Manuscript Details

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Title	The perception of bicycle crashes with and without motor vehicles: which crash types do older and middle-aged cyclists fear most?
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Abstract

Several studies have focused on the perceived risk of bicycle crashes (irrespective of crash types) and concluded that cycling near high volumes of motor vehicles deters people from cycling. The perceived risk of bicycle crash types (with or without motor vehicles) has not yet been studied. Cyclists, both in countries with low and high levels of cycling participation, are substantially more likely to sustain severe injuries in single-bicycle crashes than in bicycle-motor vehicle crashes. This questionnaire study sets out to compare which bicycle crash types are perceived to cause most hospitalizations among cyclists. The study comprised cyclists over 55 years in the Netherlands, and over 40 years in the Belgian regions of Flanders (a region with high cycling participation), Brussels and Wallonia (regions with low cycling participation). The majority of cyclists (60%) perceive bicycle-motor vehicle crashes cause most hospitalizations among cyclists. This percentage is greatest in the areas of Brussels and Wallonia and lowest in the Netherlands. Cyclists who were involved in a bicycle-motor vehicle crash themselves are more likely to regard this crash type as the most common cause of hospitalizations among cyclists, while cyclists over 60 years who were involved in a crash without a motor vehicle are more likely to perceive that crash type as the most common cause. The smaller perception bias in the study areas with higher cycling participation – particularly the Netherlands and to a somewhat lesser degree Flanders – is probably due to bicycle infrastructure being more separated from high-speed motor traffic, leaving cyclists less exposed. The outcomes show that cyclists underestimate the likelihood of severe injuries due to single-bicycle crashes. New interventions should raise the awareness of the risk of single-bicycle crashes and provide solutions to avoid such crashes.

Keywords	cycling safety; perceived risk; risk perception; single-bicycle crash; modal share
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Submission Files Included in this PDF

File Name [File Type]

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Response to reviewers.docx [Response to Reviewers]

Research Highlights.docx [Highlights]

Manuscript Perception bicycle crashes revised.docx [Manuscript File]

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March 25th, 2020

Dear Editor,

Would you please consider the enclosed revised manuscript entitled "The perception of bicycle crashes with and without motor vehicles: which crash types do older and middle-aged cyclists fear most?" for your consideration for publication in Transportation Research Part F.

The comments on our paper were very useful to improve the original manuscript (TRF_2019_644_R2). We have submitted a response to reviewers to explain how we have revised the paper.

The contents will not be submitted or published elsewhere.

Sincerely,

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Response to reviewers

The perception of bicycle crashes with and without motor vehicles: which crash types do older and middle-aged cyclists fear most?

We thank both reviewers for their useful comments. The first reviewer did not have further comments on the revised manuscript. Below we describe how the comments of reviewer 2 are addressed.

1. Line 87: It seems strange to give three references to the population figures of Belgium. Statistics Belgium is perhaps enough.

Response1: The references after this sentence have been restricted to 'Statistics Belgium', while one of the two other references has been placed after the preceding sentence.

2. Line 122-126: Figure title of figure 2 contains lots of references and explanations. Consider moving this information to a separate paragraph below the figure.

Response 2: The footnote contains a lot of references indeed. To solve this problem we have added a row at the bottom of the table with references for the type of information per column. This makes the references more specific and shorter because we don't need to write to what type of information it refers.

3. Line 186-188: Consider rewriting to clarify, e.g. "If all respondents gave the correct answer, everyone would have to answer … " (just have a look)

Response 3: Thank you, we have replaced the current part of the sentence 'Leaving aside perception bias, 100% of our respondents would have to answer …' by your suggestion 'If all respondents gave the correct answer, everyone would have to answer …' (see line 183 in the revised manuscript).

4. Line 199: Lacks a dot after etc.

Response 4: A dot has been added after 'etc'.

5. Line 252-254: Consider dividing in two figures.

Response 5: Figure 3 has been divided in two figures, Figure 3/4.

6. Line 272: Figure title - not nine but eight factor loadings

Response 6: There are nine factor loadings in Figure 5 (Figure 4 in the previous version). Two factors in the top left of the figure have almost similar factor loadings and are partly overlapping. Therefore it may seem at first glance as if the figure contains eight factor loadings.

7. Line 284: Is the effect of frequent cyclists here an artefact due to the inclusion of regions in the regression? The effect of the regions indicate the frequent cycling increase the correct perception of single accidents as most frequent crash type. Perhaps just mention this in the discussion.

Response 7: That is indeed possible because univariate analyses do not include control variables. We address this issue by the following sentences in the subsequent section 'Multivariate binary logistic regression analysis' using the following two sentences:

- First sentence of the section starting at line 287: 'Backward stepwise binary logistic regression was used to achieve a model containing statistically significant variables in which the results of variables are controlled for other variables in the model'
- Last sentence of the section starting at line 299: 'The fact that some variables such as cycling frequency were significantly associated with perception in the univariate analysis and not in this multivariate analysis suggests that these effects may have been confounded by for instance study region.'

8. Line 322: "analyses" should be replaced with "analysis"
Response 8: We kept the plural 'analyses' in the footnote. There is only one column containing outcomes of Binary logistic regression analyses with 'uOR' in the top row (odds ratio in univariate analyses). However, this column contains the results of multiple separate analyses, all with the own uOR's. The 'mOR' results do result from one multivariate analysis for each column but there are three columns for three multivariate analyses for which uOR's are reported. In both cases the results are about multiple analyses.

9. Line 417: "safer" should be replaced with "lower"
Response 9: Thank you, done!

The perception of bicycle crashes with and without motor vehicles: which crash types do older and middle-aged cyclists fear most?

Highlights

- The vast majority of cyclists admitted to hospitals are single-bicycle crash victims
- The majority of cyclists believe bicycle-motor vehicle crashes cause most hospitalizations
- This perception bias among cyclists is greater in regions with lower bicycle modal shares
- Risk perception is affected by cyclists' own crash involvement

The perception of bicycle crashes with and without motor vehicles: which crash types do older and middle-aged cyclists fear most?

