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Scenarios of crashes involving light mopeds on urban bicycle paths

R.J. Davidse*, K. van Duijvenvoorde, M.J. Boele-Vos, W.J.R. Louwerse, A. Stelling-Konczak, C.W.A.E. Duivenvoorden[1], A.J. Algera

SWOV Institute for Road Safety Research, PO Box 93113, NL-2509 AC The Hague, The Netherlands

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ABSTRACT

In the Netherlands, cyclists have to share the bicycle path with light moped riders. These riders are allowed to ride 25 km/h and do not have to wear a helmet (Dutch regulation). Due to several trends such as traffic congestion and the introduction of the scooter model, light mopeds have become more popular, both among older and younger people. This has led to an increased traffic density on bicycle paths as well as concerns about the safety of cyclists. In response to these concerns, several Dutch cities would like to ban light moped riders (LMRs) from the bicycle path and let them ride on the carriageway. However, it is uncertain what the consequences would be for the safety of light moped riders. Moreover, it is not clear to what extent the shared use of bicycle paths leads to serious crashes between cyclists and LMRs. Therefore, an in-depth crash investigation study was carried out to gain more insight into the factors and circumstances that influence the occurrence and consequences of light moped crashes on bicycle paths.

A dedicated team for in-depth road crash investigation collected and analyzed detailed information on 36 light moped crashes that occurred on an urban bicycle path. This resulted in a description of the course of events for every crash that was analyzed, including a list of factors that contributed to the occurrence of the crash and possible injuries. Crashes with a similar course of events and a comparable combination of contributory factors were grouped into (sub)types of light moped crashes.

Six types of crashes were identified. Based on the contributory crash factors of the identified crash types, remedial measures can be developed to prevent similar crashes from occurring in the future. Moving the LMR to the carriageway is only advisable on 30 km/h roads. Alternative measures to improve the safety of both cyclists and light moped riders include: 1) removing obstacles such as poles from the bicycle path, 2) following guidelines on the minimum width of bicycle paths given traffic volumes, 3) improving sight distances at intersections, 4) traffic light control without conflicts between traffic flows, and 5) introducing a helmet law for light moped riders and their passengers.

1. Introduction

A light moped is a vehicle that is very similar to the moped. The main difference is the speed limit: mopeds have a speed limit of 45 km/h, light mopeds have a speed limit of 25 or 30 km/h. Whereas the moped is used in most European countries, the light moped is only common in Belgium, Denmark, Germany, Sweden, Switzerland and the Netherlands. Regulations for light moped riders differ slightly between these countries (Davidse et al., 2017). Riders have to have a driving license except in Belgium, and they have to wear a helmet except in the Netherlands. Regulations differ the most on whether it is allowed to carry a passenger. It is always allowed in the Netherlands and never in Denmark. In the other countries it is only allowed for riders aged 18 or older (Belgium) or on light mopeds with an extra seat (Germany, Sweden and Switzerland).

In the Netherlands, as in most other countries, light moped riders (LMRs) have to ride on the bicycle path if such a path is available. Due to several trends such as traffic congestion in general and the introduction of the light moped scooter model, light mopeds have become more popular in the Netherlands, both among older and younger people (Statistics Netherlands). The total number of light mopeds has increased from 304,816 in 2007 to 680,563 in 2017. This has led to an increased traffic density on bicycle paths as well as concerns about the safety of cyclists (Methorst et al., 2011). In response to these concerns, several Dutch cities would like to ban LMRs from the bicycle path and let them ride on the carriageway.

* Corresponding author.
E-mail address: ragnhild.davidse@swov.nl (R.J. Davidse).
[1] Currently working at Rijkswaterstaat.

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This measure is comparable to the measure of moving the moped from the bicycle path to the carriageway in urban areas, which was introduced in the Netherlands in 1999. The main goal of this measure was to improve the safety of moped riders by reducing the number of collisions between cars turning right and mopeds riding on the bicycle path next to the road. The countermeasure had a positive effect on the total number of injury crashes involving mopeds of about 15% (Van Loon, 2001). A pilot study that was carried out before the countermeasure was implemented showed that in cities where mopeds were moved from the bicycle path to the carriageway, both the number of injury crashes between mopeds and cars, and the number of injury crashes between mopeds and cyclists had decreased significantly (Hagenzieker, 1994).

The question is whether a similar measure for LMRs would have the same effects. Whereas mopeds are allowed to ride 45 km/h inside urban areas – except when riding on bicycle/moped paths inside urban areas – light mopeds are only allowed to ride 25 km/h, regardless of where they ride. With speed limits being 50 km/h on most urban roads with bicycle paths, this may lead to conflicts and crashes between LMRs and motorized traffic. Moreover, there are doubts as to whether the amount of conflicts and crashes between LMRs and cyclists as a result of their shared use of bicycle paths justifies the ban of LMRs on bicycle paths (Methorst et al., 2011).

