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Typology of bicycle crashes based on a survey of a thousand injured cyclists from a road trauma registry

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Abstract

Bicycles are an alternative means of transport, promoted for health benefits. However, cycling is risky. In France the annual incidence of cycling injuries is estimated at 70 per 100,000. Most existing cycling safety studies are based on police data, which is inappropriate to cyclist safety research, being biased as to accident type (single vs. multi-vehicle crash) and recording as much as 10 times fewer cyclists than a road trauma registry for the same geographical area. The present study therefore used a postal survey sent to victims injured while cycling in 2009-2011 and identified in a road trauma registry. The survey sample comprised 1,078 injured cyclists. This article presents the construction of a Typology of Bicycle Crashes. A multifactorial approach is adopted with the Partitioning Around Medoids algorithm. Seventeen crash configurations compose the typology (7 utilitarian trips, 3 leisure rides and 7 sport practices), with 35 variables; the most discriminatory variables were "collide with another road user", "commutes", "practices sport" and "aged 60 and over". Each accident configuration is described by the proportion of its main characteristics in comparison with that in the overall sample. Some other factors, such as "avoids another road user" (10%), "bad weather" (13%), "riding at night" (14%), "off-road ride" (20%) and "slips on the road" (40%), discriminated for collisions with another road user or obstacle. Injury severity in the 17 configurations is explored.

Keywords – cyclists, crashes, typology, survey, registry, injury

1. Introduction

Bicycles are an alternative means of transport, promoted in cities because of health benefits at both micro and macro levels [1, 2]. However, cycling is risky and the benefits can be offset in two ways. Firstly, the fear of injury discourages bicycle use. Secondly, some cyclists stop cycling after an accident. Therefore, better understanding of minor to fatal accidents is important for cycling safety as well as to promote cycling. Overall, the accident risk is higher for cyclists than for car users and pedestrians but lower than for motorized two-wheel vehicle users after adjustment on exposure [3]. In France, the annual incidence of cycling injuries was estimated at about 70 per 100,000 inhabitants for cyclist over recent years [4].

However, although bicycle use keeps increasing in some main cities, such as in the present study area, the proportion of cyclists' accidents has not changed significantly over the past decade, indicating decreasing risk.

Conventionally, researchers studied road casualties using police data: for instance, severe and fatal crashes in a particular urban environment [5] or for a particular type of cyclist such as commuters [6, 7].

Other research focused on a selected type of accident [8, 9], in relation to conspicuity [10, 11] or visibility [12] as a more recent concern. In general, single bicycle crashes due to loss of control, obstacle avoidance [13, 14] or near miss collisions [15] received a little attention despite being the most frequent: up to 70% of cyclist patients according to hospital data, versus 30% for collision with another road user [4, 16, 17].

These previous studies showed that police data might not be appropriate for cycling safety studies because of an important bias regarding accident type (single vs. multiple vehicle), even though it remains the main source for safety research. As much as ten times fewer cyclists were reported in police files than in a hospital registry collecting road casualties in the same territory [18]. Therefore, research on the basis of medical data has an important advantage.

Road safety has attracted researchers' efforts for decades. Some of them have developed methods to group casualties by similarities and create typologies in order to better adapt preventive action.

One of the first cyclist accident typologies was that of cross and Fisher [19], comprising 7 types of collision and 36 subtypes. Since then, successive approaches have had in common their scant interest in bicycle-only crashes, and have mostly focused on collisions [20-22]. For example, the Pedestrian and Bicycle Crash Analysis Tool (PBCAT) Bicyclist Crash Types [23] has one 'bicycle-only' accident type out of 69. The equivalent in Europe has two bicycle-related accident types out of 120 for all road users [24].

Two typologies have been dedicated to France: one has a single 'fall' type out of ten [25] and the other is composed of 51 cyclist scenarios of urban accidents but mixes falls and collisions together; for instance, 'Cyclist Fall/Collision after a mechanical failure' is one of the 51 scenarios [26]. Thus, very few cyclist accident typologies exist, and they need to be completed by other safety research on specific aspects such as infrastructure design and cyclist behavior to better understand road users' trajectories on the road: i.e., how people interacting in a built-up environment may create incidents.

