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Single-bicycle crash types and characteristics

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Abstract
Most research on cyclist safety is focused on bicycle-motor vehicle crashes. Only a few studies address single-bicycle crashes (i.e. a fall or obstacle collision), in spite of the fact that most cyclists admitted to hospitals are single-bicycle crash victims. This study developed a categorization of single-bicycle crash types.

A draft categorization was developed based on the scarce literature that is available and theory on bicycle dynamics. This categorization was tested using a questionnaire study that was conducted in the Netherlands among bicycle crash victims treated at an Emergency Care Department. The questionnaire contained open questions about the crash and closed questions on possible direct causes, crash characteristics, and circumstances.

The results indicate that about half of all single-bicycle crashes are related to infrastructure: the cyclist collided with an obstacle (1ai), rode off the road (1aii), the bicycle skidded due to a slippery road surface (1bi), or the rider was unable to stabilize the bicycle or stay on the bike because of an uneven road surface (1bii). The first two categories happen due to the cyclist inadvertently taking a dangerous riding line, while the last two happen under more direct influence of the road surface conditions. Other types related to the cyclist are loss of control at low speed (2a), due to forces on the front wheel (2b), or poor or risky riding behaviour (2c). Bicycle defects (3) contribute to a small group of crashes. Finally, some cyclists fall because of an external force such as a gust of wind (4). The study provides per crash type statistics on victims and circumstances.

Keywords: single-bicycle crash, road safety, cycling, fall, bicycle-only crash

1 Introduction

High numbers of single-bicycle crashes (e.g. a fall or obstacle collision) are common in countries where many people use a bike as a means of transport (Veisten et al., 2007; Kroon, 1990; Ormel et al., 2008; De Geus et al., 2011; Heesch et al., 2011). For instance, most cyclists admitted to hospitals in the Netherlands are single-bicycle crash victims, e.g. three-quarters of all cyclist traffic incident victims and one-third of all traffic incident victims (Ormel et al., 2008). Despite these high crash numbers, a good description of single-bicycle crash types is missing in scientific literature. This paper aims to develop a crash typology. Also, statistics on victims, circumstances, and road type are provided per crash type.

Literature on single-bicycle crashes (Section 1.1) and bicycle dynamics (Section 1.2) are studied to develop a draft categorization of single-bicycle crash types based on direct causes.

1.1 Description of Single-bicycle Crashes in Existing Literature

A literature search was conducted to find existing studies that describe single-bicycle crashes. The results can serve as a starting point for a draft categorization of single-bicycle crash types. Google Scholar (Google, 2012) and SafetyLit (San Diego State University, 2012) were used for the literature search. The search terms were firstly “single-bicycle crash” and secondly “fall obstacle bicycle-crash”. Of the results, only 18 papers and reports referred to single-bicycle crashes (including falls off the bicycle) in the title or summary. Of those 18 papers, 2 contained crash descriptions. This may result from the fact that single-bicycle crashes are very rarely reported in official road crash statistics (Nordentoft et al., 1989; Elvik and Mysen, 1999). Since we only found 2 studies and none conducted in the Netherlands, we have asked specialists in Dutch research institutions involved in road safety research whether they knew of studies including single-bicycle crashes. This resulted in 2 additional research reports. Crash types found in the 4 studies are described in the remainder of this section.

Firstly, Nyberg et al. (1996) performed a survey study among bicyclists treated as inpatients and outpatients at the University Hospital of Northern Sweden. Only crashes of 314 victims who deemed the road or bicycle track surface to be the major contributing factor to the crash were studied. The road surface factors that had contributed to the injuries included snow, ice, wet leaves and gravel on the roadway, cracks, holes, uneven paving and a steep lateral slant. Victims also collided with kerbs and stationary objects.

Secondly, in Canada, Frendo (2010) classified the crashes of 300 injured cyclists who visited an emergency department and completed a questionnaire. Half involved no other road users and included crash types such as: collision with a man-made obstacle such as a kerb or fence, collision with a parked vehicle, fall due to the road surface such as potholes or objects on the road surface such as tree branches, collision avoidance, bicycle malfunction, wheel lodge (e.g. a grocery bag carried on the handle bars lodged in the wheel), cycling behaviour such as braking too hard or cornering too fast.

Two Dutch studies that focused on single-bicycle crashes were identified. The first, a study by Kortstra and Schoone-Harmsen (1987) was based on victims’ statements at Emergency Care Departments. The second, a study by Schoon and Blokpoel (2000) used a survey of bicycle crash victims who were treated at an Emergency Care Department in 1995. The survey was not specifically focused on single-bicycle crashes, however the answers to open-ended questions were coded to identify if the victim was involved in a single-bicycle crash. The description of single-bicycle crashes identified in these two Dutch studies is similar to outcomes reported by Frendo (2010) and Nyberg (1996). However, the Dutch studies also report crashes with older cyclists at low speed, especially loss of balance while mounting or dismounting the bike, and crashes with younger cyclists while performing stunts with their bike. This seems relevant given that in the Netherlands people of all ages use a bicycle, especially for utilitarian trips where speeds can be low (Ministry of Transport, Public Works and Water Management, 2009).