Before a decision can be made about whether moving the LMR to the carriageway is the best measure to improve the safety of both LMRs and cyclists, knowledge is needed about the crash scenarios and causation factors of light moped crashes on bicycle paths. This knowledge is currently not available. Most of the literature on mopeds is focused on those mopeds that are allowed to ride 45 km/h, which can be explained by the fact that these mopeds are much more common than light mopeds, which was also the case in the Netherlands before the introduction of the scooter model. Those studies that have focused on light moped crashes (Craen et al., 2013; Kühn et al., 2013; Methorst et al., 2011; Møller and Haustein, 2016) do not provide details about crash scenarios of light moped crashes on bicycle paths. Therefore, an in-depth crash investigation study was carried out to gain more insight into the factors and circumstances that influence the occurrence and consequences of light moped crashes on bicycle paths.

2. Methodology

An in-depth study was carried out on crashes involving a light moped rider that occurred on a bicycle path inside an urban area, and as a result of which a road user was taken to hospital by ambulance. The aim was to collect and analyze detailed information about approximately 40 crashes. This number of crashes was considered large enough for a good understanding of the most important crash and injury factors, given the specific type of crashes that was investigated (Davidse, 2007; see Boele et al., 2017 and studies by the Danish accident investigation board (www.hvu.dk) for examples of in-depth studies with a similar sample size). The study was conducted by a dedicated team for in-depth road crash investigation that focuses on all aspects of the crash. This includes behavior and background of the road users involved, type and condition of the vehicles involved, road layout and other characteristics of the crash location (e.g. presence and characteristics of obstacles on cycling facilities and possible sight restrictions). Furthermore, the team collects and analyzes information on general conditions such as weather and light conditions, the injuries sustained and damage to the vehicles.

2.1. Selection of relevant crashes

Data was collected from February 15th 2015 until December 15th 2016. The in-depth team was notified of relevant crashes by the police in the northern part of the province of South-Holland in the Netherlands (see Fig. 1); an area that includes both rural and urban areas and accounts for about 10% of all crashes that occur in the Netherlands, and 15% of all powered two-wheeler crashes in the Netherlands (Davidse, 2007; Morris et al., 2018). The police informed the team about all possible relevant crashes they registered 24/7 by means of automated notifications at the end of every day. The team received basic information on 349 crashes that seemed relevant for the in-depth study, i.e. crashes involving a LMR who was riding on a bicycle path as a result of which one of the road users involved was taken to hospital by an ambulance. The basic information included the address of the crash location, type of crash, and age, gender and contact details of the road users involved. Based on this information, the team tried to contact the rider of the light moped who was involved in the crash. If this rider was willing to cooperate with an interview (including informed consent), and this rider or the road user he collided with was considerably injured – MAIS 2+ or not able to work, attend school or carry out demanding chores for several days –, data collection was started. As injury severity had to be deduced from information provided by the road user during a telephone conversation, the team focused on fractures and concussions; these are almost always AIS 2 or higher. Exceptions are some facial fractures and fractures in fingers and toes, and concussions without loss of consciousness (Gennarelli and Wodzin, 2012). Concussions without loss of consciousness were the only reason for including crashes where MAIS was 1 for all road users involved. It was not possible to be sure whether the person who suffered concussion had lost consciousness or not. That was the reason for adding the inclusion criterion "not able to work, attend school or carry out demanding chores for several days".

2.2. Data collection

Data collection was started by one of the team's psychologists who conducted a semi-structured interview with the LMR and any other road user involved in the crash who was willing to participate. During the interview, which usually lasted about one hour, the interviewed person was asked about how the crash occurred, how he perceived the crash location, about the condition of his vehicle, maximum vehicle speed, his experience with this vehicle and familiarity with the crash location, his medical condition, his physical and emotional well-being before the crash, factors that played a role in the occurrence of the crash, any activities carried out at the moment the crash occurred (e.g. talking to a passenger, listening to music, using a mobile phone), and any injuries as a result of the crash.

Next, the light moped was inspected by the team's vehicle specialist or, if the moped was at the LMR's home address, by the psychologist after having conducted the interview. They used a standardized coding form to describe the details of the vehicle, including make and model, color, sizes, age, mileage, accessories, general condition of the vehicle, and condition of brakes and tires. In addition, they took a standard set of pictures of the light moped (from all around the vehicle), of vehicle parts such as wheels, tires and brakes, and of any damage caused by the crash. The vehicle specialist interpreted the collected information regardless of who had collected it.

Using the information from the interview, two other team members, including one road safety engineer, carried out a retrospective scene examination. They measured all road elements (e.g. road and lane width, distance between carriageway and bicycle path, road markings, curb height, distance between obstacles and road or bicycle path), drew a sketch of the road layout, took pictures of the road scene in general and of details such as obstacles on and near the bicycle path (e.g. poles and curb), assessed traffic light operations and sight distances, and made a video of the last 500 m that the light moped rider and other road users involved had ridden or driven.