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Abstract

Several studies have focused on the perceived risk of bicycle crashes (irrespective of crash types) and concluded that cycling near high volumes of motor vehicles deters people from cycling. The perceived risk of bicycle crash types (with or without motor vehicles) has not yet been studied. Cyclists, both in countries with low and high levels of cycling participation, are substantially more likely to sustain severe injuries in single-bicycle crashes than in bicycle-motor vehicle crashes. This questionnaire study sets out to compare which bicycle crash types are perceived to cause most hospitalizations among cyclists. The study comprised cyclists over 55 years in the Netherlands, and over 40 years in the Belgian regions of Flanders (a region with high cycling participation), Brussels and Wallonia (regions with low cycling participation). The majority of cyclists (60%) perceive bicycle-motor vehicle crashes cause most hospitalizations among cyclists. This percentage is greatest in the areas of Brussels and Wallonia and lowest in the Netherlands. Cyclists who were involved in a bicycle-motor vehicle crash themselves are more likely to regard this crash type as the most common cause of hospitalizations among cyclists, while cyclists over 60 years who were involved in a crash without a motor vehicle are more likely to perceive that crash type as the most common cause. The smaller perception bias in the study areas with higher cycling participation – particularly the Netherlands and to a somewhat lesser degree Flanders – is probably due to bicycle infrastructure being more separated from high-speed motor traffic, leaving cyclists less exposed. The outcomes show that cyclists underestimate the likelihood of severe injuries due to single-bicycle crashes. New interventions should raise the awareness of the risk of single-bicycle crashes and provide solutions to avoid such crashes.

Key words: cycling safety; perceived risk; risk perception; single-bicycle crash; modal share

Introduction

Studies on perceived risk among cyclists focus mainly on mode choice and route acceptability (Elvik & Bjørnskau, 2005; Noland, 1995). These studies suggest routes near high volumes of motor vehicles are less attractive and even deter people from cycling (Parkin et al., 2007; Sanders, 2015). Cyclists fear motor vehicles, but between 60% and 95% of cyclists admitted to hospitals or treated at emergency departments in a range of countries with varying bicycle modal shares appeared to be victims of crashes which did not involve motor vehicles, of which some 90% are single-bicycle crashes. A single-bicycle crash is a crash without a crash with another road user such as a fall or crash with a kerb (Schepers et al., 2015). Prevention of serious injuries among cyclists is a key policy issue (EU, 2017). As cyclists play a role in prevention, it is important that they are also aware of the risk of single-bicycle crashes. Therefore, this questionnaire study sets out to compare the perceived risk of severe injuries due to crashes with and without motor vehicles. We use the criterion of hospitalization to define serious injuries because it is easy for respondents to understand.

We hypothesize that cyclists fear bicycle crashes with motor vehicles more than crashes without motor vehicles, and that cyclists perceive crashes with motor vehicles to result in most serious road injuries among cyclists. According to risk perception theories (see e.g. Slovic, 1987), controllability and voluntariness of exposure reduce the perception of how large risks are. Cyclists may overestimate the degree of control they have to avoid falls and may perceive they have less control over critical interactions with motor vehicles in which other road users play a greater role. For instance, being overtaken without being able to see overtaking vehicles directly is likely to be perceived as involuntary and difficult to control, especially in cases of large speed differential and small lateral clearance (Dozza et al., 2016).

After comparing whether cyclists perceive crashes with or without motor vehicles cause most hospitalizations, we examine variables that may cause people to fear one of these crash types most. Next to the demographical variables of age and gender we include the following variables:

- Cycling frequency, because earlier studies found perceived risk of cycling to be related to cycling participation (Heinen & Handy, 2012).
- Involvement in crashes (self-reported), as risk perception is dependent on one's own experiences (Kasperson et al., 1988).
- Experienced mental and physical impairments as Engbers et al. (2018) recently studied the relationship between these issues and the likelihood of being involved in single-bicycle crashes. Mental impairments were found to be correlated. It is conceivable that both factors are also related to perceived risk.
- Regions with varying bicycle modal shares, because cyclists in regions with higher bicycle modal shares and dedicated bicycle infrastructure perceive cycling to be safer (Christmas et al., 2010; Felix, 2010; Fishman et al., 2012; Heinen & Handy, 2012; Van Twuijver et al., 2006).

To include regions with high and low bicycle participation our study covered the Netherlands and the three Belgian regions of Flanders, Brussels Capital Region (BCR) and Wallonia. The Netherlands and Flanders share a common language (Dutch) and border, and are highly urbanized. Brussels, the most densely populated Belgian region, is the de facto capital of the European Union, as it hosts a number of principal EU (and other international) institutions

(Vandenbulcke et al., 2011). Wallonia, whose main language is French, is the least densely populated Belgian region (Statistics Belgium, 2019). Figure 1 depicts the regions included in the study and shows that bicycle modal share (main mode of transport, i.e. without trips to and from bus and railway stations) varies from 27% in the Netherlands to 2% in Wallonia. While the Dutch share is higher than anywhere else in the world, the 18% Flemish share is impressive and comparable to the 17% of Denmark (Ministry of Transport, 2014). The 4% in BCR and 2% in Wallonia are low and comparable to other countries with lower cycling participation such as 3% in France, 2% in England, and 1% in the US (Department for Transport, 2018; Papon, 2016; Pucher et al., 2011).