1.2 The Stability of the Bicycle and the Cyclist

As research on single-bicycle crashes is scarce, theory on bicycle dynamics was explored to find potential direct causes as un underpinning for a crash typology. A controlling rider can balance a forward-moving bicycle by turning the front wheel in the direction of an undesired lean. This moves the ground-contact points under the rider (Jones, 1970). Most bicycles can balance themselves (riderless) if moving above a given speed which depends on factors such as geometry and mass distribution (Kooijman et al., 2011). Mathematical models including such factors are available to describe the bicycle's lateral stability (e.g. Meijaard, et al., 2007). Moore et al. (2009) found self-stability at speeds above approximately 15 km/h for a commonly used Dutch city bicycle and a male rider. To conclude, the studies show that sufficient speed supports the bicycle's stability.

Independent of whether the rider actively steers or not, the ridability of a bicycle depends crucially on the freedom of the front fork to swivel. If it is locked, even dead ahead, the bicycle cannot be ridden (Jones, 1970; Kooijman et al., 2011). This implies that the front wheel has to be prevented from locking up, for instance due to hard braking or a branch into the spokes of the front wheel. Otherwise the rider may lose control or be launched over the handlebars (Beck, 2008).

Another problem that can be difficult to correct once it occurs is skidding. Skidding depends on the coefficient of friction between the tires and the road surface and is also subject to the condition of the tires and the state of the road surface. As regards to the road surface condition, mud, water, wet leaves, and oil can reduce the friction. To prevent skidding while braking and cornering, the tires should offer sufficient traction (i.e. the frictional force that keeps a tire from skidding). Smooth tires of race bicycles get as good traction as those with tread, assuming appropriate inflation power. The tires of racing bikes are narrower resulting in a smaller contact patch and more weight per square inch. This doesn't affect traction on smooth road surfaces. However, a wider tire will deform easier around road surface irregularities which makes riding more comfortable and provides more grip. For riding on soft surfaces, such as sand or mud, a wide front tire is essential (Brown, 2009; Dutch Cyclists' Union, 2012).

Finally, in many cases cars will not roll over in case of a collision and they offer a level of protection to occupants if a crash occurs. On the contrary, falling is almost unavoidable for cyclists if they hit an obstacle and except for a helmet (if worn) the rider is unprotected. The cyclist may be injured by the fall or by hitting an object, e.g. a bollard. As a result, cyclists may sustain severe injuries in seemingly innocent crashes.

1.3 Crash Types Based on Direct Causes

Wagenaar and Reason (1990) identified two distinct classes of causes in road traffic accident scenarios, i.e. direct causes and latent factors. Direct causes occur immediately prior to the accident, while latent factors refer to those causes that might have been present in the system for a long time. We base our crash categorization on direct causes. The direct causes consist of causes related primarily to the infrastructure, the cyclist, or the bicycle, depending on where the force that resulted in the accident came from. Infrastructure can be a direct cause through the road surface condition or the collision energy released when crashing into an object. This subdivision may help in finding latent factors. Note that direct causes may be explainable by several latent factors. For instance, while the force may have come from hitting an obstacle (i.e. infrastructure) the latent factors may be a combination of the design decision to put the obstacle on the road way, alcohol use by the rider, and malfunction of the bicycle light making it more difficult to detect and avoid the obstacle.

Based on the literature review and theory on bicycle dynamics, we suggest the following crash categorization:

1. Infrastructure-related crashes:
    a. preceded by the cyclist inadvertently taking a dangerous riding line:
        i. colliding with an obstacle on the roadway (deliberately) designed and build by road authorities, such as a road narrowing or bollard on the bicycle track to prevent cars from entering, and parked vehicles.
        ii. riding off the road and colliding with a kerb or off-road obstacle
    b. linked to road surface quality:
        i. skidding due to a slippery road surface
        ii. loss of control due to an uneven road-surface (e.g. a pothole or damage from tree roots) or a loose object on the road surface (e.g. a branch)
2. Cyclist-related crashes; loss of control:
    a. At low speed when it requires more effort to stabilize the bicycle, e.g. (dis)mounting
    b. Due to (moving) baggage, that may hit the front wheel
    c. Riding behaviour:
        i. abrupt steering manoeuvres, e.g. avoidance
        ii. braking mistakes
        iii. stunting, e.g. doing a wheelie
3. Bicycle malfunction, e.g. chain break, broken part of the frame, etc.
4. Other, or no recall of the crash by the victim

There will be some overlap between these crash types. For instance, a cyclist goes off course because baggage carried on the handle bars hits the front wheel after which the rider hits a kerb and falls. This will be categorized both into crash type 1a and 2, because forces causing the fall are both related to the cyclist (baggage hitting the front wheel) and the infrastructure (front wheel hitting the kerb).

The reason for classifying collisions with parked vehicles in group 1a related to infrastructure is that the location of parking places relative to (bicycle) traffic is in the Netherlands described in guidelines. For example, the Dutch Design Manual for bicycle traffic advises against cycle lanes with parking bays because of opening car doors (CROW, 2007).