Information from the injuries that the light moped rider or any other road users involved had sustained were collected during the interview and from the hospital, provided that the road user had given permission to obtain this information (informed consent). Data collection was

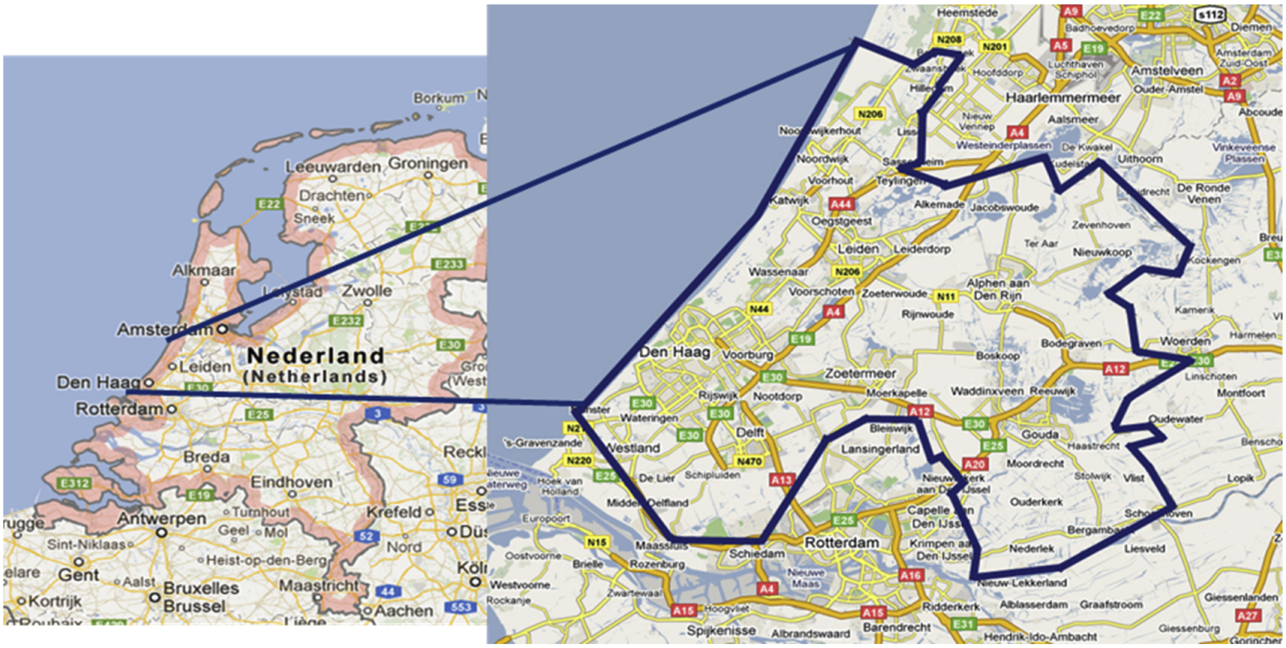


Fig. 1. Area of data collection: northern part of the province of South-Holland in the Netherlands.

carried out retrospectively, according to protocols which were composed in 2009, when the investigation team was set up and received dedicated national and international training (Davidse, 2007, 2011).

The team was able to collect information on 36 crashes; about 10% of the 349 possible relevant crashes. About 64% of the 349 possible relevant crashes was excluded in the final set of crashes because there were doubts about injury severity – not serious enough for inclusion – or whether the crash had occurred on a bicycle path (see Fig. 2). About 9% was excluded because the team was not able to contact the LMR (after three attempts had failed), and another 11% of the crashes was excluded because the LMR was not willing to cooperate. About 7% of the LMRs was not contacted yet at the time the team decided to stop the collection of additional crashes.

Chi square analyses were used to compare the general characteristics of the set of crashes that was included in this study with the characteristics of the three sets of crashes that were excluded but may have been relevant: 'not able to contact' (*Set 2*), 'not willing to cooperate' (*Set 3*), and 'not contacted yet' (*Set 4*). We compared the age distribution of the LMRs in the set of analyzed crashes with that in each of the other three sets and with that in the total set of excluded cases (four comparisons), and did the same for the gender distribution and the distribution of crash types (single vehicle, LMR vs low speed road user, and LMR versus high speed road user). None of the 12 comparisons showed a significant difference ($\alpha = .01$) between the included set of crashes and a set of excluded crashes (see Davidse et al. (2017) for detailed results). Therefore, it seems that the exclusion of cases has not caused any bias in terms of gender or age of the light moped rider or in terms of crash type.

349 notifications
- ➡ 211 crashes doubts about injury severity or crash location (bicycle path)
- ➡ 138 relevant crashes
  - ➡ 24 LMR's not contacted (yet) or one attempt *(Set 4)*
  - ➡ 114 LMR contacted
    - ➡ 38 not willing to cooperate *(Set 3)*
    - ➡ 30 not possible to contact despite several attempts *(Set 2)*
    - ➡ 14 not relevant according to additional information from LMR
    - ➡ 32 willing to cooperate (LMR or relevant other road user)
      - ➡ 4 crashes from *Set 2 and 3* (2 from each set) included based on ample information
        - ➡ 36 LMR crashes investigated *(Set 1)*

Fig. 2. Graphical presentation of numbers of excluded crashes and reasons for exclusion.