It is also noteworthy that a proportion of injured cyclists were practicing sport on the road. Obviously, off-road cyclists such as mountain-bikers are also a very specific type, and are commonly studied apart in dedicated literature.

To improve knowledge of cycling safety and address prevention, a new tool is needed to identify dangerous features for all cyclists, on- and off-road.

The present study sought to construct a Typology of Bicycle Crashes (TBC), taking 3 types of cycling together (sport, leisure and utilitarian) and distinguishing sport, commuting, utilitarian trips and riding for pleasure in leisure time. It aims to refine the characterization of cycling accidents identified in a road trauma registry. Using a multifactorial approach and classification methods, we have constructed a typology in which accident configuration is a combination of factors such as cyclist characteristics, cycling purpose, cycling infrastructure and accident factors.

The paper describes how to build up a typology and shows how bridging the gap between use, individual characteristics and accident type could contribute to improving cycling safety.

2. Materials and methods

2.1 Study sample and variables

In 2012, a questionnaire was sent to people injured while cycling, to collect accident data. Participants were identified from a medical registry collecting medical information about inpatients and outpatients from road crashes that occurred in the Rhône administrative *Département* of France, as described by Laumont et al. [27].

The Rhône *Département* has a population of 1.7 million, mainly living in the Lyon urban area. The Rhône registry is maintained by 260 departments in public and private sector hospitals, collecting information on casualties after a crash. The data contain variables such as accident date and place, road user category and crash opponent category. They also cover victim characteristics such as injury severity, age, gender, date of birth and postal address.

The registry was designed to enable complementary surveys. The present postal survey was sent to cyclists injured in the Rhône *Département* between 2009 and 2011 (N=3,337). For the purposes of the study, cyclists younger than 10 years old, deceased persons and passengers were excluded. The final response rate was 43% (N=1,078).

Compared to non-respondents, respondents were older, more often female and more often cycling on urban roads. They were also more often involved in collisions and therefore more seriously injured, as assessed on the 6-level Maximum Abbreviated Injury Scale (MAIS) (from 1 (minor) to 6 (beyond treatment)) [28]. These differences were statistically significant (p value <0.0001).

The questionnaire was divided into seven sections and covered information regarding trip purpose, traffic environment, infrastructure, road surface maintenance, objects avoided or hit, other road users' trajectories, weather and light conditions, and cyclist equipment. From all these accident factors and circumstances, 35 variables were selected, on the basis of our expertise and a preliminary univariate analysis, as most likely to discriminate between different accidents configurations. Table 1 presents the name, description and frequency of each of the selected binary variables.

2.2 Typology construction

The typology construction relies on standard clustering methods: first, an agglomerative hierarchical clustering algorithm was applied, with individuals successively merged following Ward's method, and then a partitional algorithm.

Given the nature of the variables selected for analysis, the Jaccard distance was used, because positive matches could be considered more significant than negative ones. For the partitional algorithm, Partitioning Around Medoids (PAM) was chosen, being particularly well adapted to the binary case. A multiple correspondence analysis was also performed.

The results of this analysis will not be displayed here due to lack of space, but were consistent with those obtained using the typology construction.

All analyses were performed on R software. More precisely, the *ade4* package *dist.binary*, *stats* package *hclust*, *clust* package *pam* and *FactoMineR* package *catdes* functions were respectively used for computation of distances between individuals, construction of the dendrogram, construction of the typology and description of each cluster in terms of the variables used for the typology construction; in particular, the *catdes* function computes the v-test, as described by Husson et al. [29].

Tab. 1 - Description of variables used for the construction of the Typology of Bicycle Crashes;
N=1,078 injured cyclist in 2009-2011

