Using on-road study data to explore the sequence of behaviours and factors involved in cyclists' near collisions with other road users

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Abstract

Due to the frequency of near collisions with other road users, many Australian's perceive that cycling on the public road network is unsafe; this is a significant barrier to the uptake of cycling for transport (Fishman, Washington, & Haworth, 2012). Near collisions need to be better understood to identify appropriate countermeasures, improve cycling safety, and encourage cycling participation. The aim of this study was to investigate the sequence of behaviours and factors involved in cyclists' near collisions with other road users. Twenty cyclists rode a pre-defined urban route whilst providing concurrent think aloud verbal protocols and being filmed by a researcher travelling behind. Three researchers identified near collisions from the video footage, with a near collision defined as any conflict between moving road users or situation of very close proximity (Johnson et al., 2010). The data were then analysed to identify: 1) the type of conflict; and 2) the sequence of behaviours and contributory factors involved using a sequential model of crashes/near crashes (Guo et al., 2010) and an adapted version of Stanton and Salmon's (2009) taxonomy of driver error causal factors. The majority of near collisions occurred as cyclists approached or negotiated an intersection, as car drivers attempted to overtake the cyclist, and car drivers had to swerve or break to avoid a collision. All near collisions involved contributing factors relating to road layout; the majority also involved factors related to driver behaviour and the road rules. The implications for designing countermeasures to improve cycling safety are discussed.

Introduction

Despite the potential economic, health and environmental benefits of cycling for transport (Bauman et al., 2008; Fishman, Ker, Garrard, & Litman, 2011), cycling participation is steadily declining in Australia (Gillham & Rissel, 2012; Munro, 2013) and the proportion of workers who cycle to work is estimated at only 1% of journeys (Gillham & Rissel, 2012). While many factors are likely to influence the decision to cycle to work, fear of collisions with motorised traffic is consistently found to be a significant barrier to the uptake of cycling in Australia (Bauman et al., 2008; Fishman et al., 2012; Heesch, Sahlqvist, & Garrard, 2012). This is despite the finding that at least half of serious cyclist collisions in Australia occur off the public road network, and therefore do not involve motorised traffic (Haworth, Schramm, King, & Steinhardt, 2010; Henley & Harrison, 2009). As the perceived level of risk appears to far outweigh the actual risk, it has been argued that this fear is largely underpinned by *near collisions*, which are far more frequent than actual collisions (Fishman et al., 2012). Near collisions need to be better understood to identify appropriate countermeasures, improve cycling safety, and encourage cycling participation.

Little is known about the behaviours of cyclists and other road users leading up to near collisions or the factors influencing these interactions. There are a number of studies that have examined the risk factors associated with actual cyclist-driver collisions using postevent data such as hospital and police records (Bíl, Bílová, & Müller, 2010; Boufous, de Rome, Senserrick, & Ivers, 2012; Garrard, Greaves, & Ellison, 2010; Kim, Kim, Ulfarsson, & Porrello, 2007). These studies have identified a number of common factors including: vehicle speeds, speed limits, larger vehicles, poor cycling infrastructure, road design, cyclist visibility in low light and cyclists travelling in the opposite direction to traffic.

Arguably, the best way to understand these issues is to examine near collisions in a naturalistic context. In naturalistic cycling studies, the behaviour of road users is studied in situ with the use of technologies such as video cameras, GPS, and other recording devices (e.g. Chuang, Hsu, Lai, Doong, & Jeng, 2013; Dozza & Werneke, 2014; Gustafsson & Archer, 2013; Johnson, 2010). In driving research, studies such as the 100-Car Naturalistic Driving Study have allowed researchers to collect detailed and objective information about typically unreported minor events, and gain insights into pre-event behaviours and contributing factors (Guo et al., 2010).

To date, two studies have examined cyclist near collisions with other road users using naturalistic study data (Dozza & Werneke, 2014; Johnson, 2010). In Johnson et al.'s (2010) study, six cyclists wore head mounted cameras and recorded 12 hours of cycling around Melbourne. In Dozza and Werneke's (2014) study, data were collected using five instrumented bicycles (equipped with one forward video camera, two inertial measurement units, GPS and two brake force sensors) rotated among 16 bicyclists for 2 weeks each in Gothenburg, Sweden.