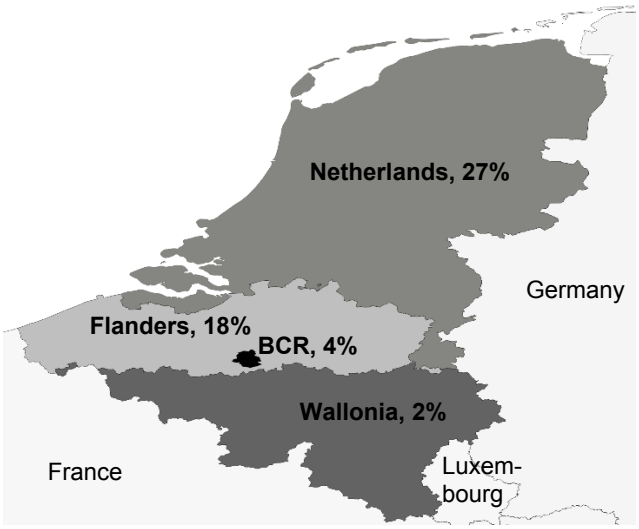

Figure 1 Regions included in the study and their bicycle modal share (FOD, 2018; Harms & Kansen, 2018)

Table 1 shows further details about the study regions, including the most recent estimate of the share of cyclists seriously injured due to bicycle crashes without motor vehicle involvement. For Belgium, the estimate refers to hospitalizations of 24 hours or more (Nuyttens, 2013). The Dutch criterion is hospitalization for injuries of 2 or higher on the Maximum Abbreviated Injury Scale (MAIS). Both countries have a share of some 83% (Nuyttens, 2013; Weijermars et al., 2018).

Table 1 Characteristics of the study regions: population, bicycle modal share, and share of fatal and serious injuries due to bicycle crashes not involving motor vehicles

	Population 2017 (million)[1]	Bicycle modal share 2016 (%)	Cyclists seriously injured due to bicycle crashes without motor vehicles (%)
Netherlands	17.1	27%	(2017) 83%
Belgium:	11.3	12%	(2004-2007) 83%
Flanders	6.5	18%	
BCR	1.2	4%	
Wallonia	3.6	2%	
Source	Statistics Belgium (2019); Statistics Netherlands (2019)	FOD (2018); Harms and Kansen (2018)	Nuyttens (2013); Weijermars et al. (2018)

Figure 2 provides the share of cyclist crashes with and without motor vehicle involvement for various levels of severity, i.e. no injuries, injuries for which treatment at an Emergency Department (ED) is needed, injuries for which hospitalization is needed (MAIS2+), and fatal injuries. The shares are similar across crashes without injuries and those for which hospital admission is required. Bicycle motor-vehicle crashes comprise a small majority of all fatal crashes.

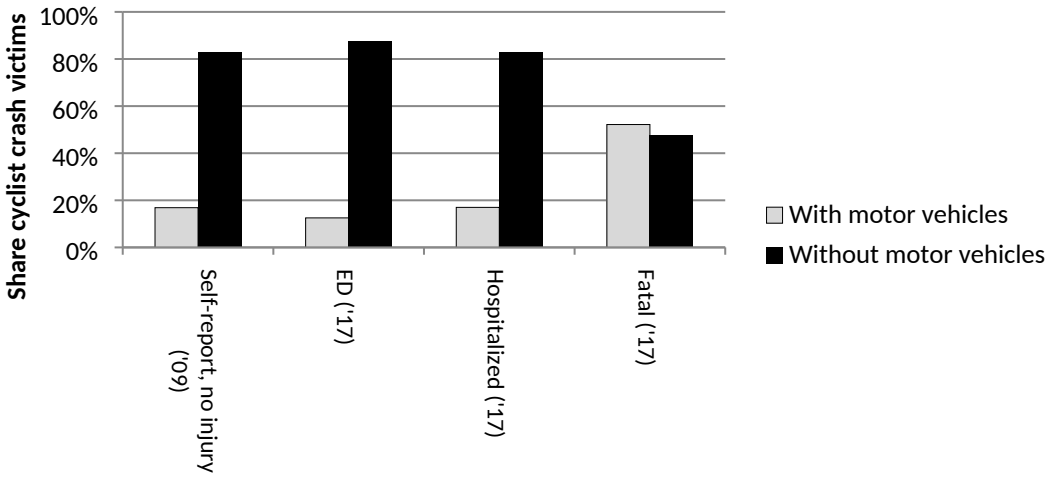

Figure 2. Distribution between bicycle crashes with and without motor vehicles in the Netherlands for different levels of crash severity ranging from no injuries (Goldenbeld et al., 2010; assuming 10% of all victims of bicycle crashes without motor vehicles are victims of bicycle–bicycle and bicycle–pedestrian crashes, see Schepers et al., 2015) to fatal injuries (Schepers et al., 2017a; Van der Does et al., 2019; Weijermars et al., 2018)

Research Design and Methods

This cross-sectional questionnaire study is part of a larger research project for which we recruited adults aged ≥ 18 years in 2017 in the Netherlands and Flanders, and in 2018 in Brussels and Wallonia. For readability, 'the Netherlands' is considered as one region. The questionnaire was available in Dutch and French. Note that the larger research project includes cyclists and non-cyclists, while this study covers cyclists ≥ 40 years only for the Belgian regions and ≥ 55 years only for the Netherlands.

Participant recruitment

In the Netherlands, participants were recruited through the panel of the National Foundation for the Elderly, which consists of older adults (≥ 55 years) volunteering in research projects. From the 2,232 invited panel members, 839 completed the paper or online version of the survey (response rate 38%). In Flanders, participants from previous studies about older adults' mobility who consented to participate in other studies were contacted by e-mail and asked to complete the online survey. Additionally, we asked 200 Flemish political, sociocultural and leisure (senior) organizations to disseminate an information letter among their members which included a link to the online survey. Forty organizations agreed to disseminate the information letter (response rate organizations= 20%) and in total 1,237 Flemish adults completed the survey. Data were collected from June to September 2017. The data collection for BCR and Wallonia was carried out between December 2018 and January 2019. The online questionnaire was distributed through the three main cycling advocacy NGOs, newsletters of the research groups involved, and the ministries of Transport. In order to increase the number of participants over 65 years of age, 26 political, sociocultural and leisure (senior) organizations disseminated an information letter to their members which included a link to the online survey. Responses were received from 174 Walloon and 594 Brussels adults, which, in total, resulted in 2,844 completed questionnaires. . The current study is restricted to people over 40 years who indicated they had cycled during past 12 months, thereby yielding a useful response from 1,931 participants. The study protocol was approved by the Medical Ethics Committee of the university hospital of the Vrije Universiteit Brussel (B.U.N. 143201732129) and Universiteit Gent.