	Variable name	Description	N=1,078	%
Age categories	Teenager	10 to 17 years old	149	13.8
	Young	18 to 24 years old	135	12.5
	Adult	25 to 59 years old	593	55.0
	Senior	60 and over	201	18.6
Gender	Men		793	73.6
Experience	Not expert	Using bicycle less than once a week	768	71.2
Injury severity	MAIS 2	Injury severity 2 on the MAIS scale (moderate)	352	32.7
	MAIS ≥ 3	Injury severity 3 or more (serious, severe, critical, maximum)	126	11.7
Trip purpose	Sport	Practicing sport: road cycling, mountain biking, BMX, etc.	405	37.6
	Leisure	Leisure cycling alone, with family or friends	187	17.3
	Friends (visiting...)	Riding for utilitarian trips except commuting	194	18.0
	Commuting	Commuting to/from work, school or university	250	23.2
Exogenous factors	Week-end	Saturday and Sunday	419	38.9
	Bad weather	Raining, snowing, etc.	145	13.5
	Tricky road	Road was difficult: not straight and flat	217	20.1
Cyclist's behavior	Dark	Night or twilight	154	14.3
	Invisible	No light or conspicuity equipment while riding	854	79.2
	Speed	Riding fast or very fast	271	25.1
	Alcohol	Had drunk alcohol	54	5.0
Road type	Dark & Invisible	No light or conspicuity equipment while riding at night	42	3.9
	Cycling infrastructure	Cycle track, cycle lane, bi-directional path only for cyclists	173	16.0
	Public Transport	Sharing with public transport: bus lane or tram tracks	47	4.4
	Pedestrian	Sharing with pedestrians: sidewalk, pedestrian crossing	90	8.3
	Intersection	Junctions: traffic line, stop sign, yield sign, roundabout	276	25.6
Accident type	Off-road	Mountain bike path, sports ground, cycle track in park, etc.	207	19.2
	Crash Opponent	Pedestrian, cyclist, two-wheeler, car or car door, other	492	45.6
	Avoid Opponent	Avoidance of another road user	103	9.6
	Collide Opponent	Collision with another road user	318	29.5
	Traj conflict	Another road user or the cyclist made a left or right turn	291	27.0
	Object	Kerbside, tramway rail, parked vehicle, pole, hole, other	364	33.8
	Avoid Object	Avoidance of an object	35	3.2
Other accident factors	Collide Object	Collision with an object	192	17.8
	Unbalanced	Bag on 1 shoulder, bag on handlebar, etc.	73	6.8
	Slip	Slipped on the road surface or on the way up/down the sidewalk	430	39.9
	Not seen	The other road user did not see the cyclist	177	16.4
	Mecha Fail	Mechanical failure: brakes, pedal, chain, fork, wheel, tire, etc.	126	11.7
Other accident factors	No maneuver	Did not have time to do any thing	632	58.6
	Did not see	Did not see the other road user or the object	186	17.3

3. Results

The dendrogram returned by the hclust function is presented in Figure 1.

The PAM algorithm was implemented from this dendrogram with a number of clusters ranging successively from 9 to 17 (corresponding to the dotted and plain lines in the figure). Although the typology with 9 clusters might seem more natural in view of the dendrogram, it appeared a little too simple and we finally opted for the more complex typology consisting of 17 clusters.

This typology especially enables clusters of individuals who could benefit from targeted prevention programs to be identified.

