Using probabilistically matched Police and hospital data, Short and Caulfield (2014) estimated that there are roughly 6 times as many cyclist injuries than recorded in Police statistics (reporting rate of roughly 17%), which is slightly lower than our finding of 23%. By comparison, findings from an international survey on underreporting of cyclist's most severe collisions found reporting rates ranging between 0% (Israel) and 35% (Germany) (Shinar et al., 2018). The International Transport Forum recently recommended that cyclist injuries be monitored using a combination of Police, hospital and insurance data (International Transport Forum, 2018). In our survey, only 39% of collisions involving injuries were either reported to the Police or resulted in a hospital attendance (or both). Our results indicate that the combined monitoring of Police and hospital data may be effective for serious injury collisions (as suggested by Foley et al. (2020)), however this is not the case for minor injuries (see Fig. 3). Although inclusion in insurance data is unknown, these statistics highlight the important contribution surveys can make in assessing the burden of cyclist injuries.

Although collisions with motorised vehicles are the largest cohort in the survey, comprising just over half of the total, they are less dominant than commonly understood (Road Safety Authority, 2020, 2014), and the survey results emphasize instead the importance of non-motorised vehicle collisions in the Irish context. Shinar et al. (2018) found that the odds of Police reporting for motorised vehicle collisions is 15 times greater than for single cyclist collisions, compared to a factor of 20 in our findings. Shinar et al. (2018) also found injury severity to be the strongest predictor of cyclist collision reporting, and our results indicate similar, with 42% of serious injuries reported to the Police. Our findings also indicate that the odds of Police reporting for serious injury collisions are 7 times greater than minor injury collisions.

4.2. Comparisons of collision characteristics

A substantial proportion (56%) of the survey cases were motorised vehicle collisions, and other survey studies have found the proportion to be lower: 13% in a survey of cyclists in Queensland, Australia (Heesch et al., 2011), and 23% in an internationally distributed survey (Shinar et al., 2018). This implies the need for interventions to reduce their occurrence, such as traffic separation (segregated cycle lanes), improvements to junction designs, or reductions in speed limits (in areas of mixed traffic) (Elvik et al., 2009; International Transport Forum, 2013; Thompson et al., 2017), though further investigation is required to identify effective strategies for the Irish context. Our findings indicate that compared to motorised vehicle collisions, a larger proportion of non-motorised vehicle collisions occurred in rural environments with higher posted speed limits and lighter traffic conditions. They also have lower odds of occurring at junctions, and higher odds of occurring in unfamiliar locations, on roads with curves or downhill gradients, in inclement weather conditions, or on roads with hazardous surface conditions. A higher proportion of cyclists involved in non-motorised vehicle collisions were females, and occurred during leisure, training, racing trips as opposed to utility, commuting, or work trips. These collisions also occurred at higher cycling speeds than collisions with motorised vehicles. The resulting injuries are generally at a higher severity level for non-motorised vehicle collisions (with the exception of cyclist-pedestrian collisions), contrary to previous findings (Heesch et al., 2011; Shinar et al., 2018). For example, only 27% of single cyclist collisions involve no injury, and 23% involved a serious injury. This may be influenced by recall bias, whereby collisions resulting in injuries or involving other road users may be inherently more memorable, biasing the reporting of injurious single cyclist collisions to the survey. Nevertheless, it emphasizes the importance of single cyclist collisions and injuries due to ground contact in the overall cycling injury burden.

Due to differences in collision characteristics, prevention strategies for motorised vehicle collisions are not likely to be as effective for non-motorised vehicle collisions (single cyclist collisions in particular). Furthermore, decreases in cyclist-motorised vehicle collision risk has been shown to accompany increasing cyclist modal share, according to the so-called 'Safety in Numbers' effect (Elvik and Bjørnskau, 2017), however internationally it is known that risk for single cyclist collisions does not decrease in the same way (Schepers et al., 2015). Therefore, Irish policymakers should be aware that safety strategies are needed to address increasing numbers of single cyclist collisions that may accompany increasing modal share of cycling in Ireland. For example, 43% of people in the Netherlands cycle every day (compared to 5% in Ireland) (European Commission, 2013), and single cyclist collisions are a significant contributor to the road safety problem, comprising 74% of cyclist injuries and 41% of all road crash injuries (Schepers et al., 2015). In the Netherlands a large proportion of single cyclist collisions are related to infrastructure, by way of the cyclist colliding with road furniture, or skidding/loss of control due to a hazardous road surface (Schepers and Wolt, 2012). A large proportion are also caused by cyclist related factors, including loss of control at low speed, or risky riding behaviours (ibid.). Infrastructural improvements to the Irish road network, and a safe systems approach must be taken to address the causes of single cyclist collisions, however, further investigation is required to identify appropriate prevention strategies for the Irish context.