The data have been weighted to match the age and gender distribution of the cyclist population in the study regions. We compared the response of Dutch cyclists (≥ 55 years) to the results of a 2016 representative questionnaire study among Dutch cyclists by research company KANTAR, using their panel (see Schepers et al., 2018). The KANTAR study was conducted to acquire a control group for a Dutch study on bicycle crashes. It was preferred over the Dutch National Travel Survey that asks about travel behavior on a survey day but not about whether participants cycle during the whole year or not. The weights per group were calculated to achieve the same age and gender distribution as the KANTAR study. For instance, the weight was 2 for male cyclists in age group x if this group comprised 20% of the KANTAR sample and 10% of our sample (20%/10%) so that this group also represents 20% of our final results. For the three Belgian regions, we multiplied the share of cyclists per age and gender groups according to the 2009 Belgian National Travel Survey (Cornelis et al., 2011) by population per group for each region in 2018 (Statistics Belgium, 2019). The resulting age and gender distributions were compared with the response in these regions in our survey (≥ 40 years).

Measures, dependent variable

Participants self-reported socio-demographics, transport behaviour and involvement in crashes during the previous year. To compare perceived risk of severe cyclist injuries between bicycle crash types (the dependent variable in this study), respondents were given the following question:

> *Which of the following three bicycle crash types do you believe causes most hospitalizations among cyclists?*
>
> - *Crash with a car, lorry, moped or other motor vehicle*
> - *Crash with another cyclist or pedestrian*
> - *Crash with an obstacle or fall*.

If all respondents gave the correct answer, everyone would have to answer that crashes with an obstacle or fall cause most hospitalizations among cyclists because these comprise some 75% of all bicycle crashes for which hospitalization is needed (Schepers et al., 2015).

Measures, independent variables

Respondents were asked how often they cycled in winter, spring, summer, and autumn(frequency for each season: never, less than 1 day per month, 1-3 days per month, 1-2 days per week, 3-4 days per week, or 5-7 days per week). Those cycling 5-7 days per week in at least one season and minimally 1-2 days per week in all remaining seasons were classified 'frequent cyclist'. Respondents were asked to report bicycle crashes in which they were involved over the past year. If they were involved in multiple crashes, they were asked to report the two most severe ones. Respondents could select the following crash types: fall while cycling, fall while (dis)mounting, crash with an obstacle such as a kerb or bollard, crash with a cyclist or pedestrian, crash with a motor vehicle (car, lorry, scooter, etc.), other crash type. In the last case, the respondents' description of the crash in their own words was used to categorize these crashes. This allowed us to categorize all crashes in the same categories as were used to describe risk perception. To include mental and physical impairments experienced while cycling we used the same nine questions as Engbers et al. (2018). Participants had to answer how often they experienced a described situation on a 6-point scale ranging from 'never' to 'always'. The following items measure the first composed variable 'Mental impairments': (1) feeling insecure while cycling, (2) needing intensive concentration and attention while cycling, (3) feeling uncomfortable in messy, chaotic or unclear traffic situations while cycling, and (4) feeling anxious about falling or crashing with other road users while cycling. The second composed variable was named 'Strength and Functionality impairments': (5) having a reduced reaction speed, (6) having less strength in the arms for cycling and braking, (7) having less strength in the legs, (8) being less able to look back and (9) having coordination or stability issues. Higher scores on each question suggest more frequently experienced impairments.

Analyses on perceived risk of bicycle crash types

All analyses were done using IBM SPSS Statistics 26. Binary logistic regression and multinomial logistic regression were used to examine the relationship of perceived risk. We ran univariate binary logistic regression analyses followed by backward stepwise binary and multinomial logistic regression to achieve models containing statistically significant variables.

The binary outcome variable in the binary logistic regression is equal to one for participants who answer that 'crashes without motor vehicles' result in most hospitalizations (crashes with cyclists and single crashes) and 0 for those answering 'crashes with motor vehicles'. Multinomial logistic regression analysis was conducted to compare the group of participants who perceive crashes to cause most hospitalizations with the groups perceiving 'bicycle-bicycle' and 'single bicycle crashes' to result in most hospitalizations among cyclists. Multinomial logistic regression is an extension of binary logistic regression that allows for more than two categories of the dependent variable to evaluate the probability of categorical membership (Hosmer & Lemeshow, 2000). The analyses include age, gender, actual crash involvement, region, 'Mental impairments' and 'Strength and Functionality impairments'. To relate crash types to risk perception we used the first reported crash for the 12 respondents who reported both a 'crash with a motor vehicle' and a 'crash without a motor vehicle'. This yielded a categorical variable grouping respondents into those without a crash, those involved in a crash without a motor vehicle, and those involved in a bicycle motor-vehicle crash. We conducted Principal Components Analysis (PCA) on the items for 'Mental impairments' and 'Strength and Functionality impairments' to derive a reduced number of uncorrelated factors representing all of the variance of the observed variables (Floyd & Widaman, 1995; Garson, 2012). We ran additional analyses split between middle-aged (40-59 years) and older respondents (≥60 years) to explore whether variables interact with age, because the outcomes may help identify target groups for interventions.

Results of analyses on perceived risk of bicycle crash types

The most important outcome of this study is shown in Figure 3 and indicates that the majority of participants (60%) perceive bicycle-motor vehicle crashes to be the most common cause of hospitalizations among cyclists. This share is greatest in BCR and Wallonia (71%-78%), followed by Flanders (63%). In the Netherlands a small majority ranks crashes without motor vehicles as major cause of hospitalized cyclists. These results contrast with self-reported crashes in Figure 4. Over the past year some 14% to 34% (23% on average) of the crashes reported by Dutch, Flemish and Walloon respondents were due to bicycle-motor vehicle crashes. Falls and crashes comprise the greatest share ranging from 61% to 75% (66% on average). The size of the sample varies and is smaller for BCR and Wallonia, resulting in more random variation and uncertain results for those regions.