Loss of control due to an uneven road-surface or a loose object on the road surface are both classified in one group because a bump or loose object on the road may result in the same instability. However, the measures to prevent these problems are different.

1.4 Crash Circumstances and Factors

Wagenaar and Reason (1990) suggest that to be effective, countermeasures for reducing single-bicycle crashes should focus on the identification of latent factors rather than direct causes. We have searched for such factors in the literature in order to develop a questionnaire (see Section 2). The following potentially important factors were found in the literature:

- Age and sex

  Both younger and older cyclists have a higher risk per kilometre travelled by bicycle of being treated at an emergency care department after a single-bicycle crash. However, the risk of being hospitalized is increased only among elderly, see Figure 1. Among younger cyclists, men have the highest risk, among older cyclists women have the highest risk (Ormel et al., 2008).

- Amount of bicycle use
  Schepers (2011) has found that the risk of having a single-bicycle crash per kilometre travelled decreases as the amount of bicycle use increases. He suggests improved control and greater physical fitness as explanations, factors that may also be correlated to crash types. Heesch et al. (2011) found in their questionnaire study that respondents who had cycled less than 5 years were more likely to report an injury due to a bicycle crash.
- Light condition: dark and twilight versus daylight
  As visibility of bicycle infrastructure has been found to be related to cycling performance (Fabriek et al., 2012) visual factors such as light condition may also be related to the likelihood of crash types.
- Road situation curves and intersections versus straights
  Skidding may be more likely to happen in curves and at intersections where cyclists are turning. While cornering, the tire has to create cornering force (Brown, 2009). Also, imbalance due to an uneven road surface or objects on the road may be more difficult to compensate for while negotiating curves and turns.
- Bicycle surface condition: wet or dry
  Skidding may be more likely to happen at wet road surfaces due to a decreased friction between the tire and the road surface (Brown, 2009).
- Type of bicycle
  Racing bikes may be more likely to skid as their thin tires have less grip than the wider tires of other bikes (Brown 2009). Mountain bikes have wider tires and a knobbly surface that may provide more traction.
- Speed
  Low speed is one of the criteria that were used to categorize crashes. High speed may also be an important circumstance because skidding and imbalance may be more likely at higher speeds. The higher the speed (or smaller the turn radius) the more lean is required and the more cornering force has to be created by the tires (Jones, 1970; Lowell and McKell, 1982).
- Familiarity with the accident location
  Familiarity with the accident location might affect crash types where expectations regarding the location of dangers such as obstacles or sudden changes in the course of the road is beneficial. Expectations play a role in the allocation of visual attention (Horrey et al., 2006).
- Alcohol use
  Cycling under the influence of alcohol has also been linked to single-bicycle crashes (Öström, et al., 1993). Psychomotor skills and vision are compromised by alcohol use (Moskowitz and Fiorentino, 2000) and this may affect different crash types differently.
- Physical problems
  Problems with vision, balance, and muscles may be related to single-bicycle crashes because of the importance of these factors in balancing the bike. Hence these factors are potentially important in some crash types.

We do not claim that the list is complete and we hope that it can be expanded in future research. Note that none of the above described research results was based on the dataset used for the current study.