4.3. Descriptive comparisons to Irish Police statistics

In Police statistics 87% of injurious cyclist collisions occurred on urban roads with lower speed limits (less than or equal to 60 km/h) (Road Safety Authority, 2020). Similarly, in the survey results where speed limit was indicated/known, 83% were on roads with speed limits less than or equal to 60 km/h. The majority (78%) of collisions reported to the survey occurred in county Dublin, compared to 61% in Police statistics (ibid.), though our findings also indicate that collisions in county Dublin have lower odds of being reported to the Police. Situations where cyclists are required to cross paths with other transport modes are common sources of cyclist collisions: 40% of our survey collisions occurred at junctions, which is lower than the proportion in Police statistics (51%) (ibid.). This is likely a result of non-motorised vehicle collisions being underreported in Police statistics, supported by the fact that half of motorised vehicle collisions in the survey occurred at junctions. In Police statistics 74% of cyclists are male (ibid.), similar to respondents involved in collisions in the survey (70%). In Police statistics 79% of collisions occurred on weekdays (ibid.), equal to the survey results. However, in Police statistics 33% of collisions occurred between 06:00−12:00 (ibid.), compared to half in the survey results, and correspondingly fewer were between 12:00−00:00.

In Police statistics between 2014 and 2015, the ratio of serious to minor injuries was 1:5.9 (Road Safety Authority, 2018b, 2016), compared to 1:2.5 in our survey cases. This is counterintuitive in that our findings indicate that minor injuries have lower odds of being reported than serious injuries, which should result in a higher proportion of minor injuries for the survey cases. This may in part be a result of recall bias, whereby collisions involving serious injuries are inherently more memorable than those involving minor injuries. It is also known that injury severity according to the definitions used in this study (Table A1) is sometimes misclassified by Police in the UK (Department for Transport, 2012), resulting in some serious injuries being misclassified as minor.

4.4. Limitations

For this study there was no means of obtaining a fully representative sample of the population of cyclists in Ireland. The Irish census contains a module on the commuting travel preferences which can be used to compare to our survey results (Central Statistics Office, 2016), and the membership details of Cycling Ireland (the national body for sports cycling in Ireland) can be used as a proxy for leisure/racing cyclists. The proportions of survey respondents by county are similar to those for the commuting population of cyclists in Ireland (Fig. A2), though there are differences for the leisure/racing population, with a disproportionate number of survey respondents coming from Dublin. A smaller proportion of survey respondents were male (63%), when compared to both the commuting population in Ireland (73%), and the membership of Cycling Ireland (80%). Since no child cyclists (<18) were included in this study, collision factors that may be specific to younger cyclists are not available in our results. However, as detailed in 4.3, after accounting for underreporting biases, broad collision characteristics for cyclist collisions in the survey are similar to those seen in Police statistics.

Self-reporting has associated biases, one of which (recall bias) may have the effects of 1) underrepresenting the overall share of single cyclist collisions, 2) overrepresenting the proportion of injurious single cyclist collisions, and 3) increasing the overall severity of injuries in the survey results. For sensitive questions, social desirability bias may be a factor (Krumpal, 2013), which may contribute to the low reporting of mobile phone and alcohol usage in our findings. Furthermore, although helmets are not mandatory in Ireland, a high proportion of survey respondents reported wearing a helmet (81%), compared to 47% in Police statistics (Road Safety Authority, 2020). However, it is also possible that self-selection bias may be a factor, whereby cyclists who chose to take part in the survey may be more safety conscious than the general population of cyclists in Ireland. Since only cyclists were surveyed, the Police reporting rates for collisions involving a second road user (vehicle driver, pedestrian, or other cyclist) are likely underestimates.

Clearly these results do not include fatal cyclist collisions, and future work should include an analysis of fatalities as part of a more complete impression of cyclist safety priorities in the Irish context. It was not possible to code the injuries according to the Abbreviated Injury Scale, which is used to standardise injury outcomes, making international comparisons more difficult. The definitions used for minor and serious injuries in this paper are the same as those used in Ireland and the UK, though they differ by varying degrees to those used across the EU (European Commission, 2015).