Although they were conducted in different countries, both studies identified similar rates of near collisions: approximately .80 per hour of recorded cycling. However, the factors identified as important differed across studies. In Johnson et al's (2010) study a high proportion of near collisions involved light vehicles (as opposed to other road users), and occurred while participants were travelling straight ahead. Females were more likely than males to be using bike lanes at the time of the event, and males were more likely to head check prior to the event than females. In Dozza and Werneke's (2014) study, cycling near an intersection, intersections with visual occlusions, poor maintenance of the road, and pedestrians or other cyclists crossing into the cyclists' path were identified as important factors. These differences are likely due to differences in how events of interest were defined and the data analysis strategies employed.

Despite these differences, these studies show that naturalistic cycling data can provide detailed information about near collisions; however, the analyses provided little insight into the sequence of events. Guo et al. (2010) proposed a model for analysing the sequence of behaviours and factors involved in crash and near crash events in naturalistic driving study data. The model, shown in Fig. 1 captures not only the vehicle trajectory, but also relevant behaviours, responses to the situation, and contributing factors. Guo et al. (2010) found that this model was a useful tool for comparing the sequences of events involved in crashes and near crashes.

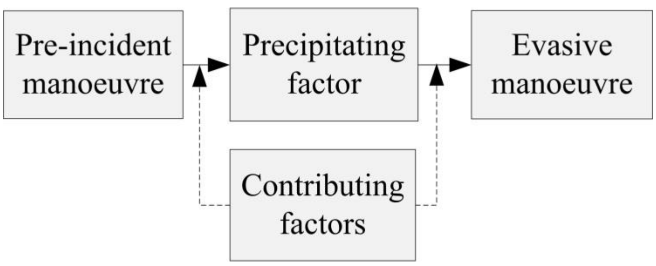

Figure 1. Sequential factors of crash or near crash (adapted from Guo et al., 2010)

The aim of this study is to examine the sequence of behaviours and contributing factors involved in cyclists near collisions using quasi-naturalistic on-road study data. The model proposed by Guo et al., 2010 was utilised to analyse the cycling near collision events identified from the data.

Method

Design

The study used a semi-naturalistic paradigm whereby participants cycled around a pre-defined urban route while being filmed by a researcher travelling behind on a bicycle. Participants provided concurrent verbal protocols as they negotiated the route. The verbal protocols allow access to cyclists' decision-making processes in addition to collecting objective event video data. The data analysed in this study was collected as part of a larger study examining road user situation awareness (Salmon, Lenne, Walker, Stanton & Filtness, 2014).

Participants

Twenty participants (15 male, 5 female) aged 21-64 years (mean = 32.4, SD = 10.42) took part in the study. On average participants cycled 6.6 (SD = 5.23) hours per week for transport. Participants were recruited through a weekly Monash University newsletter and flyers put up around the campus. Participants were compensated $50 for their time. Ethics approval was granted by the Monash University Human Ethics Committee.

Materials

A desktop driving simulator was used to practice the verbal protocol method prior to cycling the route.

A 15km urban route was selected for the on-road study component. The route was in the south-eastern suburbs of Melbourne, Victoria, and comprised a mix of arterial roads (50, 60 and 80km/h speed limits), residential roads (50km/h speed limit), and university campus private roads (40km/h speed limit). Five distinct road environments were represented: residential streets, intersections, arterial roads, shopping strips and roundabouts. The intersections comprised a mix of fully signalised (i.e. all turns controlled by traffic lights), partially signalised (i.e. some but not all turns controlled by traffic lights) intersections, and non-signalised intersection and required seven right hand turns, four left hand turns and four straight through manoeuvres. None of the intersections provided dedicated cycling lanes. The arterial roads component comprised approximately 6.2kms of arterial roads along the route. These had 3 lanes and an 80km/h posted speed limit and did not provide dedicated lanes for cyclists. The shopping strip section of the route was approximately half a kilometre in length, had a 60km/h posted speed limit, and had shops and car parking spaces running parallel to the road on either side. Finally, three roundabouts were located in a 40km/h section of the route and required two straight on manoeuvres and one right hand turn manoeuvre.

Participants cycled the route using their own bicycles and helmets. To record the visual scene and their verbal protocols, participants wore Imaging HD video cycling glasses. The researcher following participants also used their own bicycle and helmet. The helmet was fitted with an ATC9K portable camera to record participants' interactions with the road environment.

Procedure

All trials were conducted at 10am or 2pm Monday to Friday to control for traffic conditions. Prior to the study, the route was piloted at these times to confirm the presence of similar traffic conditions.