2.3. Data analysis

Each of the 36 included crashes was analyzed in detail. Based on the information collected via the interviews, scene investigations and vehicle inspections, the multidisciplinary investigation team discussed every single crash and tried to determine the most likely course of events. In addition, possible contributing factors were systematically discussed using a standardized list of factors that could have played a role in the occurrence of a crash and possible injuries (see Davidse et al. (2017) for the total list of factors). The major part of this list was drawn up by the team in 2009, and it was partly based on the results of the European TRACE-project (Van Elslande et al., 2008). A distinction was made between contributory factors related to the road users involved, their vehicles, the road, and general conditions at the time of the crash. All factors that played a role in the occurrence of the crash were selected. In addition, for each selected factor the team indicated how certain they were about that factor's contribution to the occurrence of the crash or any injuries. The result of each crash analysis was a description of the crash pattern for every active road user involved in the crash (i.e., rider of the vehicle): 1) the pre-crash traffic situation, 2) the factors that played a role in the occurrence of the crash, 3) the critical situation to which these factors led, 4) the actual crash, 5) the injuries sustained by the road users involved in the crash, and 6) factors that caused the injuries or increased their severity (see Van Elslande and Fouquet (2007) for a similar approach).

After all crashes had been described in this manner, crashes with a similar course of events and a comparable combination of contributory factors were grouped into (sub)types of crashes. To this end, every crash was represented by a one-page description of the crash pattern, and the total set of one-page descriptions was sorted into piles of similar crash patterns. We aimed at an optimal combination of homogeneity within groups and heterogeneity between groups. This sorting or classification task was carried out by three team members independently. The results of these classifications were discussed until these team members agreed on the composition of all subtypes. Next, these subtypes were described based on their general crash pattern, the characteristics of the light moped riders involved and any other characteristics that the crashes of that subtype shared. The result was a prototypical scenario for each subtype. A prototypical scenario is the common denominator of all crashes of that specific subtype. Therefore, it is not the scenario of a real crash, but a characteristic description of that particular type of light moped crash. The aim of developing these prototypical scenarios was to visualize the most common types of crashes, which will help in understanding the common crash mechanisms and subsequently in selecting measures for preventing these types of crashes in future. The aim was not to statistically test any differences between groups of crashes.

3. Results

3.1. General characteristics

All the investigated crashes occurred on an urban bicycle path, with 10 of them taking place on a road section of a bicycle path and 26 on an intersection. About two thirds of the bicycle paths were one-way paths (n = 22). The majority of the bicycle paths were situated along a 50 km/h road (n = 26; three quarters).

In all but two of the crashes another road user was involved. This road user either collided with the LMR (in 27 crashes) or his presence or behavior forced the LMR to act, as a result of which the LMR fell (7 crashes). In more than half of the cases (20 crashes) the other road user was driving a car or other type of motorized vehicle (moped, motorcycle, van, or tram). In 10 cases there was a conflict between a LMR and a cyclist, and in 3 cases the LMR was confronted with a pedestrian on the bicycle path.

Two thirds of the LMRs was a male rider. The age of the LMR varied from 16 to 77 with all age groups in between being represented. Female riders were less old: the oldest female rider was 58 years of age, whereas 8 of the male LMRs were over the age of 60. Most LMRs rode on a scooter model (n = 29; 80%). The rest drove on a more old-fashioned model (n = 6; 20%), which is a bit smaller (60–70 cm instead of 70–95 cm), and weighs less (50–55 kg instead of 90–125 kg) than the scooter model (see Fig. 3), or on a speed-pedelec (n = 1), which was considered a light moped in Dutch legislation at the time this study was conducted (since 1st of January 2017, speed-pedelecs are mopeds according to Dutch and European legislation).

Maximum vehicle speed was known for 29 of the 36 light mopeds that were involved in the investigated crashes; speeds that were either measured by the police or indicated by the light moped rider. Maximum vehicle speed varied from 25 to 58 km/h. About half of these light mopeds (n = 16) could ride faster than allowed, including a margin of 4 km/h (25 + 4 = 29 km/h), and 11 of them could even ride faster than 35 km/h. The latter would no longer be allowed to ride on public roads if these high vehicle speeds would be established by the police. Such tuned vehicles – vehicles that were manipulated to ride faster than their original speed – have to be restored into their original state and then tested by the Vehicle Authority before they are allowed on the road again. The riders of these tuned vehicles were both women and men, mostly younger than 50 years of age. Riding on a light moped that can travel at a speed higher than 35 km/h does not necessarily mean that the LMR also drove too fast at the time of the crash. It only indicates that the vehicle could ride faster than it is allowed to.