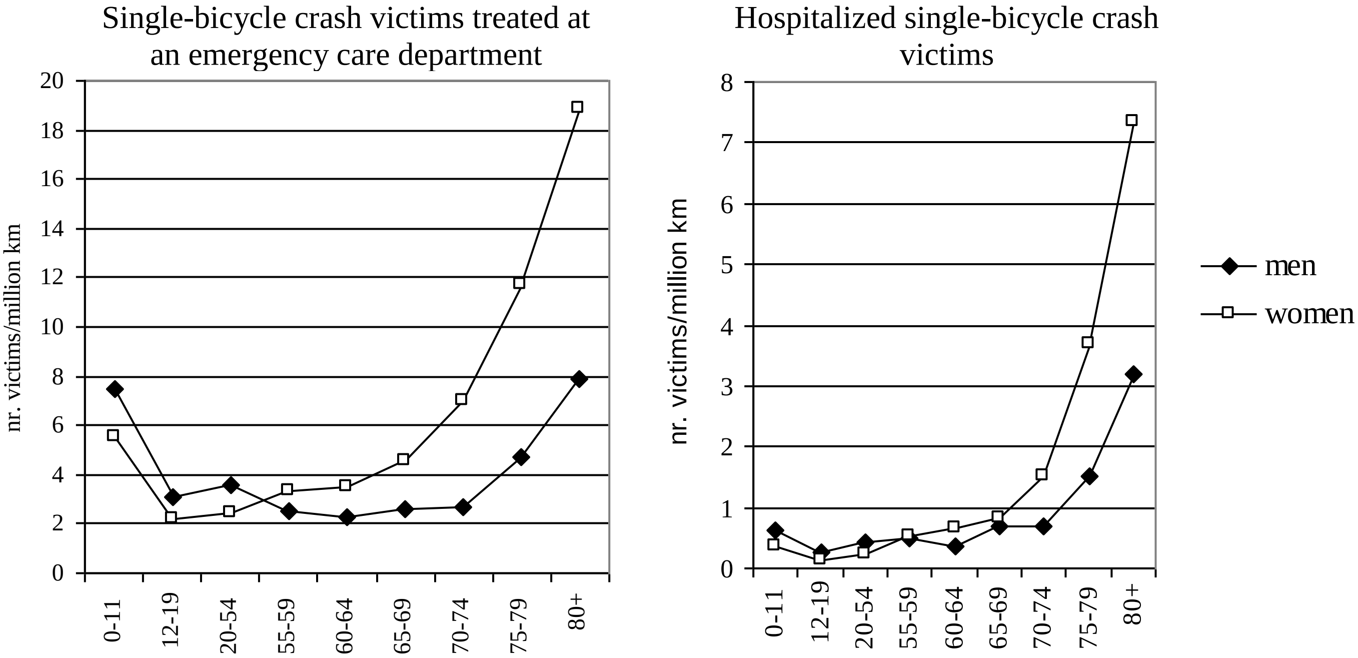

Figure 1 **Single-bicycle crash victims treated at an emergency care department and hospitalized victims per million kilometres per year travelled by bicycle (Source: Ormel et al., 2008)**

Road type

Many studies have focused on road type, especially on the question of whether bicycle tracks prevent bicycle-motor vehicle crashes (see Elvik and Vaa, 2009 for an overview). An analysis on the frequency of single-bicycle crashes and road types (using the same dataset as used for the current study) has been conducted by Schepers (2008). He found that on the basis of kilometres travelled by bicycle within built-up areas, the number of single-bicycle crashes differs little between bicycle paths (physically separated from the road), bicycle lanes, and roads with mixed traffic. In Figure 2, it is shown that the share of single-bicycle crashes per road type equals the share of kilometres travelled by bicycle per road type. Therefore, this crash characteristic is not further included in the current study.

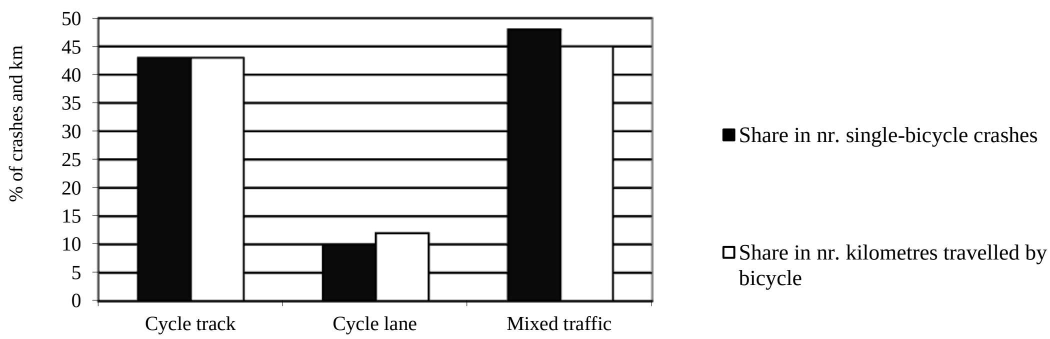

Figure 2 **The share of single-bicycle crashes and kilometres travelled by bicycle per road type (Source: Schepers, 2008)**

2 Procedures and Method of Study

Many road crash studies are based on police reported crashes. However, single-bicycle crashes are very rarely reported in official road crash statistics (Nordentoft et al., 1989; Elvik and Mysen, 1999). Therefore, VeiligheidNL ("Consumer Safety Institute") performed a retrospective study. Questionnaires were sent to cyclists who had had an accident with their bicycle and were treated at an Emergency Care Department. These participants were retrieved from LIS (LetselInformatieSysteem; Dutch Injury Surveillance System). LIS records statistics of people being treated at the Emergency Care Departments of a selection of hospitals in the Netherlands, following an accident, violence or self-inflicted injury. The selection of hospitals is a sample of hospitals in the Netherlands with a continuously staffed Emergency Care Department. Thirteen hospitals spread over the Netherlands, representative of the Dutch population in terms of level of urbanization, participated in this study.

The outcomes of the previous studies on single-bicycle crashes that were mentioned in section 1 were used to develop a questionnaire consisting of closed and open-ended questions. The open-ended questions and an example of a closed question are included in Table 1. Other questions were about direct causes, latent factors (e.g. alcohol use prior to the crash), circumstances, and characteristics of the victims. Parents were asked to fill in the questionnaire together with their child if the victim was younger than 12 years of age. On average, it took respondents about 20 minutes to answer all of the 40 questions. The survey was sent to the victim 2 months after treatment at the Emergency Care Department. Between February and June 2008, 2,975 questionnaires were sent, 1,156 (39 per cent) were returned. A total of 1,142 could be used for analyses. Of these participants 16 per cent were hospitalized after treatment at the Emergency Care Department. Crashes that occurred on unpaved roads through woods or of which the road type is unknown are excluded because they may not meet the official Dutch definition of a road traffic accident that includes the criterion that the crash should have occurred on a public road. A total of 669 single-bicycle crashes in which the cyclist (not the passenger) was injured were analysed in this study.

Answers on both open and closed questions were used to categorize crashes according to the crash typology (see Section 1.3). This was done by two researchers independently. The results were compared and discussed to arrive at a final categorization.