Upon arrival, participants completed a consent form and a demographics questionnaire, and were briefed on the research and its aims. Participants received instructions on how to provide concurrent verbal protocols, and completed a test drive on a driving simulator whilst providing a verbal protocol. A researcher monitored the test drive and provided concurrent feedback on the quality of their verbal protocol. Participants were then shown the study route and asked to memorise it. When comfortable with the verbal protocol procedure and route, participants were then given a demonstration of the Imaging HD video cycling glasses, which were then set to record. Participants were then asked to begin negotiating the study route. A researcher followed behind on a bicycle filming participants' interactions with the road environment. The researcher was instructed to intervene if the participants strayed off route.

Participants' verbal protocols were transcribed verbatim using Microsoft Word.

Data analysis

Two researchers identified near collision events from the video data. Near collisions included: "near crashes, requiring rapid and evasive manoeuvre to avoid a crash; crash-relevant, requires evasive manoeuvre to avoid a crash, less severe than rapid movement; proximity conflict, extraordinarily close proximity of the subject vehicle with another vehicle" (Johnson, 2010, p.36). Seventeen events were agreed on by both analysts. The video data and sections of the verbal protocol transcript were then extracted for these events.

The video and verbal protocol extracts for each event were then analysed independently by three researchers. For each event, researchers identified: 1) the type of conflict (lead, following or multiple vehicle, conflict with other types of road user); 2) whether participants appeared to be aware of the conflict (yes, no); 3) the pre-incident manoeuvre, which was defined as the cyclists' action just prior to the beginning of the event; 4) the precipitating factor, which was defined as the action by the cyclist or another road user in the near vicinity that begins the sequence; 5) whether an evasive manoeuvre (e.g. steering, braking, accelerating) was required, and if so, who performed the evasive manoeuvre; and 6) the contributing factors involved. Researchers then classified the contributing factors according to Stanton and Salmon (2009) taxonomy of causal factors for driver error, which was adapted to describe the cycling context (shown in Fig. 2). This taxonomy was developed from a review and synthesis of the driver error literature. The original taxonomy comprised five higher level categories (Road Infrastructure, Vehicle; Driver, Other road Users and Environmental), each with a number of sub-categories. For the purposes of the current analysis, the category "Vehicle" was changed to "Bicycle" and "Driver" was changed to "Cyclist". Two categories were added to the taxonomy: "Cyclist Behaviour" and "Other". Classifications of events across researchers were compared; there was 90% agreement. The few disagreements identified were resolved through discussion.