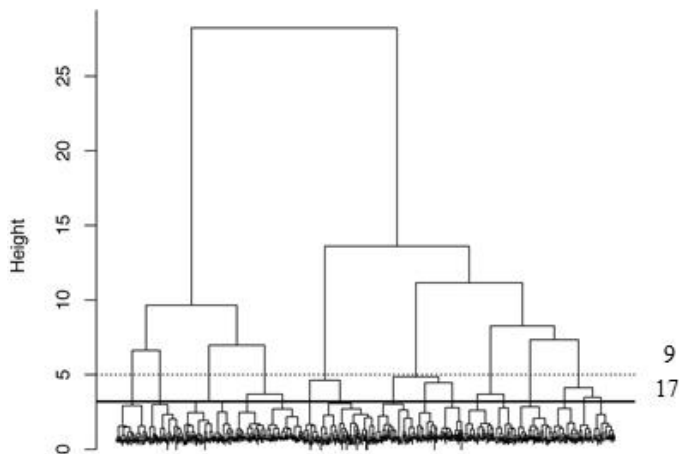


Fig. 1 - Dendrogram

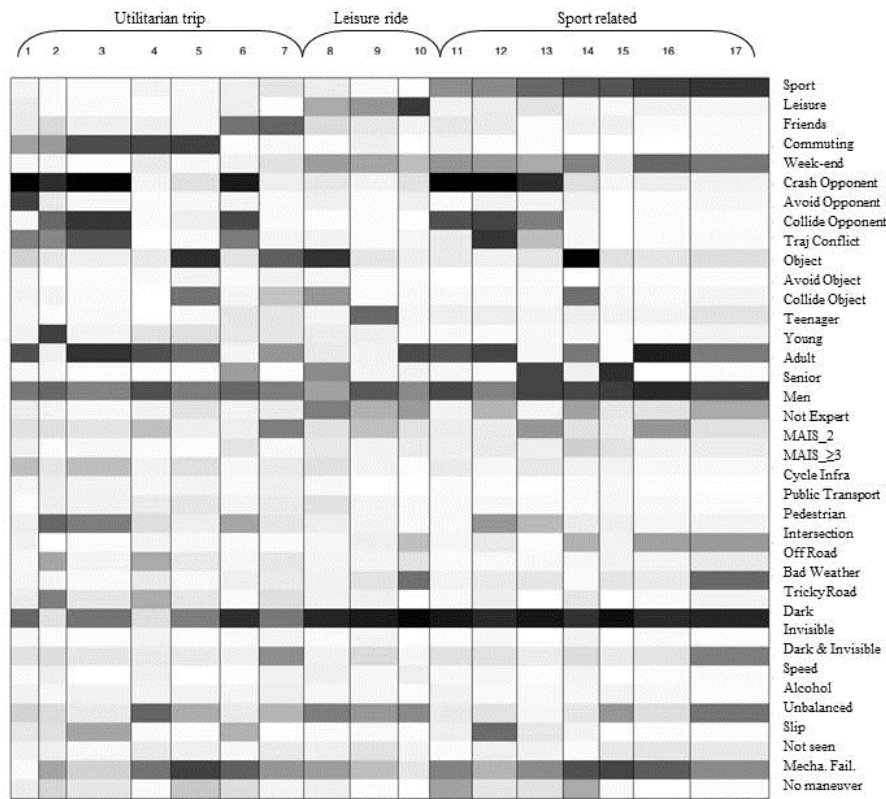
The typology is presented in Figure 2 and detailed in Tables 3 to 5. These Tables, as well as the figure, are divided into 3 parts, for clarity. Clusters are classified by “trip purpose”. Accidents while commuting and utilitarian trips are separated from the others; leisure activities (in the center) are like a bridge between sport (on the right side) and utilitarian activities (on the left side).

Within each cluster there is difference in grey tone: each tone is proportional to the mean of the characteristics for the group of individuals composing the cluster. For example, a ‘crash opponent’ is the main factor for ‘Avoidance of another road user’. Conversely, when a characteristic is absent for the whole group, we used white color. Furthermore, the width of each cluster is proportional to the number of cyclists composing it. The smallest cluster had 39 individuals and the biggest one 110. In the right-hand part of the typology, variables are grouped by the categories displayed in Table 1 (Figure 2).

Table 2 shows the p-value of the v-test for each variable and should be read along with Figure 2. In particular, the variables ‘Crash.Opponent’, with a frequency of 45.6% in our database (see Table 1), and ‘Collide.Opponent’ (29.5%) were the most discriminatory variables, with p-values of 1e-236 and 8e-204 respectively. ‘Trip purpose’ is also very important in the typology: the ‘Commuting’, ‘Sport’, ‘Leisure’ and ‘Friends’ variables were all highly significant, suggesting that the nature of a crash is related to the purpose of the trip.

Other important factors in the typology are trajectory conflicts and object collisions. Tables 3 to 5 present the 3 types of accident related to trip purpose: utilitarian trips, leisure and sport. Each type is divided into several subtypes. These Tables present the configuration name, cluster size, main characteristics and other characteristics for the 17 configurations.

All 35 variables were statistically significant for the typology construction; they were ordered in the Table based on the v.test score. In Tables 3 to 5, only the variables that were most interesting and meaningful for interpretation are presented. To understand each of the accident configuration characteristics, proportions in the cluster should be compared with proportions in the whole study population.



From left to right: Commuting and utilitarian trips, leisure activities, sport.
 Each grey tone is proportional to the mean of the characteristic for the group of individual composing the cluster.