Accident-category modelling (or Accident-collision modelling, see Vandenbulcke-Plasschaert, 2011) with binary logistic regression was used to assess the association of single-bicycle crash types with the following variables (see also Section1.4): sex, age (0-17, 17-59, and >60 years of age), light condition at the time of the accident, alcohol use, physical problems, road characteristics (curve and intersection versus straight stretch of road), speed, road condition (wet, or dry), type of bicycle (racing bike, or other). Regression coefficients tend to be biased if the number of events per independent variable in logistical regression analysis is too small, with about 10 events per variable as a minimum (Peduzzi et al., 1996). To avoid a too high number of variables, the least significant variable that did not meet the predefined p-value of 0.1 was removed. This process was repeated until all remaining parameters were at least significant at the 0.1 level (sometimes called 'borderline' significant). Also, only crash types with at least 40 crashes were included in the analyses to achieve a minimum number of cases per independent variable. Odds ratios (OR) for each crash type versus the other crash types with 95 per cent confidence intervals (CI) were calculated.

Table 1 Two examples of questions in the survey[1]

Questions
Nr 1. Description of the crash. We would like to know what happened precisely when you had the crash.
1a. On what kind of road were you riding? What was the purpose of your trip? Was there an extraordinary situation?
1b. What happened next, what went wrong?
1c. Were you injured? What injury did you sustain? Which area(s) of your body was wounded?
Nr 4. What happened exactly (you can mark more than one category)?
I fell:
☐ While mounting the bike
☐ While dismounting the bike
☐ While braking
☐ While descending a slope
☐ While climbing a slope
☐ While overtaking
☐ While turning left
☐ While turning right
☐ While I was just cycling (no specific manoeuvre or activity)
☐ Other, …
I collided with an object or obstacle:
☐ Lighting post
☐ Traffic sign
☐ Bollard
☐ Fence or wall
☐ Kerb
☐ Tree
☐ Animal
☐ Other, …

[1] The original Dutch questionnaire is included in Appendix 1 in the report on single-bicycle crashes that is available on the Internet (Ormel et al., 2008): http://www.fietsberaad.nl/library/repository/bestanden/Onderzoek_Enkelvoudige_fietsongevallen.pdf

3 Results

Classification in Crash Types

Two researchers have independently classified the crashes according to the crash typology (see Section 1.3). The results show that fifteen percent of the cases were categorized differently. This low percentage shows that the crash typology is suitable to categorize single-bicycle crashes. The differences were subsequently discussed and a final categorization was chosen. We classified 88 per cent of the crashes in at least one of the categories described in Section 1.3, 17 per cent in two and 1 per cent in three categories. The researchers agreed that 12 per cent did not fit in one of the categories. These were assigned to a fourth group. The groups are described in the following with numbers and percentages of the single-bicycle crashes in the sample between brackets.

Crash characteristics

Binary logistic regression analyses are used to compare the crash types on a number of variables. Two groups – stunting and bicycle malfunction – are not analysed because of the low number of victims involved in these crash types. The results are shown in Table 2 with Odd ratios. The Table also includes in the first row and column the numbers of participants per category. The average age of the participants was 43.9 (SD=24.1).

Crashes with both racing bikes and mountain bikes were compared to crashes with other bicycle crash types. However, mountain bikes were neither more nor less often involved in one of the crash types. Therefore, mountain bikes were combined in one category with other bicycle types. Furthermore, light condition is not included in Table 2 because none of the crash types was related to this variable. The results are described in the remainder of this Section along with a description of the crash classification.

Group 1. Infrastructure-related crashes:
1a. preceded by the cyclist inadvertently taking a dangerous riding line
i. collisions with obstacles on the road (n=77; 12%)
More than half of the objects that cyclists collided with were bollards that were put on the road to prevent cars from entering a cycle track or stretch of the road, or road narrowings to slow down motorized vehicles. Most bollards stood in the middle of the road and a few on the verge of the road. About one third of the victims hit a car door or parked vehicle. A few cyclists hit a fence that was put on the road to clear it for a cycle race or road works.
Results of the regression analysis 1ai: Collisions with obstacles occur more often with older cyclists, and cyclists who are unfamiliar with the crash location. Cyclists who cycle at least one day per week are more often involved than cyclists who cycle less. Differences between straight road sections and curves and intersections may result from where obstacles such as bollards and road narrowings are located. We do not have data on this but it is possible that they are more often present at straight sections.
ii. riding off the road (n=142; 21%)
Two thirds of the victims hit a kerb, in most cases with the front wheel. In a few cases the cyclist kept too little distance from the kerb and hit the kerbstone with one of the pedals. One third of the victims swerved into the shoulder. They were unable to steer back to the road because of the height difference between the road and shoulder surface. Other victims fell because of an uneven or sandy shoulder surface or they collided with obstacles on the shoulder like trees, light posts, and fences.
Results of the regression analysis 1aii: Younger cyclists are more likely to ride off the road compared to adult cyclists. Cyclists under the influence of alcohol and cyclists with physical problems are also more likely to be involved in this crash type.
1b linked to road surface quality
i. skidding due to a slippery road surface (n=118; 18%)
All the crashes in this group have in common that one of the wheels, mostly the front wheel, skidded because of a slippery road surface. Skidding crashes without a clear link to the road surface were not included in this group. There were several subcategories:
- The road surface was slippery in more than one third of the cases due to dirt, e.g. sand, gravel, mud, wet leaves, oil or grease on the road surface.
- Elements in the road surface with lower friction caused a little over a quarter of the skidding accidents: iron plates and concrete plates with metal edges for temporary road surfaces, moss-covered or synthetic tiles, certain marking materials, wooden (bridge) surfaces without an asphalt layer on top of it, tram rails, cattle grids, drain covers, etcetera. The road surface was wet in most of these cases.
- One fifth of the victims skidded on ice or snow.
- Almost one fifth of the crashes resulted from longitudinal grooves or raised edges in the road surface. A wheel can easily skid when crossing raised edges or tram rails at too small an angle. The front wheel skidded and got stuck in the tram rails in a few cases.
ii. loss of control due to an uneven road-surface or loose object on the road (n=46; 7%)
About two thirds of the victims rode over bumps or potholes. They lost control over their bike and fell or swerved over the road to crash with a kerb or an object. Other victims rode over an object on the road and lost control. A few of them flew over de handlebars after a piece of wood or branch got tangled into the front spokes.
Results of the regression analysis 1bi and 1bii: Both crash types related to road surface quality happen more often to cyclists on racing bikes. Skidding happens more when the road surface is