3.2. Contributory crash factors and human functional failures

The major part of the analysis of the crashes consisted of team discussions on the most likely course of events and on which factors had contributed to the occurrence of the crashes. These team discussions focused on single crashes and crash factors were determined for all active road users involved in the crash (i.e., LMR and the driver of the other vehicle involved). Table 1 shows the results of the aggregated data for all 36 crashes. It shows the most frequent contributory crash factors for the LMR per type of factor.

From the point of view of the other road user involved in the crash, the most frequent contributory crash factors were restricted sight on other traffic (30–37%), intersection layout (26–37%), vehicle position (30–33%) and the behavior of the LMR which forces him to act (22%). The percentages refer to the 27 crashes in which another road user was involved – not necessarily in terms of a collision – and about whom there was enough information available to determine contributory crash factors.

The behavior of the road users involved in the crash can be summarized based on their functional failures (Van Elslande and Fouquet, 2007). These functional failures are linked to the five stages of information processing: detection, interpretation, prediction, decision and action. The use of the word ‘failure’ does not imply that the road user was to blame for the crash, as this failure is related to or provoked by characteristics of the road user, his vehicle, another road user and/or characteristics of the road environment: the contributory crash factors. Table 2 presents the functional failures for the LMR and the other road users involved in the crash. The most frequent functional failures of the LMR were at the stage of information detection and prediction of the situation. The failures at the information detection stage were either the result of not having looked for traffic or ‘looked but failed to see’. The failures at the stage of prediction are typical for crashes in which the LMR collides into a door of a parked car that was opened just before he passed the car, and for crashes that occur when a LMR has right of way and a motorist who was waiting suddenly starts to cross. The most frequent functional failure of the other road user involved in the LMR crash was at the detection stage: they had looked but failed to see the LMR.

3.3. Types of crashes involving light moped riders who ride on an urban bicycle path

Six types of crashes were identified. They represent sets of investigated crashes that had a similar course of events and a comparable combination of contributory factors. The prototypical scenarios of these crash types are described in Table 3. A prototypical scenario is the common denominator of all crashes of that specific subtype. Therefore,

Fig. 3. Example of a traditional light moped (left) and a light moped scooter (right).

Table 1
Most frequent contributory crash factors for the LMR.

Type of factor	Contributory factors	Share of crashes[a]
General factors	Behavior of another road user, such as not yielding, forces the LMR to act in order to avoid a collision	69–72%
	Wet road surface	14–19%
	Visibility conditions: twilight/darkness	8–11%
Human factors	Speed:	19–28%
	-Above speed limit	6–8%
	-Too high given circumstances or riding ability	14–19%
	Internal conditioning of LMR (e.g. rigid attachment to right of way status)	14–25%
	Psychophysiological condition (e.g. in a hurry, fatigue)	11–17%
	Unfamiliarity with vehicle or traffic situation	8–17%
	Lateral position of the LMR (e.g. too close to the edge)	8–14%
Vehicle factors	Vehicle condition (e.g. bad condition of brakes, tires)	8–14%
	Tuned vehicle (maximum vehicle speed > 35 km/h)	6–17%
Road factors	Sight restriction	19–25%
	Intersection layout (e.g., traffic light control)	14–17%
	Bicycle path too narrow	8–14%
	Obstacle on bicycle path	11%

[a] The first and lowest number in brackets indicates the percentage of crashes in which the contributory crash factor (almost) certainly played a role. The second percentage also includes those crashes about which there was some doubt about the validity of that particular factor.

Table 2
Functional failures for the LMR and the other road user involved.

Functional failure	LMR	Other road user
Information detection	10 (28%)	17 (63%)
Interpretation of the information	3 (8%)	2 (7%)
Prediction of the situation	9 (25%)	1 (4%)
Decision on what to do	2 (6%)	1 (4%)
Execution of the planned action	5 (14%)	1 (4%)
Unknown	7 (19%)	5 (19%)
Total	36 (100%)	27 (100%)

it is not a real crash, but a characteristic description of that particular type of light moped crash. It also means that not every crash represented by the scenario occurred in exactly the same way. The aim of the prototypical scenarios is to visualize the most common types of crashes, which will help in understanding the common crash mechanisms.

A list of all six identified crash types is included in Table 4. The first column briefly describes the crash type. The second column indicates whether these crashes seem to occur more often on road sections or intersections, and which other type of road user is usually involved in this type of crash. The third column shows which contributory factors the crashes of that type had in common, with the ones that played a role in the most crashes on top.