Fig. 2 - Typology of Bicycle Crashes; 1,078 injured cyclists in 2009-2011

Tab. 2 - Significance level of the typology variables

	P-value		P-value
Crash Opponent	1.12e-236	Not.Expert	3.45e-53
Collide Opponent	8.40e-204	Slip	2.60e-48
Commuting	2.62e-194	Teenager	1.47e-47
Senior	1.05e-168	Did not see	8.52e-44
Sport	1.47e-153	Young	2.98e-42
Traj Conflict	5.07e-149	Dark	1.05e-40
Adult	3.74e-116	Speed	1.30e-34
Collide Object	4.13e-105	Bad.Weather	3.09e-33
Object	7.02e-99	MAIS_2	2.05e-31
Not seen	6.22e-93	No Maneuver	3.11e-31
Leisure	1.77e-82	Cycle.Infra	1.08e-28
Off.Road	5.84e-78	MAIS_≥3	4.86e-07
Avoid.Opponent	1.43e-77	Pedestrian	1.35e-04
Week-End	3.87e-70	Men	4.56e-04
Tricky.Road	4.25e-70	Public.Transport.	1.85e-03
Intersection	1.71e-65	Alcohol	2.31e-03
Friends	3.89e-61	Mecha.Fail.	1.94e-02
Invisible	1.14e-55		

Table 3 contains seven accident configurations in utilitarian trips. A distinction between utilitarian trips and commuting is made because the latter are very specific trips between home and the work or study place, and it can be supposed that cyclist's knowledge of dangerous situations is greater on this trip that is made on an almost daily basis. For instance, commuters and other utilitarian bicycle users are both concerned by collisions with objects in configurations n°5 and n°7. But utilitarian riders reported riding fast more often than commuters ('Speed': 62% vs. 14%; 25% for the study population as a whole), and therefore sustained moderate injuries whereas commuters sustained only minor injuries.

Table 4 gives three accident configurations for leisure cycling. 'Seniors' Sunday rides' (n°8) concerns the most inexperienced cyclists, 66% of whom rode less than once a week versus one-third for the study population as a whole. In addition, this group had the smallest proportion of men (57%), in a largely male population as a whole (73%).

Table 5 presents seven accident configurations for sport cycling, three of which correspond to off-road cycling: 'Obstacle in sport', 'trailbike riders' and 'sensational off-road'. The remaining four configurations concern cyclosportive cycling: 3 'collisions with another road user' and one 'slip on the road'. The 'slip on the road' category comprises seniors crashing on weekdays, whereas the other sport configurations mainly concern weekends. The configuration named 'collide with another road user who has not been seen' singles out a specific risk of collision not in an intersection, without conflict of trajectory.

Some results are important regarding our research objective. Firstly, there are some very specific situations of interaction between road users: for instance, in the 'Avoidance of another road user' configuration, 82% of cyclists avoided another road user, while only 10% had to do so in the global population.

Tab. 3 - Seven accident configurations on a utilitarian trip: names, characteristics, proportion in cluster and in study population, and descriptions