5. Conclusions

Cyclists in Ireland are responsive to self-reported surveys relating to collision events, suggesting they are an engaged cohort for road safety. Due to difference in road environments, and cycling levels, safety priorities vary between countries. However, the findings of this study may have international relevance for countries with an increasing popularity of cycling starting from a relatively low base.

The results demonstrate that serious injury collisions may be well addressed by the combined monitoring of Police and hospital data, however, self-reporting is highlighted as an important data source for minor injuries. Just over half of cyclist collisions reported to the survey were with a motorised vehicle, and this proportion holds even for serious injuries. Single cyclist collisions accounted for roughly 3 out of 10 collisions, and only a small proportion of these were reported to the Police. This suggests that Police-based statistics on the burden of cyclist collisions in Ireland are biased towards those involving motorised vehicles, and policymakers should be aware of the considerable burden of single cyclist collisions. Less severe injuries have also been shown to be underreported, and to contribute to the safety problem to a far greater degree than observed in Police statistics. In efforts to inform prevention strategies, future work should focus on identifying the configurations of these underreported collision types.

CRediT authorship contribution statement

Kevin Gildea: Conceptualization, Data curation, Formal analysis, Investigation, Methodology, Resources, Validation, Visualization, Writing - original draft, Writing - review & editing. **Ciaran Simms:** Conceptualization, Funding acquisition, Methodology, Project administration, Resources, Writing - original draft, Writing - review & editing.

Declaration of Competing Interest

The authors report no declarations of interest.