wet and at curves and intersections where cyclists have to steer. Losing control due to an uneven road surface occurs more often at higher speeds. Older cyclists are less often involved in this crash type than younger cyclists.

Group 2. Cyclist-related crashes:

2a loss of control at low speed (n=105; 16%)

The majority of single-bicycle accidents at low speed happened while mounting or dismounting the bike. A lot of victims caught their coat, bag, or shoelace on a part of the bicycle and were unable to stabilize the bike or themselves. Some victims lost balance as their food slipped off the pedal or as they tried to make a sharp turn or look behind for traffic before dismounting. Others fell after they dismounted, because they carried a heavy load on their bicycle, used only one hand to hold the handle bars, or twisted their ankle.

Results of the regression analysis 2a: The chances of losing control at low speed are strongly elevated among older cyclists. Women, cyclists with physical problems and cyclists who cycle less than 1 day per week have an increased likelihood of these crashes too.

2b loss of control due to forces on the front wheel or handlebars (n=54; 8%)

Many victims put baggage on the handlebars. They lost control as it hit the front wheel, was pushed against the handlebars while moving the pedals, or became entangled in the front wheel spokes. Some of the bikes flipped over in the latter case. In some cases a foot slipped off a pedal and became tangled in the front wheel spokes. Some got off balance as a passenger or baggage on the luggage carrier moved.

Results of the regression analysis 2b: Older cyclists are least likely to lose control due to forces such as baggage hitting the front wheel. The crashes happen less often to cyclists under the influence of alcohol, possibly because people carry less baggage while going out.

2c loss of control due to riding behaviour:

i. abrupt steering manoeuvres (n=87; 13%)

Most of the victims in this category did not manage to balance or stay on the bike while they got out of the way for traffic or displayed a shock reaction after being scared by traffic. Victims made steering faults like steering too much, braking too much while steering, or holding the handle bars with only one hand while steering. Some occurred with children with limited cycle skills (according to their parents who filled in the questionnaire).

Results of the regression analysis 2ci: Losing control due to abrupt steering manoeuvres happens more often to women than to men and more often at higher speeds.

ii. braking mistakes (n=41; 6%)

This accident group is a combination of brake defects and wrong braking. In most cases one of the wheels skidded or the cyclist flew over the handlebars. It is not always clear whether the rider was braking too hard or braking hard without using the rider's arms to brace against the deceleration. In some cases the brakes did not work well or even broke down (these could have been categorized as defect as well).

Results of the regression analysis 2cii: Losing control due to braking mistakes happens more often to cyclists who cycle less than 1 day per week. These crashes are more likely at bends and at intersections.

ii. stunting (n=11; 2%)

A small group of adolescents stunted with their bike and got out of balance, for instance while doing a wheelie.

Group 3. Bicycle malfunction (36; 5%):

Several defects resulted in single-bicycle crashes: the chain broke or came off, the tire inflation was too low resulting in skidding while cornering, the fender or the front fork broke off, a wheel, saddle, or handlebars were loose or broke off.

Group 4. Other or unknown (n=80; 12%)
Some victims were unable to describe the details of their accident as they were unconscious because of the event or they were unable to provide enough information for us to categorize the crashes. Other victims had accidents that did not fit into one of the other categories. A substantial number of crashes could have been classified in an additional category of crashes due to external forces unrelated to the cyclist and the infrastructure. This finding could be useful for future research. Several cyclists fell because an animal ran against their bike, they lost control due to a gust of wind and a few were victims of an act of aggression, e.g. they were pulled off their bike.