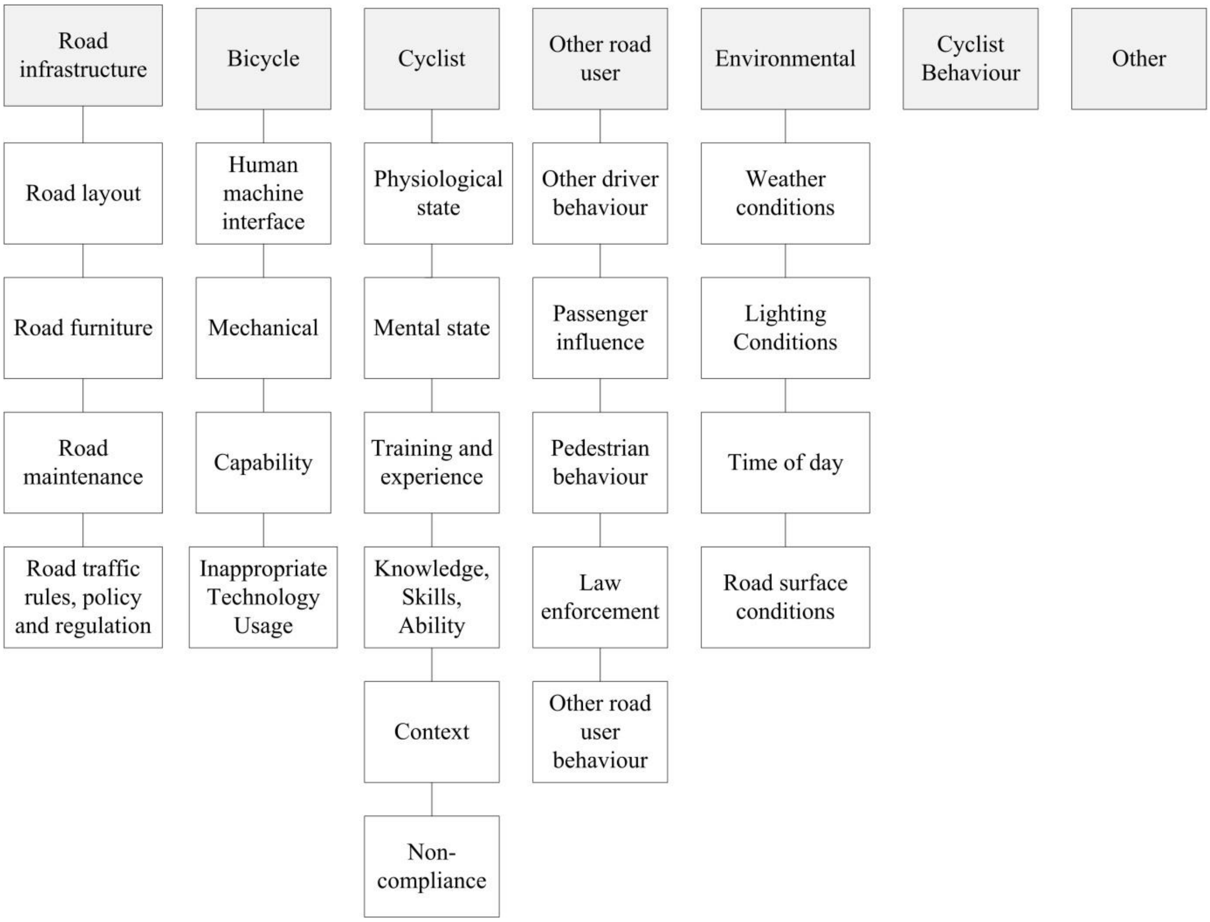

Figure 2: Taxonomy of contributing factors in cyclist near collisions (adapted from Stanton & Salmon, 2009)

Results

Number of near collisions identified

From approximately 14 hours of recorded cycling with 20 participants, 17 near collisions were identified (including 13 crash-relevant events and 4 proximity conflicts).

Participants involved in near collisions

Almost half of the total sample (9 out of 20) were involved in near collisions, of which 6 participants were male and 3 were female. On average, these participants were 32 years' old (SD = 10.74) and cycled 6.8 (SD = 3.2) hours per week for transport. In comparison, 9 male and 2 female participants were not involved in near collisions. On average, these participants were 32 years' old (SD = 10.67) and cycled 5 (SD = 2) hours per week for transport. Independent samples t-tests showed that there were no significant differences in age or number of hours cycled per week for transport. Four cyclists were involved in one near collision, three cyclists were involved in two, one cyclist was involved in three and one cyclist was involved in four near collisions.

Type of conflict

The majority of near collisions were classified as conflicts with single (n = 11) or multiple (n = 2) following vehicles; all of these near collisions involved vehicles overtaking participants.

Two near collisions where classified as conflicts with lead vehicles, these involved cyclists overtaking a parking or waiting vehicle. Two near collisions were classified as conflicts with other road users; both involved pedestrians moving unexpectedly into participants' path.

Awareness of conflict

In the majority of near collisions, participants appeared to be aware of the potential conflict as prior to the precipitating factor (n = 15). Awareness was indicated through participants looking (often repeatedly) at the vehicle involved in the conflict and through statements identified in the verbal protocols. For example, "[I'll] indicate, just in case the guy behind me wants to go straight ahead. He does. He goes. Oh, I love this place." (Cyclist 2, Event 1). Most participants also commented on the near collision after the event. For example, "That lorry was really close." (Cyclist 6, Event 4) and "Some guy just tried to get around me. That was really dumb, he could have killed someone but anyway such is life." (Cyclist 12, Event 1).

Pre-incident manoeuvre

The pre-incident manoeuvre refers to the participants' action just prior to the beginning of the event. In the majority of near collisions, participants were approaching or traversing an intersection (n = 12). In three near collisions, participants were travelling along an arterial road or a shopping strip. In two near collisions, participants were travelling along a residential road.

Precipitating factor

The precipitating factor is the action by the participant or other road user in the near vicinity that begins the sequence. In twelve near collisions, the sequence was initiated by the actions of car drivers; in ten of these near collisions, this involved car drivers attempting to overtake the participant on the left or right as they negotiated an intersection. In three near collisions, participants attempting to merge into the flow of traffic initiated the sequence. In two near collisions, pedestrians moving unexpectedly into participants' path initiated the sequence.