N°	Configuration name	Main characteristics ¹	% in		Configuration description	Other characteristics ²	% in	
			cluster	all			cluster	all
1	Avoidance of another road user (N=51)	Avoid Opponent	82	10	Cyclist avoiding another road user on a dedicated bicycle facility. There is a trajectory conflict, while commuting, on a straight road between junctions.	Traj conflict	67	27
		Crash Opponent	98	46		Commuting	57	23
		Cycle infra	49	16		Tricky road	8	20
						Intersection	12	26
2	At night, bad weather, at a junction (N=39)	Young	82	13	Young cyclist riding in the dark, in bad weather, reaching a junction and colliding on the daily trip to/from work, school or university. There is a trajectory conflict. Crash happening on a road shared with public transport. Some cyclists ride after drinking alcohol, others do not see an antagonist. Cyclist is visible (light on/or/and wearing fluorescent clothing).	Commuting	59	23
		Dark	67	14		Traj conflict	64	27
		Bad Weather	56	13		Public Transport	13	4
		Intersection	72	26		Alcohol	13	5
		Collide Opponent	72	29		Did not see	31	17
3	Commuter collides with another road user (N=91)	Commuting	79	23	Cycling to or from work, the cyclist collides, in a trajectory conflict setup, with an antagonist who does not see the cyclist at the junction. The cyclist is riding on a bicycle facility or on infrastructure shared with public transport systems such as bus or tram. Cyclists implicated are more often women and more often experienced.	Cycle infra	49	16
		Collide Opponent	86	29		Adult	87	55
		Traj conflict	79	27		Public Transport	9	4
		Not seen	56	16		Men	65	74
		Crash Opponent	99	46		MAIS 2	20	30
		Intersection	66	26		Week-End	2	39
4	At night, bad weather, slips on the road (N=56)	Commuting	80	23	Commuter is riding at night. The weather is bad and he/she slips on the road. The victim is an adult, with moderate injuries. The cyclist shows reckless behavior, riding after drinking alcohol and without any lights or fluorescent equipment.	Adult	79	55
		Bad Weather	55	13		MAIS 2	48	30
		Dark	54	14		Alcohol	11	5
		Slip	73	40		Dark & Invisible	9	4
5	Cyclist doesn't see an obstacle (N=69)	Commuting	83	23	Commuter collides with an object he/she has not seen. In some cases, the cyclist tries to avoid something and collides with an object or slips on the surface. He/she rides with a moderate speed between junctions and sustains minor injuries. If a pedestrian is involved, he or she has seen the bicycle.	No maneuver	83	59
		Collide Object	70	18		Pedestrian	19	8
		Object	87	34		Slip	54	40
		Did not see	41	17		Speed	14	25
6	Senior collision (N=55)	Friends (visiting)	69	18	On a utilitarian trip, a senior cyclist collides with another road user who has not seen him or her at the junction. The cyclist cannot avoid the crash by an emergency maneuver and is seriously injured.	Intersection	56	26
		Collide Opponent	80	29		No maneuver	75	59
		Senior	58	19		MAIS ≥3	20	12
		Not seen	53	16				
7	Obstacle on a utilitarian trip (N=63)	Friends (visiting)	73	18	On a utilitarian trip, such as visiting friends, the cyclist is riding fast and sustains moderate injuries after a collision with or avoidance of an object. This accident can happen on a road shared with public transport or at night. In general, the cyclist is experienced but slips on the object despite having seen it in his/her path.	Avoid Object	10	3
		Object	75	34		Public Transport	11	4
		Speed	62	25		Dark	24	14
		MAIS 2	67	30		Slip	52	40
		Collide Object	44	18		Did not see	8	17

¹ The most significant (v.test); ² other significant variables (v.test).

Tab. 4 - Three accident configurations on a leisure ride: names, characteristics, proportion in cluster and in study population, and descriptions

N°	Configuration name	Main characteristics ¹	% in		Configuration description	Other characteristics ²	% in	
			cluster	all			cluster	all
8	Seniors' Sunday rides (N=65)	Senior	63	19	A senior cyclist collides with an object during a leisure ride. He/she is an occasional rider and slips on the surface of the road; usually infrastructure shared with pedestrians. The accident occurs at the week-end, possible after a drink and away from an intersection. Victims are more often women riding slowly.	Slip	66	40
		Object	86	34		Pedestrian	22	8
		Collide object	60	18		Week-End	58	39
		Leisure	55	17		Alcohol	11	5
		Not Expert	66	29		Speed	9	25
					Men	57	74	
9	Teenagers' week-end rides (N=68)	Teenager	72	14	A teenager is having a leisure ride. He/she lacks experience and slips on the surface. He/she sustains moderate injuries; the accident occurs at the week-end. The cyclist sometimes falls because of mechanical failure or, infrequently, because of an antagonist or object	Slip	60	40
		Leisure	60	17		MAIS_2	47	30
		Not expert	53	29		Week-End	56	39
						Mecha Fail	21	12
						Avoid Opponent	1	10
				Object	19	34		
10	Inexperienced trailbike riders (N=44)	Leisure	84	17	Riding for leisure on a difficult road, a cyclist going uphill or downhill or around a curve has an off-road crash. He/she is an adult, lacks experience and slips on the surface. Sometimes the accident is a simple loss of control or occasionally the cyclist has drunk alcohol.	Adult	80	55
		Tricky road	70	20		Slip	64	40
		Off-road	48	19		Alcohol	11	5
		Not expert	59	29		Collide Object	5	18

¹ The most significant (v.test); ² other significant variables (v.test).