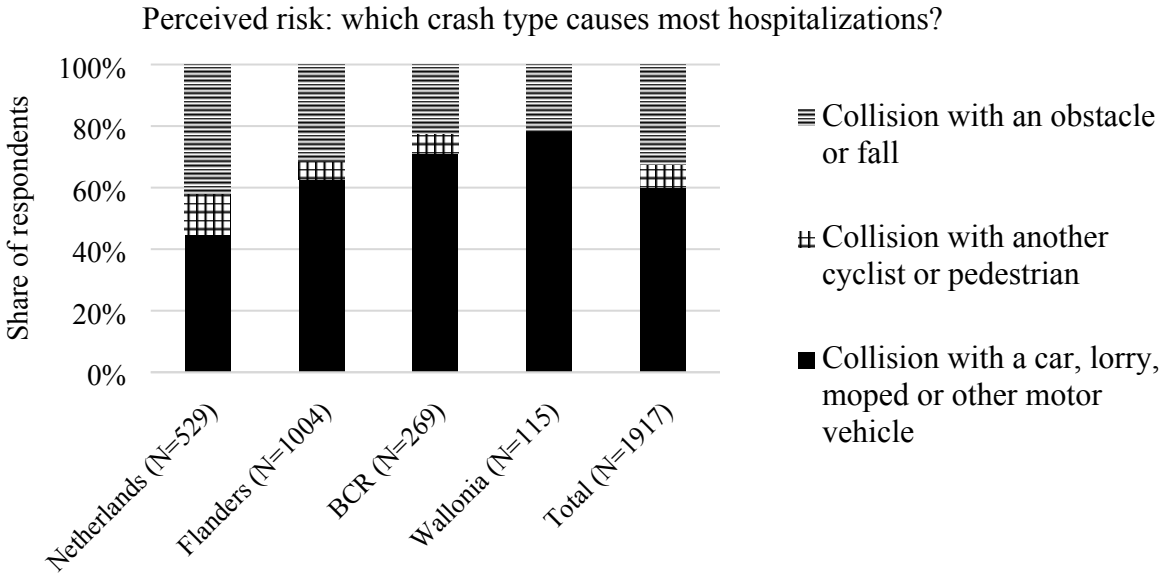

Figure 3. Perceived risk of crash types: number of participants answering which of the three crash types results in most hospitalizations among cyclists

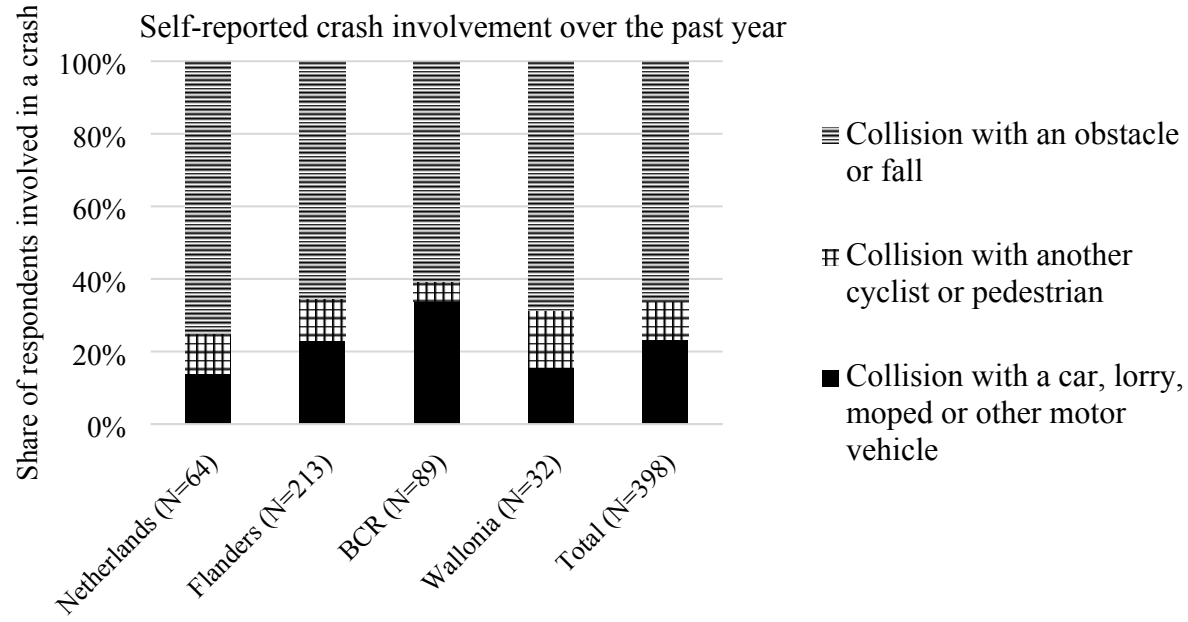

Figure 4. Self-reported crash involvement per crash type in the bottom figure (involvement over the past year for the three crash types)

Impairments

PCA on the nine items related to Mental impairments and Strength and Functionality impairments yielded two factors with eigenvalues greater than 1 (see Research Design and Methods Section, Subsection Measurements). Figure 5 shows the loadings of the items on these two factors. As expected, the first 4 items had the highest factor loadings on the first factor of the varimax-rotated solution (>0.75), while the last 5 items had the highest loadings on the second factor (>0.60). However, the fifth item was removed as it also had a high factor loading on the first factor (0.44). In the final solution, the first 4 items had loadings on the

Mental impairments factor over 0.75 and loadings under 0.3 on the other factor. Items 6 up to 9 had loadings over 0.6 on the Strength and Functionality impairments factor and loadings under 0.3 on the other factor.