3.4. Injuries of the road users involved in light moped crashes

The road user who was most severely injured as a result of the crash had a Maximum Abbreviated Injury Severity (MAIS) of 1 in half of all cases (50%), a MAIS of 2 in one third of the cases (33%) and a MAIS of 3 or more in one sixth of all cases (17%). In the majority of the cases (86%), the LMR was the one who was most severely injured, and they were all taken to hospital by ambulance. About half (51%) of those 31 LMRs had to spend at least one night in hospital (1–24 nights). One of the hospitalized patients died in hospital. Half of all LMRs (n = 19) had a MAIS of 2 or above. Seven of them sustained the severest injuries to their head (four of them AIS 3), six of them to their lower extremities (one of them AIS 3), and five of them (also) to their upper extremities (all AIS 2). Four LMR were (also) most severely injured to their thorax (three of them AIS 3).

Of those crashes in which a cyclist was involved (n = 10), the LMR was the most severely injured in six cases, and mostly also the only one who sustained injuries (i.e., cyclist not injured). In four cases the cyclist was the only one who was injured (one had MAIS 2, three had MAIS 1). Seven LMRs were carrying a passenger on their moped. Five passengers sustained injuries as a result of the crash and four of those injured passengers were brought to hospital (MAIS 1 or 2).

None of the LMRs, their passengers or the cyclists involved in the light moped crashes was wearing a helmet. Given the nature and location of their head injury, a helmet could have reduced injury severity or prevented head injuries for 19 out of 31 injured LMRs, 2 out of 4 injured passengers and 3 out of 5 injured cyclists.

4. Discussion

The aim of this in-depth study was to gain more insight into the factors and circumstances that influence the occurrence and consequences of light moped crashes on urban bicycle paths. Six types of crashes were identified. In addition, we were able to identify the most common contributory factors per crash type. Road user behavior played a role in all but one type of crash; the one in which the LMR is put to the test by the road layout. In three of the other crash types, the behavior of the crash opponent of the LMR played the most important role in the occurrence of the crash. This crash opponent, mostly a car driver, did not give right of way to the LMR, mainly because he had not noticed the LMR. In one type of crash, it was the LMR who was not giving right of way and taking risks. In general, the LMR's contribution to the occurrence of the crash, if any, was a speed that was too high for the circumstances or a too rigid attachment to his right of way status. Sight restrictions due to road layout or trees and parked vehicles that blocked the view played a role in three of the six identified crash types. Other common crash factors related to the road layout were traffic light configuration, too narrow bicycle paths and obstacles on the bicycle path.

It must be noted that the six scenarios and the description of common contributory crash factors were based on a qualitative investigation of a relatively small number of crashes that occurred in a restricted sampling area. A quantitative analysis of a larger set of crashes would be useful to validate these results. However, national databases of road traffic accidents do not contain the details necessary to select light moped crashes on bicycle paths, and in-depth accident investigations are too expensive for collecting hundreds of accidents of one specific type. A comparison of the general characteristics of our dataset and those of crashes involving LMR in general in the Netherlands, as well as those of crashes involving LMR investigated in in-depth studies in other European countries, would shed a light on the representativeness of our sample. Two thirds of the LMRs involved in the crashes investigated in this study was a male rider, and the age of the LMR varied from 16 to 77. De Ceunynck et al. (2018), who studied

Table 3
Prototypical scenarios of the identified types of LMR crashes on urban bicycle paths.

Prototypical scenario of a LMR who is being put to the test by the road layout

A light moped rider rides on a bicycle path and approaches an obstacle. He does not notice the obstacle or notices it but cannot control his light moped when passing the obstacle. Either way, the obstacle puts the LMR to the test as it is situated at a spot where the LMR has to focus his attention on other matters, or the demands of passing the obstacle are too high for two-wheelers riding on the bicycle path. The LMR cannot avoid the obstacle and falls down. As a result, the LMR sustains serious injuries to his head or lower extremities (legs). Injury severity varies from MAIS 1 to 3 (75% MAIS 2+).

Prototypical scenario of a LMR who loses control after anticipating the behavior of another road user

A light moped rider and his/her[a] passenger ride on a one-way bicycle path and notice that another road user threatens to obstruct their way. A pedestrian is about to cross the bicycle path, a cyclist is blocking the bicycle path or a motorist does not seem to give way. Therefore, the LMR reduces speed. While doing so he loses control of his vehicle. He loses his balance, partly due to the wet road surface, the condition of his brakes or tires, and/or his riding experience. As a result, he skids and lands on the pavement. He sustains light to moderate injuries to his upper and/or lower extremities (bruises, grazes and broken bones) and suffers a concussion. Injury severity varies from MAIS 1 to 3 (57% MAIS 2+).

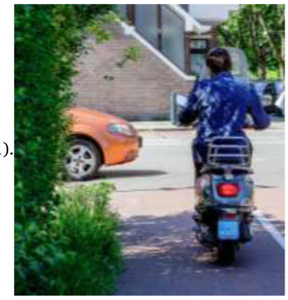
Prototypical scenario of a LMR who collides with a cyclist riding in the same direction after one of them changes direction without indicating his intentions

A light moped rider wants to overtake a cyclist near an intersection. The cyclist wants to turn left at that intersection but did not or not clearly indicate his intentions. The road layout also plays a role, as the intersection layout does not accommodate the local traffic flows of cyclists; there is no designated area for left-turning traffic or there is no intersection at all. When the cyclist starts turning left, the LMR swerves to avoid a collision. As a result, the LMR falls and sustains various injuries (50% MAIS 2+). The cyclist hardly sustains any injuries, i.e. not seriously enough for a visit to the hospital.