Tab. 5 - Seven accident configurations relating to sport: names, characteristics, proportion in cluster and in study population, and descriptions

N°	Configuration name	Main characteristics ¹	% in		Configuration description	Other characteristics ²	% in	
			cluster	all			cluster	all
11	Collide with another road user who has not been seen (N=60)	Crash Opponent	100	46	A road user collides with a cyclist who did not see him/her. The cyclist is an adult, practicing sport at least once per week. The accident occurs during the week-end. The cyclist is quite invisible for other road users.	Adult	77	55
		Collide Opponent	78	29		Week-end	60	39
		Not seen	57	17		Invisible	93	79
		Sport	62	38		Not Expert	10	29
12	Cyclo sportive collisions (N=63)	Not seen	71	16	The cyclist has not been seen in a conflict of trajectory and collides with another road user, at an intersection, while practicing sport. The victim is an adult who lacks experience, riding less than once a week.	Not Expert	52	29
		Traj conflict	86	27		Adult	81	55
		Collide Opponent	81	29		Week-end	59	39
		Crash Opponent	100	46				
		Intersection	60	26				
					Sport	63	38	
13	Experienced cyclo sportif (N=65)	Senior	82	19	A senior cyclist collides with another road user while riding on a road for sports. The accident occurs more often at the week-end, at a junction, and because of a trajectory conflict.	MAIS_2	60	30
		Crash Opponent	88	46		Intersection	51	26
		Collide Opponent	66	29		Traj conflict	49	27
		Sport	72	38		Week-end	55	39
14	Obstacles in sport (N=51)	Collide Object	71	18	A cyclist collides with an object that he/she has not seen while practicing an off-road sport. Injuries are serious. The victim practices less than once week. In addition, he/she does not try any emergency maneuver because he/she did not anticipate an object on the trajectory.	MAIS ≥3	35	12
		Object	98	34		Not Expert	57	29
		Did not see	55	17		Week-end	65	39
		Off-road	53	19		No maneuver	78	59
		Sport	76	38				
15	Senior cyclo sportive slips (N=48)	Senior	88	19	A senior cyclist practicing sport cannot try any emergency maneuver and slips on the surface. The victim is seriously injured.	MAIS ≥3	21	12
		Sport	77	38				
		No maneuver	81	59				
		Slip	60	40				
16	Trailbike riders (N=80)	Off-road	58	19	Practicing an off-road sport at the week-end, an adult is moderately injured. Most of the time he/she does not have time to make an emergency maneuver and sometimes the bicycle has a mechanical failure.	MAIS_2	60	30
		Sport	84	38		Men	89	74
		Adult	91	55		No maneuver	75	59
		Week-end	73	39		Mecha Fail	19	12
17	Sensational off-road ride (N=110)	Tricky road	73	20	A cyclist is on a difficult road (curved path or downhill road). He/she is practicing an off-road sport and speeding. He/she loses control and slips on the ground. The victim is an adult or a teenager and rides a few times per month.	Slip	69	40
		Off-road	59	19		Not Expert	55	29
		Sport	85	38		Adult	67	55
		Speed	66	25		Teenager	21	14
		Week-end	68	39				

¹ The most significant (v.test); ² other significant variables (v.test).

Secondly, exogenous factors mostly affected commuters' safety. "Bad weather" and "riding at night" were reported by respectively 13% and 14% of cyclists but mostly concerned young commuters colliding with another road user at a junction (configuration n°2: 67% "bad weather" and 56% "at night") and adults slips on the road (n°4: 55% and 54%, respectively).

Finally, injury severity factors were related to age and trip purpose. The risk of serious injury (or worse) in the 'senior cyclo sportive slips' configuration was considerable, and twice as high in 'senior collisions' as in other accident configurations. Serious injuries also occurred three times as often in a "collision with an obstacle which has not been seen" during off-road sport (n°14).

Moderate injuries mostly occurred in configurations where the cyclist slipped on the road, such as in clusters 4 and 9 (respectively 48% and 47%, vs. 30% in the global population). 60% of 'trailbike riders', cycling off-road and during week-ends, sustained moderate injuries, whereas only 30% of the study population as a whole did so.