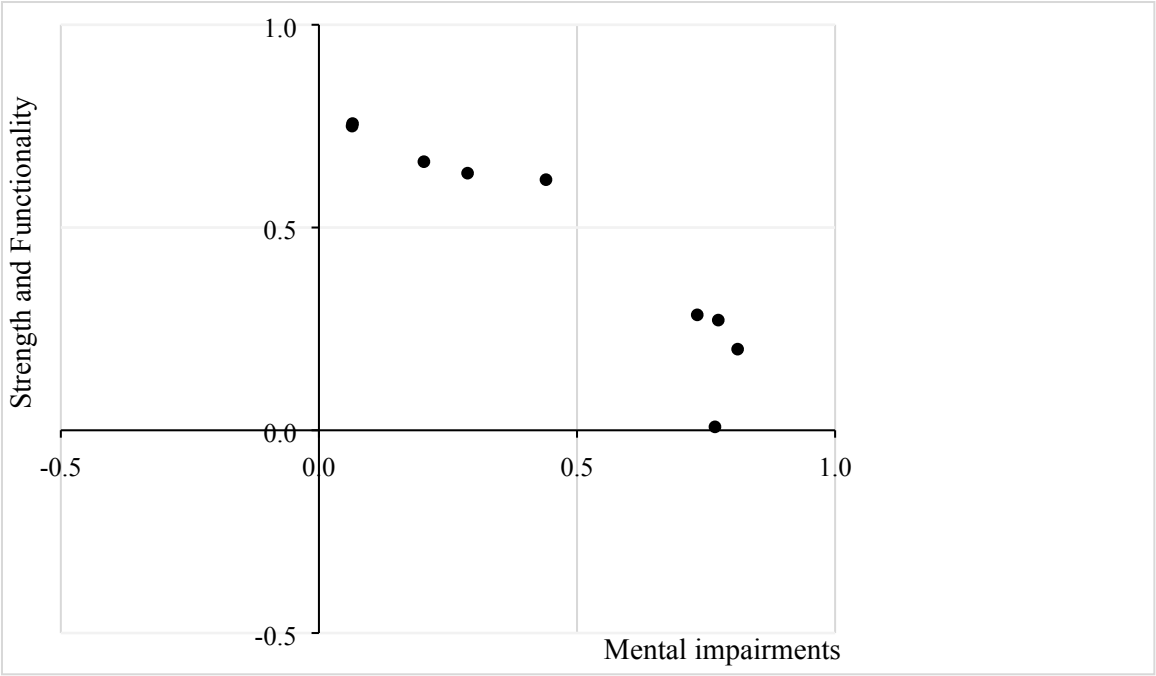

Figure 5. Factor loadings of the nine impairment items on the Mental impairments factor and Strength and Functionality factor

Univariate binary logistic regression analyses

Univariate binary logistic regression was conducted to examine the contribution of individual factors to risk perception. Odds ratios (uOR's in Table 2) over 1 indicate that the given variable is positively associated with the perception that most hospitalizations among cyclists are due to crashes without motor vehicles and thus negatively associated with the perception that bicycle-motor vehicle crashes cause most hospitalizations.

Older cyclists (≥60 years) are more likely to perceive bicycle crashes without motor vehicles as the most common cause of hospitalizations among cyclists. Strength and Functionality impairments are also positively associated with this type of perception. The relationship with Mental impairments is negative. Frequent cyclists and those who were involved in a bicycle-motor vehicle crash are less likely to perceive bicycle crashes without motor vehicles to result in most hospitalizations. The outcomes show that the already mentioned difference between regions is highly significant. However,

Multivariate binary logistic regression analysis

Backward stepwise binary logistic regression was used to achieve a model containing statistically significant variables in which the results of variables are controlled for other variables in the model. Compared to Dutch respondents, a greater share of Flemish regard bicycle-motor vehicle crashes as the most common cause of hospitalizations among cyclists, and this share is even greater for BCR and Wallonia. Switching the Netherlands and Flanders as the reference category in the logistic regression analysis shows that the difference between Flanders and Wallonia and Brussels is also significant ($P=0.04$ and $P<0.01$, respectively).

Importantly, the perception is affected by involvement in (self-reported) crashes during the previous year. Participants who reported crashes with motor vehicles were more likely to believe most hospitalizations result from such crashes. There was no significant relationship with self-reported involvement in crashes without motor vehicles. The latter category was also included in the results of the multivariate regression analysis as it was part of the categorical variable for crash involvement of which another category was significant. The fact that some variables such as cycling frequency were significantly associated with perception in the univariate analysis and not in this multivariate analysis suggests that these effects may have been confounded by for instance study region.

Multivariate multinomial logistic regression analysis

Backward stepwise multinomial logistic regression analysis was used to compare the groups perceiving single-bicycle crashes and bicycle-bicycle crashes as the most common cause of hospitalizations with those perceiving bicycle-motor vehicle crashes as the most frequent cause. This analysis appeared to suffer from low numbers per subgroup. As none of the Walloon respondents believed bicycle-bicycle crashes are the most common cause of hospitalizations among cyclists, we combined Wallonia and BCR into one region in the analysis. The results for both single-bicycle and bicycle-bicycle crashes were comparable to the results of the binary logistic regression analyses. Flemish cyclists are less likely to perceive both crash types without motor vehicles as the most common cause of hospitalizations and this applies even more to cyclists in Wallonia and BCR.

Among cyclists who believed bicycle-bicycle crashes to be the most common cause of hospitalizations among cyclists, there were no respondents reporting a bicycle-motor vehicle crash. Therefore, we combined all cyclists reporting bicycle crashes into one category 'crash with or without motor vehicle'. The OR is significantly lower than 1 for cyclists who believe bicycle-bicycle crashes to be the most common cause of hospitalizations which is due to the fact that they did not report bicycle-motor vehicle crashes. We ran an additional multinomial regression analyses with the original variable for crash involvement to provide more details regarding the group of cyclists who perceive single-bicycle crashes to result in most hospitalized cyclists. Participants within this group who reported crashes with motor vehicles were more likely to believe most hospitalizations result from such crashes (OR=0.26; CI=0.12 to 0.57). The variable for crash involvement in the multinomial regression analyses for single-bicycle crashes in Table 2 is non-significant due to the combination of bicycle-motor vehicle crashes with bicycle crashes without motor vehicles.