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Appendix A

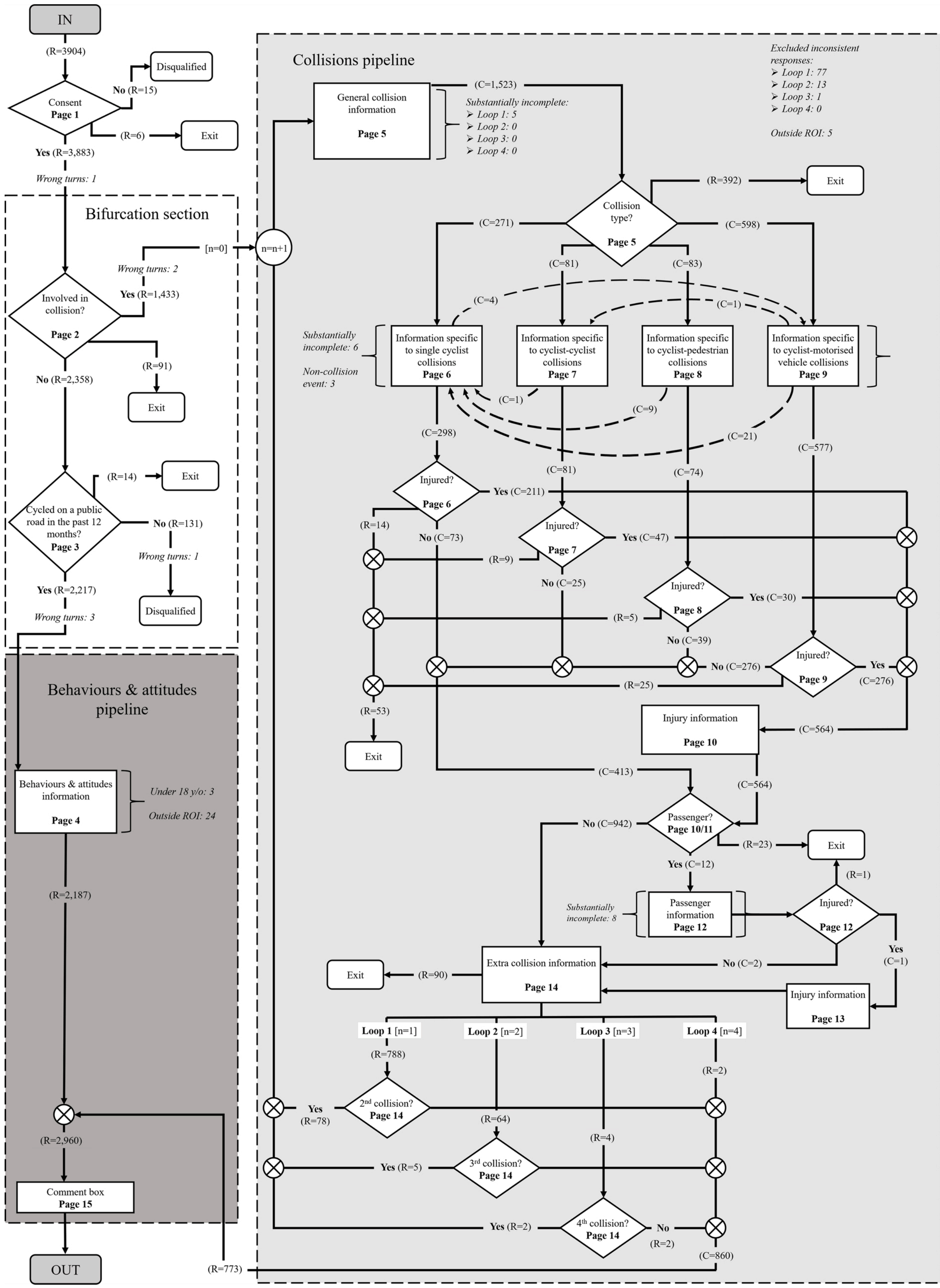

Fig. A1. Flowchart of the survey questionnaire including numbers of respondents entering, exiting, and excluded (R: Respondent, C: Collision).

Fig. A2. Survey respondent numbers by county (N = 2,509), compared to census data for commuting cyclists in the Republic of Ireland in 2016 (N = 82,123) (in parentheses: '()'), and Cycling Ireland's membership in 2017 (N = 21,470) (in square brackets: '[]').

Table A1
Nomenclature and definitions.

Nomenclature	Definition	Reference
Single Cyclist Collision (SCC)	Collisions where a cyclist falls or is injured in which no other road user/in-use vehicle is made contact with, either by the cyclist themselves or the bicycle e.g. collision with obstacle, skidding out on a wet road surface, collision with a kerb due to an avoidance manoeuvre etc.	
Cyclist – Motorised Vehicle Collision (MVC)	Collisions in which contact is made between a cyclist/bicycle and an in-use motorised vehicle	Similar to Schepers and Wolt, 2012 and Hertach et al., 2018
Cyclist – Cyclist Collision (CCC)	Collisions in which contact is made between a cyclist/bicycle and another cyclist/in-use bicycle.	
Cyclist – Pedestrian Collision (CPC)	Collisions in which contact is made between a cyclist/bicycle and a pedestrian.	
Unreported Collision	A collision which was neither reported by the cyclist to the Police at the scene nor subsequently.	NA
Minor Injury (Overall)	An injury of a minor character such as a sprain or bruise.	
Serious Injury (Overall)	An injury for which the person is detained in hospital as an 'in-patient', or any of the following injuries whether or not detained in hospital: fractures, concussion, internal injuries, crushing's, severe cuts and lacerations, severe general shock requiring medical treatment.	(European Commission, 2015)

Table A2
Pooled results of 30 imputations for the binary logistic regression on Police reporting.

Variables in the equation	β	S.E.	Sig.	Fraction Missing Info.	Relative Increase Variance	Relative Efficiency
Sex: (ref: Male)						
Female	-.245	.244	.314	.007	.007	1.000
Age	.016	.010	.104	.038	.039	.999
Locus familiarity: (ref: Familiar)						
Unfamiliar	-.445	.661	.501	.007	.007	1.000
Setting: (ref: Urban)						
Rural	-.630	.433	.146	.027	.027	.999
Day: (ref: Weekday)						
Weekend	.025	.333	.941	.031	.032	.999
Time: (ref: 18:00 to 24:00)						
00:00 to 06:00	.653	.659	.322	.009	.009	1.000
06:00 to 12:00	.013	.296	.964	.025	.026	.999
12:00 to 18:00	-.487	.322	.131	.020	.020	.999
Trip purpose: (ref: Leisure/Training/Racing)						
Commuting/Utility/Work trip	-.131	.335	.696	.022	.022	.999
Location: (ref: County Dublin)						
Rest of Ireland	.800	.301	.008	.046	.048	.998
Collision Type: (ref: MVC)						
Single Cyclist Collision (SCC)	−2.991	.375	.000	.005	.005	1.000
Cyclist – Cyclist Collision (CCC)	−2.281	.536	.000	.006	.006	1.000
Cyclist – Pedestrian Collision (CPC)	−1.416	.523	.007	.009	.009	1.000
Injury Severity: (ref: Serious injury)						
No injury	−3.194	.318	.000	.020	.021	.999
Minor injury	−1.942	.276	.000	.017	.017	.999
Constant	.544	.592	.358	.032	.032	.999

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