Infrastructure-related crashes account for more than half of all the single-bicycle accidents in the sample (n=350; 52 per cent). There is no overlap between groups 1 and 2, nor between groups 3 and 4. There is some overlap (n=33; 5 per cent) of group 1 and 2 with group 3 and 4 as mechanisms in group 3 and 4 result in mechanisms in group 1 and 2.

Table 2 Association of single-bicycle crash types with latent causes and circumstances (significant Odd ratios underlined; 95 per cent CI in brackets)

		Infrastructure-related crashes				Cyclist-related crashes			
Crash types		1ai obstacle collision	1aii run-off road	1bi skidding at slippery surface	1bii Loss of control due to uneven road surface	2a loss of control at low speed	2b loss of control due to forces on front wheel	2ci loss of control due to abrupt steering manoeuvres	2cii loss of control due to braking mistakes
Variables:	*n*	77	142	118	46	105	54	87	41
Sex: man	301	1.54 (1.00-2.39)	0.69 (0.45-1.05)			0.39 (0.23-0.66)		0.53 (0.32-0.85)	
women (reference)	368	1	1			1		1	
Age (year): > 60	225	2.66 (1.35-5.25)	0.60 (0.34-1.07)		0.28 (0.12-0.64)	12.39 (4.62-33.20)	0.25 (0.13-0.52)		
18-59	298	1.66 (0.85-3.26)	0.56 (0.32-0.97)		0.83 (0.47-1.45)	2.45 (0.88-6.81)	0.96 (0.58-1.60)		
0-17 (reference)	146	1	1		1	1	1		
Bicycle use before the crash: daily	42	2.05 (0.71-5.87)				0.41 (0.16-1.03)			0.35 (0.17-0.71)
1-4 days per week	239	3.06 (1.07-8.74)				0.35 (0.13-0.90)			0.37 (0.17-0.79)
< 1 day per week (reference)	373	1				1			1
Road situation: curves and intersections	189	0.34 (0.18-0.62)	1.49 (0.95-2.32)	2.25 (1.47-3.45)					3.00 (1.86 to 4.83)
straights (reference)	480	1	1	1					1
Road surface condition: wet	46	0.23 (0.04-1.22)		8.01 (4.22-15.20)					
dry (reference)	623	1		1					
Bicycle type: racing bike	56			2.12 (1.10-4.08)	2.31 (1.06-4.99)				0.27 (0.06-1.16)
other bicycle types (reference)	596			1	1				1
Speed prior to the crash: > 25 km/h	49				3.54 (1.32-9.53)			2.59 (1.13-5.93)	
15-25 km/h	139				2.59 (1.20-5.59)			1.50 (0.80-2.81)	
5-15 km/h	243				1.87 (0.90-3.91)			1.21 (0.72-2.06)	
< 5 km/h (reference)	216				1			1	
Familiar with accident location: no	92	2.04 (1.20-3.47)						0.53 (0.25-1.12)	
yes (reference)	570	1						1	
Alcohol use[1]: yes	74		2.19 (1.18-4.06)				0.12 (0.03-0.52)		
no (reference)	595		1				1		
Physical problems: yes	53		2.10 (1.03-4.30)			2.38 (1.13-5.03)			
no (reference)	615		1			1			

[1] Number of alcohol containing beverages, six hours before the accident

4 Discussion

Literature on single-bicycle crashes is scarce which can be explained by the fact that despite the high numbers of serious injuries incurred (Schepers, 2011), single-bicycle crashes are very rarely reported in official road crash statistics (Nordentoft et al., 1989; Elvik and Mysen, 1999). We have therefore based a draft crash typology not only on crash literature but also on bicycle dynamics. This categorization was tested using a questionnaire study that was conducted among bicycle crash victims treated at an Emergency Care Department. The typology appeared to be suitable to categorize single-bicycle crashes shown by the fact that the classifications conducted by two researchers independently were consistent (only fifteen per cent of the cases were categorized differently).

4.1 Infrastructure-related Crash Types

One group of infrastructure-related crash types is preceded by a dangerous riding line (i.e. riding off the road and obstacle collisions) and the other group is related to the road surface condition (i.e. skidding and loss of control due to an uneven road surface). This study suggests that the following problems may contribute to the crashes in the first group: physical problems, alcohol use, knowledge of the crash location and the whereabouts of obstacles. Stabilizing the bicycle may worsen due to the first two problems. Because cyclists are unfamiliar with a certain location, they may lack expectation to guide visual search for dangers such as obstacles. In a recent study in which crash scenes were inspected it was found that the visual design of the infrastructure also plays a role in these crashes, e.g. the conspicuity of obstacles (Schepers and Den Brinker, 2011).

Skidding at a slippery road surface and losing control at an uneven road surface are directly related to the quality of the road and road maintenance. These crashes seem to be related to (technical) circumstances in combination with speed. For instance, both crash types happen more often to cyclists on racing bikes. Racing bikes have narrower tires offering less grip to prevent skidding, also depending on road surface quality (e.g. the presence of road surface irregularities). Skidding happens more when the road surface is wet (i.e. when friction is reduced) and at bends and intersections where cyclists have to steer (i.e. where more friction is needed). Losing control due an uneven road surface occurs more often at higher speeds, which could be explained by the fact that the disturbance of a bump in the road is greater at higher speeds.