Prototypical scenario of a LMR who is not alert or takes risks in a traffic situation with an obstructed view on traffic for which he has to yield

A light moped rider rides on a bicycle path and approaches an intersection with an obstructed view on the traffic he is about to cross. Despite the obstructed view, the LMR rides at quite a high speed. When he finally has a good view on the other traffic it is too late: he cannot avoid a collision. The other road user involved was also taking risks. He was running or cutting the corner. Eventually the LMR and the other road user collide. As a result, one of them sustains injuries (MAIS 1 to 3; 40% MAIS 2+), with the injuries of the LMR being more severe (MAIS 1 to 3; 67% MAIS 2+) than the injuries of the other road user (MAIS 1).

Table 3 (*continued*)



Prototypical scenario of a LMR who is not given right of way and who collides with a car

A light moped rider approaches an intersection that he wants to cross. This intersection is controlled by traffic lights or by an exit type construction (traffic on the bicycle path has right of way over traffic that crosses it). When the LMR approaches the intersection, a car wants to turn right. The traffic light operation does not prevent conflicts between traffic flows; the car driver and LMR have a green traffic light simultaneously. At the intersections without traffic lights, the car driver's view on the LMR is obstructed by trees or parked vehicles. The high speed of the LMR also reduces the chance that the car driver will notice him. When the LMR notices that the car driver is about to turn right, he applies his brakes, but cannot prevent a crash. Not all LMRs check for turning traffic: they have right of way and act accordingly. The LMR and turning car collide, as a result of which the LMR sustains injuries to his head and his upper and/or lower extremities (MAIS 1 to 3; 63% MAIS 2+). The other road user involved does not sustain any injuries or only minor injuries (MAIS 1).

Prototypical scenario of a LMR who is hindered by and collides with a parked car

A light moped rider rides on a bicycle path and approaches a vehicle that is parked close to the bicycle path. When the LMR is about to pass this parked vehicle, one of the doors is opened. The one who opened the door had not noticed the LMR or only when he opened the door. The LMR cannot avoid the door. His vehicle collides with the door and the LMR falls down. As a result, he sustains injuries to his head, upper and/or lower extremities (MAIS 1-2; 33% MAIS 2+). The other road user involved does not sustain any injuries.

[a] These scenarios apply to both crashes of males and females. For readability reasons the masculine pronoun is used in these scenarios.

both crashes of light mopeds and mopeds in urban areas in Belgium, report that three quarter of the riders were males, and the age of the riders ranged from 16 years to 80 and above. Møller and Haustein (2016), who investigated crashes of young light moped riders (aged 16 or 17) in Denmark, report that 81% of the LMRs was male. The only German study on light moped crashes, by Kühn et al. (2013) did not report on the type of LMRs involved in crashes. These distributions all point in the same direction: the majority of the riders is male and all age

Table 4
Identified crash types of light moped riders who were involved in a crash that occurred on a bicycle path inside an urban area.

Type of crash	Location & Other road users involved	Common contributory factors
Light moped rider (LMR) is being put to the test by the road layout (n = 4)	Road sections and intersections Obstacle	• Obstacle on/next to bicycle path • Visibility conditions: darkness or low sun • Unfamiliarity with vehicle or traffic situation
LMR loses control after anticipating the behavior of another road user (n = 8)	Road sections Various road users	• Behavior of another road user forces the LMR to act in order to avoid a collision • Wet road surface • Psychophysiological condition (in a hurry, fatigue) • Inexperienced in riding on a light moped • Sight restriction for LMR and/or other road user • Other road user blocks the bicycle path • Worn tires of the light moped • Speed too high given circumstances • Width of the bicycle path is too narrow
LMR collides with a cyclist riding in the same direction after one of them changes direction without indicating his intentions (n = 2)	Intersections Bicyclists	• Other road user does not indicate his direction of travel • Intersection layout
LMR is not given right of way by a cyclist or motorized traffic (n = 10)	Intersections Motorists	• Other road user does not yield and forces LMR to act • Internal conditioning of LMR (rigid attachment to right of way status) • Intersection layout (traffic light control does not prevent conflicts between traffic flows) • Sight restriction for other road user (trees, parked cars) • Riding speed of LMR too high
LMR is not alert or takes risks in a traffic situation with an obstructed view on traffic for which he has to yield (n = 5)	Intersections Various road users	• Sight restriction for LMR and other road user • Riding speed of LMR too high • Psychophysiological condition (in a hurry, fatigue) of other road user
LMR is hindered by a parked car: a door is opened or a car drives away and crosses the bicycle path (n = 3)	Road sections Motorists	• Other road user opens door or crosses the bicycle path • Tuned vehicle, riding speed unknown • Car is parked on or very close to bicycle path