328 Table 2 Results of logistic regression analysis on respondents' perception that most
329 hospitalizations among cyclists are due to crashes without motor vehicles (N=1,898)

		Binary logistic regression		Multinomial logistic regression	
Dependent variable		without motor vehicles vs bicycle-motor vehicle	without motor vehicles vs bicycle-motor vehicle	single-bicycle vs bicycle-motor vehicle	bicycle-bicycle vs bicycle-motor vehicle
		uOR (95% CI)[1]	mOR (95% CI)[1]	mOR (95% CI)[1]	mOR (95% CI)[1]
Constant		1.00 (0.71 to 1.41)			
Categorical variables	*Share*[2]				
Age					
40-59 (reference)	624				
60-69	650	1.50 (1.21 to 1.85)**			
≥70	624	1.75 (1.38 to 2.21)**			
Gender					
male (reference)	976				
female	922	1.07 (0.89 to 1.28)			
Cycling frequency					
infrequent cyclist (reference)	1121				
frequent cyclist[3]	777	0.81 (0.67 to 0.97)*			
Region					
Netherlands (reference)	529				
Flanders	987	0.48 (0.39 to 0.60)**	0.50 (0.40 to 0.61)**	0.54 (0.43 to 0.68)**	0.34 (0.23 to 0.49)**
BCR	268	0.33 (0.24 to 0.46)**	0.36 (0.26 to 0.50)**		
Wallonia	114	0.23 (0.14 to 0.37)**	0.23 (0.14 to 0.37)**		
BCR and Wallonia	382			0.34 (0.25 to 0.46)**	0.23 (0.13 to 0.41)**
Reported crash involvement in the previous year					
no crash (reference)	1600				
crash without motor vehicle	236	0.91 (0.69 to 1.20)	1.03 (0.77 to 1.37)		
crash with motor vehicle	62	0.17 (0.08 to 0.37)**	0.20 (0.09 to 0.45)**		
crash with or without motor vehicle	298			0.89 (0.68 to 1.18)	0.42 (0.22 to 0.81)**
Continuous variables	*Mean (SD)*				
Mental impairments	0 (1)	0.90 (0.82 to 0.99)*			
Strength and Functionality impairments	0 (1)	1.17 (1.07 to 1.28)**			

330 * significant at the 5% level** significant at the 1% level
331 [1] uOR, odds ratio in univariate analyses; mOR, odds ratio in multivariate analyses; 95% CI, 95% Confidence
332 Interval
333 [2] Number of included cases, cases with missing values for one of the variables are excluded
334 [3] Frequent refers to cycling 5-7 days per week in at least 1 season and minimally 1-2 days per week in all
335 remaining seasons, while infrequent refers to less frequent cycling
336
337

Additional regression analysis split between age groups

We ran additional logistic regression analyses for middle-aged and older respondents (≥60 years) with the same variables as the final multivariate models to explore whether results differ between age groups. In the binary logistic regression analysis of all respondents of 60 years and older, those reporting a crash without a motor vehicle were significantly more likely to regard such crashes as the cause of most hospitalizations among cyclists (OR=1.50; CI=1.00 to 2.35). The OR for crashes with motor vehicles was of the same order of magnitude as in Table 2 for the ≥60 group (OR=0.24; CI=0.07 to 0.86). By contrast, middle-aged cyclists who reported a crash without a motor vehicle were not more likely to regard such crashes as the cause of most hospitalizations. Multinomial logistic regression analyses with the original variable for crash involvement (no reported crash involvement, reported bicycle-motor vehicle crash and reported crash without a motor vehicle) yielded similar results for the group of respondents who perceive single-bicycle crashes as the most common cause of hospitalizations. The OR for those reporting involvement in a bicycle crash without a motor vehicle was 1.79 (CI=1.15 to 2.79), while the OR for those reporting a bicycle-motor vehicle crash was 0.32 (CI=0.09 to 1.16). The analyses on the group perceiving bicycle-bicycle crashes as the most common cause of hospitalizations was done with the binary variable for crash involvement (due to the low numbers of cases per cell, distinguishing only between those reporting a crash and those not reporting a crash). It was not statistically significant.

Discussion

The majority of cyclists over 40 years (60%) perceive bicycle-motor vehicle crashes to be the most common cause of hospitalizations among cyclists. By contrast, medical registrations show that some 80% of severe injuries among cyclists in the study regions are due to bicycle crashes without motor vehicles (single-bicycle crashes and crashes with cyclists and pedestrians). The share is comparable for self-reported crashes in this study, i.e. some 80% due to bicycle crashes without motor vehicles which is comparable to previous studies in the Netherlands and Belgium (De Geus et al., 2012; Goldenbeld et al., 2010). These results show that risk perception is biased. Previous studies have not compared risk perception between crash types, but the results are explainable by findings from previous studies that fear of motor vehicles deters people from cycling (Noland, 1995; Sanders, 2015). The result is in line with our hypothesis based on risk perception theory as described in the introduction. The risk that motor vehicles pose to cyclists may be perceived as greater because the exposure is involuntary and difficult to control (Slovic, 1987).

Difference between regions

Risk perception appeared to vary substantially between the four study regions. The percentage of respondents that regard bicycle crashes without motor vehicles cause most hospitalizations among cyclists varied from 55% in the Netherlands to 37% in Flanders, and 22%-29% in Brussels and Wallonia. We suspect that this result is not because the Dutch have a greater fear of single-bicycle crashes, rather, because of the Dutch separated bicycle infrastructure and traffic calming measures (see e.g. Schepers et al., 2017b; Weijermars & Wegman, 2011), they are less exposed to high-speed motor vehicles and therefore fear bicycle-motor vehicle crashes less. Moreover, motorists are likely to adjust their behaviour in the presence of high

volumes of cyclists, such as in the Netherlands and Flanders, the so-called 'safety-in-numbers' phenomenon (Elvik & Bjørnskau, 2017; Fyhri et al., 2017; Jacobsen, 2015). Having been involved in a bicycle-motor vehicle crash appears to be related to fear of that crash type. The higher share of self-reported bicycle-motor vehicle crashes in Flanders and particularly BCR may explain in part the fear of that crash type in these two regions. BCR is a large densely populated city with congested traffic. On the other hand, the Walloon respondents reported few bicycle-motor vehicle crashes but had the highest fear of this crash type of all four regions. We recommend future research include a larger sample in large cities such as Brussels.