Evasive manoeuvre

Thirteen near collisions involved an evasive manoeuvre, 8 involved an action undertaken by car drivers and 5 involved action undertaken by the participant. Car drivers' evasive manoeuvres typically involved a combination of swerving and breaking as they overtook participants through intersections.

Contributing factors

On average, near collisions involved 4.2 (SD = 1.6) contributing factors, with a range of between 2 and 7 contributing factors. Table 1 summarises the contributing factors identified classified according to Stanton and Salmon's (2009) adapted causal factor taxonomy. The most frequently identified factors were classified as relating to road layout (17 near collisions), driver behaviour (13 near collisions), and road rules (8 near collisions).

Table 1: Contributing factors classified according to Stanton and Salmon's (2009) adapted causal factor taxonomy. Numbers in brackets indicate number of near collisions within which the category/contributing factor was identified.

Taxonomy category	Contributing factors
Road layout (17)	Four lane intersection: participant needs to merge across two lanes to turn right (6) No marked path for cyclists on approach or through intersections (6) Bike lane ends on approach to intersection (2) Parallel parking on the left with only two narrow lanes (2) Lanes at intersection allow both straight and right turn (2) No markings indicating lanes (2) Bus lane ends at intersection, bus must merge into right lane (1) Lack of pedestrian crossing (1) Multiple exists at intersection (1) Solid line separating traffic (1) Dual use parking/bike lane (1) Two lanes of traffic merge to one at end of intersection (1)
Driver behaviour (13)	Car driver overtaking through intersection (7) Car driver overtakes very close and at speed (2) Car driver overtakes while participant is overtaking parking vehicle (1) Car driver comes out of driveway into path of participant (1) Car driver overtakes participant into on-coming traffic (1) Bus driver speed overtaking participant (1) Driver parallel parking (1)
Road rules (8)	80km/hr speed limit at intersection (5) Cannot cross solid line (1) Bus light priority at intersection (1)
Bicycle capability (7)	Participant speed negotiating intersection (7)
Cyclist behaviour (5)	Participant overtakes parking vehicle (2) Participant in extreme left of lane (3) Participant in far right of lane (1) Participant merged too early (1)
Cyclist KSAs (4)	Participant not aware of traffic behind (2) Participant believes cars will move to avoid him (1)
Road furniture (2)	Telegraph pole blocking drivers view of cyclist (1) Bus light (1)
Pedestrian behaviour (2)	Pedestrian does not check road for traffic before opening car door (1) Pedestrian crosses road into path of cyclist (1)
Other (1)	Size of bus (1)

Discussion

The aim of this study was to examine the sequence of behaviours and contributing factors involved in cyclists' near collisions using quasi-naturalistic on-road study data. Seventeen near collisions were identified from 14 hours of recording cycling with 20 participants. The majority of near collisions occurred as cyclists approached or negotiated an intersection (pre-incident manoeuvre), as car drivers attempted to overtake the cyclist on the left or right (precipitating factor), and car drivers had to swerve or break to avoid a collision (evasive manoeuvre). All near collisions involved contributing factors relating to road layout; the majority also involved factors related to driver behaviour and the road rules. In addition, bicycle capabilities, cyclist behaviour and KSAs, road furniture and pedestrian behaviour were identified as contributing factors in some near collisions. Overall the results suggest that current road designs, especially intersections, do not safely accommodate interactions between cyclists, drivers and pedestrians.

The rate of near collisions identified in this study – approximately 1.2 per hour - was slightly higher than that identified in similar studies (Dozza & Werneke, 2014; Johnson, 2010). This is likely because in this study cyclists navigated a pre-determined route, which was selected to be representative of a range of road environments in the public road network. In contrast, in previous studies which adopted a purely naturalistic methodology cyclists may have actively avoided road environments such as large intersections, favouring less busy roads, therefore decreasing their risk of a near collision.

Nevertheless, it was a surprise that so many near collisions were identified from such a relatively small data set. The study included only 20 participants. Each participant spent only 40 minutes on-road yet 50% of participants were involved in a near collision, with some participants experiencing multiple near collisions. If these data are representative of general cycling experiences, then it is perhaps little surprise that many Australians are reluctant to cycle on public road networks and express fear of cycling (Bauman et al., 2008; Fishman et al., 2012; Heesch et al., 2012). The findings from the current study support Fishman et al.'s argument that to increase levels of cycling for transport it is necessary to re-evaluate thinking which prioritises the allocation of road space to motor vehicles.