4.2 Cyclist-related Crash Types

The most frequent cyclist-related crash type is losing control at low speed when steering is needed for stability. This mostly occurs while mounting or dismounting the bike. The likelihood is strongly increased among older cyclists, cyclists with physical problems and cyclists who cycle less than 1 day per week. This may be related to levels of strength and skills needed for (dis)mounting, accelerating and braking. Research on walking falls has shown that reduced muscle strength, especially of the lower limbs, is an important risk factor (Pijnappels et al., 2008). Research on single-bicycle crashes including measurement of muscle strength in victims could be conducted for efficient prevention and identification of individuals at high risk of bicycle falls.

It is surprising that older women run a markedly higher risk of crashes at low speed than older men, because men are often advised to change from a men’s to a women’s bicycle for safe mounting and dismounting. The top tube of women's bicycles slants down (while it is parallel to the ground in men’s bicycles) to intersect the seat tube, typically about halfway down, making it easier for the rider to step over the frame. Men move their leg over the luggage carrier to (dis)mount. There are two hypotheses for women’s elevated risk in this crash type that could be tested in future research. A first hypothesis would be greater muscle strength in men than in women. However, it is not completely clear from the literature to what degree older men have greater muscle strength than older women. Research by Lindle et al. (1997) shows that women tend to better preserve eccentric muscle quality (strength per unit of muscle) that is needed to take off and accelerate and that there is virtually no gender difference in muscle quality after around 60 years of age. On the contrary, according to research by Van Laarhoven (1984), female cyclists between 50 and 60 years of age have 80 per cent of the strength that men have for cycling. A second hypothesis would be that contrary to what is commonly thought, the way men mount and dismount is safer than the way women generally seem to do it. It could be that mounting like men do is an easier way to take off, accelerate and profit from improved stability that comes along with increased speed. Alternatively stepping over the middle of the frame like women do for mounting and dismounting may require more flexibility.

While older cyclists are most likely to fall at low speeds, they are least likely to lose control due to forces such as baggage hitting the front wheel. This seems to indicate that, like older drivers (De Raedt et al., 2000; Michon, 1989), older cyclists compensate for reduced physical function. They seem to take precautions while preparing the trip (i.e. strategic compensation), for instance by carrying baggage in panniers to prevent baggage hitting the front wheel. The high likelihood of older cyclists to be involved in crashes at low speed could be due to a lack of opportunities and time to compensate for decreased skills and strength. This is similar to the increased risk of left turning crashes in drivers (on right-hand drive roads). In contrast to other manoeuvres turning left is a complex manoeuvre under time pressure resulting in a lack of time to compensate (Yan et al., 2007; Davidse, 2007). In other situations older drivers often have the opportunity to reduce speed, i.e. tactical compensation (Michon, 1989). This tactic seems less favourable for older cyclists since a lower speed reduces the bicycle's stability. It could be that older cyclists have less opportunities for tactical compensation than older drivers.

4.3 The Effect of Bicycle Use on Crash Likelihood

In a recent study on single-bicycle crashes in which data on the amount of bicycle use was included, it was found that cyclists are less likely to be involved in severe single-bicycle crashes in municipalities with a high amount of cycling (Schepers, 2011). One explanation was that cyclists gain better control and greater physical fitness the more they cycle. This hypothesis is supported by some of the outcomes of this study. Cyclists who cycle the least (i.e. less than one day per week) are most likely to be involved in two crash types that seem to be linked to cycling skills and strength, i.e. falling while (dis)mounting and loss of control due to braking mistakes. Low speed while (dis)mounting requires steering skills to stabilize the bike while braking requires braking techniques (Beck, 2004).

4.4 Recommendations on Future Research

Research on single-bicycle crashes is still in its infancy. Given the high numbers of seriously injured victims in countries with high amounts of cycling (Veisten et al., 2007; Kroon, 1990), more research seems to be needed to develop preventive policies. Some research questions have already been mentioned. Research can be focused on specific crash types such as crashes related to visual aspects, e.g. the recent study by Schepers and Den Brinker (2011), to find certain latent causes to enable the development of countermeasures. To achieve more knowledge of cycling performance, it may be fruitful to expand from crash research to experimental research. For instance Fabriek et al. (2012) conducted an experiment on a closed track where participants' vision, in particular their contrast sensitivity, was impaired. Cycling performance and cyclists' feelings of safety worsened in conditions where the visibility of obstacles and the road's course were the poorest. This offers insight into how the visual design may contribute to single-bicycle crashes.

5 Conclusions

This study shows that single-bicycle crashes can be categorized according to direct causes. Depending on where the force that resulted in the crash came from, crashes can be classified as related to infrastructure, the cyclist (e.g. poor riding behaviour), the bicycle (e.g. a defect), or an external force (e.g. a strong gust of wind). Infrastructure-related crashes make up the largest group. They occur due to the cyclist inadvertently taking a dangerous riding line, or under more direct influence of the road surface conditions. This study provides some insight into the various latent conditions that may contribute to these direct causes. However, research on single-bicycle crashes is still in its infancy and more research is needed to develop and evaluate countermeasures.

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