groups are represented. Other crash characteristics, such as the crash opponent and the injuries sustained, are more difficult to compare, as the studies differed in the types of crashes that were investigated, and no distinction was made between crashes on bicycle paths and crashes on the carriageway. Based on a comparison of the investigated and not investigated crashes in the sampling area of our study, as well as a comparison between crashes in the sampling area and the rest of the Netherlands, the results of this study seem to be representative for the Netherlands (Davidse et al., 2017). As some traffic rules differ for LMRs in the Netherlands compared to LMRs in other European countries, results may not be representative for other countries. However, they may be representative for countries where LMRs and cyclists share the bicycle path, except for the percentage of LMRs that sustain head injuries, as the Netherlands is the only European country in which LMRs are not obliged to wear a helmet.

Our results confirm earlier findings that LMRs do not pose a large threat to cyclists on the bicycle path (Methorst et al., 2011). Cyclists were involved in about a quarter of the light moped crashes on bicycle paths but did not sustain injuries more often than LMRs as a result of these crashes, and if cyclists did sustain injuries the injuries were minor to moderate (MAIS 1 to 2). However, these crashes would not have occurred if the LMR would have ridden on the carriageway. The same applies for crashes that occurred when a turning motorized vehicle did not yield to a LMR who was riding on a bicycle path. One of the contributing factors of the latter type of crashes is the speed of the LMR; the high speed of the LMR may have made it more difficult for the motorist to notice the LMR. This is one of the arguments for banning LMRs from the bicycle path and letting them ride on the carriageway: LMRs would be more visible to motorists. However, LMRs are only supposed to ride 25 km/h, which is much lower than the speed limit on most urban roads with bicycle paths (50 km/h). Also taking into account that wearing a helmet is not obligatory for LMRs in the Netherlands, the safety of LMRs may be at stake. Therefore, moving the LMR to the carriageway is only advisable on 30 km/h roads. Based on the contributing crash and injury factors identified in this study, alternative measures to improve the safety of both cyclists and light moped riders include: 1) removing obstacles such as poles from the bicycle path, 2) following guidelines on the minimal width of bicycle paths given traffic volumes, 3) improving sight distances at intersections, 4) traffic light control without conflicts between traffic flows, and 5) introducing a helmet law for light moped riders and their passengers (Boele-Vos et al., 2017; Davidse et al., 2017; Leijdesdorff et al., 2012).

As regards the latter measure, the light moped became a separate type of vehicle in the Netherlands when the helmet law for moped riders was introduced in the Netherlands. People who were not able or willing to wear a helmet could use a light moped instead of a moped. A precondition was that the speed of the light moped was restricted to 25 km/h and could not easily be changed. Nowadays, the pedelec (electrically assisted bicycle up to 25 km/h) would be a good alternative for people who are not willing to wear a helmet – on either a moped or light moped – and are not fit enough to use a bicycle. However, two of the drawbacks of light mopeds also apply to pedelecs. First, pedelec riders also ride faster than the average cyclist – especially in case of older cyclists – and hence faster than motorists expect. This may lead to car-light moped crashes being replaced by car-pedelec crashes. Second, it is even easier to tune pedelecs than it is to tune light mopeds. Therefore, speeding pedelecs may create the same problems as light mopeds.

5. Conclusion

Six types of crashes of light moped riders on urban bicycle paths were identified and described using prototypical scenarios. The identified crash types are:

- LMR is being put to the test by the road layout;
- LMR loses control after anticipating the behavior of another road user;
- LMR collides with a cyclist riding in the same direction after one of them changes direction without indicating his intentions;

- LMR is not given right of way by a cyclist or motorized traffic, which results in a collision;
- LMR is not alert or takes risks in a traffic situation with an obstructed view on traffic for which he has to yield, which results in a collision;
- LMR is hindered by and collides with the opened door of a parked car.

The aim of developing these prototypical scenarios was to visualize the most common types of accidents, which will help in understanding the common accident mechanisms and subsequently in selecting measures for preventing these types of accidents in future. The scenarios and their contributing crash factors show that LMRs do not pose a large threat to cyclists on the bicycle path. Cyclists were only involved in about a quarter of all light moped crashes on bicycle paths, and did not sustain serious injuries more often than LMRs as a result of these crashes. Given the maximum speed of light mopeds of 25 km/h, it is not advisable to move the LMR to the carriageway on roads with a speed limit above 30 km/h. Alternative measures to improve the safety of both cyclists and light moped riders include: 1) removing obstacles such as poles from the bicycle path, 2) following guidelines on the minimum width of bicycle paths given traffic volumes, 3) improving sight distances at intersections, 4) traffic light control without conflicts between traffic flows, and 5) introducing a helmet law for light moped riders and their passengers.

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