In particular, consistent with the findings of Dozza and Werneke (2014), this study found that approaching and turning right at intersections are particularly risky for cyclists. These results, combined with findings that show that serious injuries to cyclists predominantly occur at intersections (Watson & Cameron, 2006), suggest that intersections should be considered as a top priority to improve cyclist safety. The findings show that interactions between the road infrastructure, the road rules and driver behaviour need to be targeted. In relation to road infrastructure, the key factors identified were: 1) no marked path for cyclists though intersections; 2) cyclists are required to navigate across two to three lanes of traffic to turn right; and 3) the right turning lane also allows traffic to travel straight ahead. These factors increase the number of decisions that cyclists are required to make on approach to intersections and increase close interaction with motorised traffic. Compounding these factors, the speed limits at the intersections were between 60-80km/h. Consequently, it was far beyond the capabilities of the cyclist to keep pace with the flow of traffic. The speed limit and the speed of the cyclist appear to encourage drivers to overtake cyclists as they negotiate the intersections, despite the fact that this is violation. This analysis suggests that rethinking intersection design and the road rules is required to improve interactions between drivers and cyclists at intersections.

Many of the factors identified as playing a role in near collisions in this study are also evident in studies of actual cyclist-driver collisions (Bíl et al., 2010; Boufous et al., 2012; Garrard et al., 2010; Kim et al., 2007). In particular, vehicle speeds, speed limits, larger vehicles, poor cycling infrastructure and road layout all appear to be common factors in actual and near collisions. This suggests that countermeasures designed to address near collisions will also have an impact on the number serious injuries and fatalities to cyclists.

It is interesting that not all participants were involved in a near collision, which suggests that there may be differences in characteristics or behaviours that influence near collisions. With regard to characteristics, no significant differences were identified in gender, age, or hours cycled per week, however, there may be other differences that were not explored in this study. With regard to behaviour, the majority of participants did appear to be aware of the potential conflict prior to the beginning of the sequence of events, which suggests that they may have been able to avoid the near collision. However, the majority of near collisions were initiated by the actions of car drivers (e.g. aggressive overtaking) which participants had no control over. Given that the actual time recorded on-road was quite limited in this study, it could be speculated that all cyclists are equally likely to experience a near collision given enough time cycling on the public road network. This claim is supported by the findings from similar studies (Dozza & Werneke, 2014; Johnson, 2010) which included longer time on-road: in these studies all participants were involved in a near collision at some point during the study. Further research is needed to determine whether there are characteristics or behaviours that influence near collision involvement, which could potentially impact on the efficacy of countermeasures targeting system design.

The main strength of this paper was the use of a novel method to analyse the sequence of behaviours and contributing factors in naturalistic cycling study data. The study demonstrates that Guo et al.'s (2010) model of vehicle crashes/near crashes also applies to cyclist near collisions, and that the application of the model assists in the development of insights into the sequence of events. It was also found that Stanton and Salmon's (2009) taxonomy of driver error causal factors was easy to adapt to the cycling domain. Both methods were shown to have high levels of inter-rater reliability when applied independently by three researchers.

Finally, as in other on-road studies, the main limitation of this study is the data itself. The data analysed in the study was limited to a single route in Melbourne, a limited number of adult cyclists, and a specific time of day. In the future, data from multiple studies conducted across multiple locations and environments could be combined to give a more robust understanding of the sequence of behaviours and factors involved in cyclist near collisions. In addition, ensuring that the identification of near collisions was reliable and distinguishing between "near crash", "crash-relevant" and "proximity conflicts" was challenging. In particular, the distance between cyclists and other roads users was often difficult to accurately estimate from the video data; therefore we included only near collisions identified independently by two researchers. Potentially more near collisions could have been identified if objective data was available on cyclists' bicycle control and proximity to other vehicles, as has been obtained in other naturalistic cycling studies (e.g. Chuang et al., 2013; Dozza & Werneke, 2014).

This paper has examined the sequence of behaviours and factors involved in cyclist near collisions using quasi-naturalistic on-road study data. It was found that the majority of near collisions occurred as cyclists approached or negotiated an intersection (pre-incident manoeuvre), as car drivers attempted to overtake the cyclist on the left or right (precipitating factor), and car drivers had to swerve or break to avoid a collision (evasive manoeuvre). Critical interactions between the road design, the road rules and road user behaviour were identified which contribute to the initiation of near collisions. Overall the results suggest that countermeasures should target road design and the road rules in order to improve the safety of interactions between cyclists and other road users.

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