4. Discussion

This Typology of Bicycle Crashes was constructed with a classification method using a postal survey addressed to cyclists. The typology is consistent with previously published cycling crash typologies. The five collision configurations involving another road user at a junction partly match the second accident type (Class B) in Cross and Fisher (1977). Some single-bicycle crash configurations, such as 'teenager's week-end rides' or 'obstacle on utilitarian trip while riding fast' or 'at night, bad weather, slips on the road', are compatible with Harkey et al.'s PBCAT Bicyclist Crash Type study (2000).

Bicycle-only crashes (subtype n°400) can include 10 of our present subtypes (4, 5, 7, 8-10 & 14-17). Focusing on French studies, Got et al. (1991), studying fatal cycling accidents, found one single-bicycle crash type ('CHUTE', meaning "fall") and one of loss of control resulting in a collision with a motor vehicle. Both these are relevant to the typology presented in the present article. There are, however, important differences between the present study and existing typologies. Cross and Fisher (1977), for example, deleted the factor "riding at night", whereas it appears as a constructive variable for three configurations in the present Typology of Bicycle Crashes (n°2, 4 & 7). Another difference concerned road regulation observance, which is an important factor taken into account in the literature; research based on police data contain this information, while ours did not.

There are some limitations to the present study. Firstly, contrary to police data based studies, this typology construction was based on a survey providing only the cyclist's point of view. Hence, information regarding a third party, if any was involved in the crash, is less accurate. Secondly, there were some differences between respondents and non-respondents.

However, the medical registry which was used to identify participants is almost exhaustive. Therefore, the accident configurations composing the typology are a good picture of the diversity of cycling crashes, but the distribution of configurations may not be fully accurate because of response bias. For instance, the proportion of cyclists in collision-related clusters may be overestimated, and underestimated in clusters dealing with off-road practice. Finally, cluster sizes are an asset of this study, enabling complementary analyses using some of the remaining variables.

The present study is quite original and closer comparison with existing cyclist typologies is not greatly relevant, as previous typologies were constructed from and conditioned by pre-existing data, whereas the present survey was designed with a view to constructing a typology: we first drew up a questionnaire to collect all the variables that might be relevant in an accident, and then selected the constructive variables for the typology. Most of the accident factors used to construct this Typology of Bicycle Crashes have already been studied and its pertinence regarding cycling safety can be partially assessed from the literature. Firstly, trip purpose and age are important accident factors in the present model; these findings are consistent with the results of Amoros et al. [4] and Thulin and Niska [16]. The cluster analyses suggest that the main accident characteristics are not necessarily the real issues for prevention. For instance, in the case where a cyclist collides with an object that he or she did not see (n°5), the information relevant to preventing a crash is the fact that the cyclist was sharing the path with pedestrians: as shown by

Schepers and Den Brinker [12], cyclists paying attention use focal vision, and if they are watching a pedestrian trajectory their ambient vision may fail to perceive an object and they may collide with it. This also connects with Chong et al.'s study [30] of road sharing between vulnerable road users. In addition, half of the cyclists injured in avoiding another road user while commuting (n°1) were cycling on dedicated infrastructure (bike lane or path). This knowledge is important for cyclist infrastructure design and could go unnoticed if trip purpose and infrastructure are studied separately. This also links some subtypes of the typology to near-miss crash research such as the Safer Cycling Prospective Cohort Study [31]. The present typology brings together the different aspects of cycling safety studied by the following papers: [5, 6, 13, 32-34]. Finally, the specificity of cycling accidents is confirmed as well as the need to develop medical data and specific surveys to improve knowledge of cyclist safety.

5. Conclusions

This paper presents a Typology of Bicycle Crashes based on a variety of accident factors such as trip purpose, cyclist characteristics, accident type, infrastructure and some more conventional accident factors. TBC improves knowledge of cyclist safety, showing how some accident factors are strongly associated with trip purpose or individual characteristics, and it highlights some secondary factors as prime issues for prevention. For instance, the results suggest that bicycle maintenance should be upgraded to avoid crashes due to mechanical failure (12%), especially for adolescents (n°9). Alcohol consumption appears to contribute to some configurations (n°2, 4, 8, 10). Moreover, cyclist conspicuity should be improved, by day as well as at night (configurations n°3, 4, 6 & 12). Lastly, each configuration is associated with a cyclist type and hence could be used to better address prevention. In a future article the typology will be further studied using the remaining variables from the survey: for instance, which type of cycling infrastructure appears in a configuration.

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