Involvement in crashes

Conceptual models of risk perception suggest both personal experiences and information from other people and news media play a role (Kasperson et al., 1988). The role of personal experiences was confirmed by the finding that the perception of bicycle crashes was related to self-reported crashes. Those who were involved in a bicycle-motor vehicle crash regarded this crash type as the cause of most hospitalizations among cyclists. For bicycle crashes without motor vehicle involvement, the relationship was less strong and non-significant for the whole group of respondents (middle-aged and older), but was stronger and significant for respondents aged 60 years or older. Older cyclists may be more aware of their increased frailty and risk of sustaining severe injuries in the event of, for instance, a fall. After having fallen of their bicycles, older victims may realize that there is a risk of sustaining more severe injuries should they fall again in the future. In the univariate regression analysis, older cyclists were found to fear crashes without motor vehicles more than younger cyclists. The fact that this was not found in the multivariate regression analyses may be explained by older cyclists' involvement in these crashes. The finding that self-reported crash involvement is related to its perception may explain why a substantial share, 40% of all respondents, believe most hospitalizations among cyclists are due to crashes without motor vehicles. Cyclists report far more bicycle crashes without than with motor vehicles. Using the figures reported in Table 2 (thus excluding missing values on variables included in the regression analyses), there were 298 cyclists involved in crashes without motor vehicles over the past year, which means they are involved in such crashes every 6 years (1,898/298). In regions where many people cycle, this means people also have friends, relatives or colleagues sustaining injuries in such crashes (in absolute numbers, the number of crashes per person cycling tends to be lower in areas with high cycling participation, Elvik & Bjørnskau, 2017).

Reflection with regard to the three categories of dependent variable

We hypothesized that cyclists fear bicycle crashes with motor vehicles more than crashes without motor vehicles, but respondents were asked about *three* bicycle crash categories. Single-bicycle crashes and crashes with other cyclists and pedestrians constitute the categories of bicycle crashes without motor vehicles. This allowed us to ask about the three most frequent bicycle crash categories according to medical registrations (Schepers et al., 2015). By asking about one category for bicycle-motor vehicle crashes and two categories for bicycle crashes without motor vehicles in the questionnaire, participants may have been primed to think about bicycle crashes without motor vehicles more than about bicycle-motor vehicle

crashes. The different number of categories for crashes with and without motor vehicles may have resulted in a framing effect (see e.g. Kahneman, 2011), meaning fewer participants answered that most hospitalizations among cyclists are due to bicycle-motor vehicle crashes. The fact that this was in fact answered by the large majority of the respondents therefore offers strong support for the hypothesis, but the share found in this study may be an underestimate of the real share of cyclists fearing bicycle-motor vehicle crashes most.

Study limitations and recommendation for future research

Although we asked which crash type is feared most, we do not know the degree to which respondents fear crashes in general. We do not know whether a larger share of Dutch respondents regarding crashes without motor vehicles as the most common cause of cyclist hospitalizations means they fear those crashes more than cyclists in other study regions do, or that they fear other crashes less. We expect that they fear bicycle-motor vehicle crashes less than cyclists in other regions. In the Netherlands, only for taking children to school is road safety mentioned as a reason to travel by car instead of by bike (Van Twuijver et al., 2006). This line of reasoning would need to be substantiated by a measure of the overall level of perceived risk. Estimating the level of perceived risk is a complex issue. We recommend building on research by Elvik and Bjørnskau (2005) to combine research into the risk of crash types with research on the overall level of risk perceived by cyclists.

A second limitation concerns the representativeness of the sample. The results were weighted to match the age and gender distribution of the population of cyclists in the study regions. As the description by Cornelis et al. (2011) of the age and gender of Belgian cyclists applies to the whole of Belgium, we have made the assumption that the same age and gender distribution applies to the three Belgian study regions. Also, the recruitment strategies for the four study regions differed and the sample may differ from the cyclist population in those regions with regard to other characteristics such as its geographical distribution. We recommend trying to obtain a more representative sample in future research.

Recommendations for practitioners

The most sustainable improvement to cycling safety is to provide a safer road environment to cyclists (Schepers, 2013), for instance by physically separated bicycle paths along roads with speeds of 50 km/h or higher to prevent bicycle motor-vehicle crashes (Weijermars & Wegman, 2011). Road authorities can reduce the risk of single-bicycle crashes due to uneven road surfaces, pot-holes and slippery surfaces by regular maintenance, providing separate cycle routes and tram lines, and applying sloped and levelled kerbs rather than right-angled ones, etc. (Hertach et al., 2018; Janssen et al., 2018). Biased risk perception is problematic for interventions aiming to change the behaviour of cyclists. Cyclists who are insufficiently aware of the risk of severe single-bicycle crashes are less likely to attend a course on safe cycling, take safety into consideration when selecting and buying a new bicycle, choose a safe route, etc. Given the health benefits of cycling (Mueller et al., 2015), the challenge is to not frighten and deter people from cycling but to raise awareness of the risk of single-bicycle crashes and developing solutions for cyclists to avoid such crashes. We recommend further research be conducted on how cyclists' risk perception is formed. This study suggests that personal experiences such as crash involvement play a role. Applying Kasperson's conceptual

framework on social amplification of risk (Kasperson et al., 1988) raises the question of what other signals individuals are receiving outside of their own experience. Which statistics and information are disseminated by official organisations such as governments about different crash types, and how do news and social media cover this issue? Qualitative research on cyclists' risk perception may be needed to examine to what degree and how risk perception can be changed to entice cyclists to take measures to avoid single-bicycle crashes. Measures to raise public awareness may also be needed to encourage road authorities and bicycle manufacturers to contribute to the prevention of this problem.

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590

Statement of originality

This is to certify that to the best of my knowledge, the content of the paper "The perception of bicycle crashes with and without motor vehicles among middle-aged (40+) and older cyclists in regions with varying modal shares of cycling: which crash types do cyclists fear most?" is our own work. This paper has not been submitted elsewhere.

I certify that the intellectual content of this paper is the product of our own work and that all the assistance received in preparing this paper and sources have been acknowledged.

Paul Schepers
Also on behalf of the co-authors