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Development and reproducibility of an instrument to assess behavioral and environmental aspects related to cyclist safety

Desenvolvimento e reprodutibilidade de um instrumento para avaliar aspectos comportamentais e ambientais relacionados à segurança do ciclista

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Abstract – In urgency and emergency services, the bicycle is the second means of transportation more widely used by the victims at the time of the accident. However, aspects associated with major and minor accidents are poorly understood. The aim was to develop an instrument and test its reproducibility, in order to evaluate behavioral and environmental aspects related to cyclist safety. The instrument was based on footage taken through a camera attached to the cyclist helmet and from a review of literature. Take part in the study academics that used the bicycle for transportation at least once a week. Participants were instructed to indicate any safety-critical events on their way and situations of minor gravity based on the perception of real imminence of an accident. In order to identify aspects related to cyclist safety, the routes were divided in periods of 30 seconds. In order to test inter-rater reproducibility, two researchers received theoretical-practical training and performed the instrument in a sample of 100 periods. In order to evaluate the intra-rater reproducibility, one of the evaluators performed a second application after 07 days. The reproducibility of the categorical variables of the instrument were tested through general agreement and Kappa index. For the variables with continuous measuring range, the Intraclass Correlation Coefficient (ICC) was used. The percentage agreement varied between 88-100% and the Kappa values varied between 0.76-1.00. The ICC values ranged from 0.96-0.99. The developed instrument presents adequate reproducibility for use in research to evaluate the cyclist safety in urban contexts.

Key words: Accident prevention; Bicycling; Reproducibility of results; Traffic accidents.

Resumo – *Em serviços de urgência e emergência a bicicleta é o segundo meio de locomoção mais utilizado pelas vítimas na hora do acidente. No entanto, os aspectos associados aos acidentes de maior e menor gravidade são pouco conhecidos. O objetivo deste trabalho foi desenvolver e testar a reprodutibilidade de um instrumento para avaliar aspectos comportamentais e ambientais relacionados à segurança de ciclistas. O instrumento foi baseado em filmagens realizadas através de câmera acoplada no capacete e a partir de revisão de literatura. Participaram do estudo universitários que utilizavam a bicicleta para deslocamento ao menos um dia por semana, foram orientados a indicar no trajeto eventos críticos, situações de menor gravidade baseadas na percepção de iminência real de acidente. Para identificar os aspectos relacionados à segurança, os trajetos foram fracionados em períodos de 30 segundos. Para testar a reprodutibilidade interavaliador dois pesquisadores receberam treinamento teórico-prático e realizaram a aplicação do instrumento em uma mostra de 100 períodos. Para avaliar a reprodutibilidade intra-avaliador, um dos avaliadores realizou uma segunda aplicação após 07 dias. A reprodutibilidade das variáveis categóricas do instrumento foi testada através da concordância geral e índice Kappa. Para as variáveis com escala de medida contínua foi utilizado o coeficiente de correlação intraclasse. Os percentuais de concordância variaram entre 88 e 100% e os valores de Kappa entre 0,76 e 1,00. Os valores de CCI variaram entre 0,96 e 0,99. O instrumento desenvolvido apresenta reprodutibilidade adequada para o emprego em pesquisas para avaliação da segurança de ciclistas em contextos urbanos.*

Palavras-chave: *Acidentes de trânsito; Ciclismo; Prevenção de acidentes; Reprodutibilidade dos testes.*

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INTRODUCTION

The external causes of morbidity and mortality situations related to accidents and violence constitute a public health problem in Brazil[1,2]. In 2016, deaths from these causes accounted for 11.9% of total deaths in the year[3]. Among external causes, transport accidents represent 24.5% and are the second most frequent cause of this type of accident[3]. In the year of 2016, 1,262 deaths were from cyclists[3].

While the death of cyclists represents a small part of the total number of fatalities on road traffic accidents, the bicycle has been reported by the Brazilians' emergency and urgency services, in the country's capitals[4], as the most often mode of transportation used at the time of accidents. In the city of São Paulo, from 2011 to 2013, the most prevalent characteristics among bicycle accidents were: male; age up to 24 years old; type of victim (pilot vs. pedestrian); period of the day from 07:00 A.M to 06:00 P.M; leg injury; immediate hospital discharge[5] and use of the bicycle for transportation[6]. These data from "Sistema de Vigilância de Violência e Acidentes" (VIVA) show that: male, pedaling in urban areas could be positively associated with the chance of a bicycle accident, whereas higher level of education and the use of the bicycle as a commute had an inverse association[7].

However, these data were obtained through information systems such as VIVA, and despite their relevance, they exhibit some limitations. Victims of minor seriousness accidents usually do not seek care in health services, and therefore are not included in the statistics, resulting in an underestimated data[8]. Yet, despite characterizing the victims, these data do not allow identifying the risk factors for the incidence of accidents, limiting the creation of effective public policies to control and to prevent aggravation. Therefore evaluating these accidents and minor gravity events may help to generate a better understanding of accidents that involve the use of the bicycle. In this regard, events of lesser gravity such as falls and small collisions or the ones that are closely related to accidents, such as braking and abrupt changing of direction are defined as critical events[9].

Thus, to investigate characteristics, beyond those that the information systems are able to produce, and critical events one of the alternatives found was to conduct investigations at the time and place where the events occur. This can be accomplished through the use of portable cameras attached to the cyclist helmet, which through its record allows the details of the critical event[6,10,11] to be seen and recovered after its occurrence[6,12]. One of the studies conducted with this approach identified that the risk of suffering a critical event was ten times higher when the surface of the pathways were considered poorly maintained[11]. Also, a fourfold higher risk was observed in the proximity of intersections, being it threefold higher in intersection with visual occlusion and when pedestrians and other cyclists crossed the cyclist's trajectory[11].

Thereby, in order to be able to identify which behavioral characteristics of cyclists and environmental variables may be associated with critical events, it is essential to have instruments that allow the registration of these variables with adequate reproducibility. Therefore, the objective of this study was to develop and test the reproducibility of an instrument to evaluate behavioral and environmental aspects related to the safety of cyclists on public roads.

METHOD

A reproducibility study with cross-sectional design was carried out. The steps of development and reproducibility analysis of the instrument were adopted.

Development of the instrument

The instrument was developed to describe information during bicycle trips taken by university students, which would allow the evaluation of variables potentially associated with critical events.

The items that were included in the form were selected according to the literature on the topic and previously recorded videos (pilot study). According to the literature review[12] variables such as demographic factors, built environment, climate conditions, street lighting and behavioral conditions should be considered when evaluating the safety of the cyclist. Thus, based on the factors cited in the literature, an observer familiarized with the use of the bicycle for transportation[6] developed a registration form founded on the variables indicated by the literature review and on the pilot study videos. Those were taken through camera positioned on the helmet of 28 cyclists during the period of seven days. From these images the characteristics that could be visualized integrated the instrument.

The instrument was tested in a sample of periods taken from the pilot study by two evaluators familiarized with the use of the bicycle for transportation. The final version of the instrument was established through the consensus of the evaluators who participated in the data collection. Box 1 presents the instrument variables, divided into three sections.

Among the categorical variables, the instrument shows different possibilities of the quantity of responses. Five variables are dichotomous, "crossing lane", "presence of mandatory stop sign", "presence of preferential sign", "presence of traffic lights" and "There is no traffic control". The variables "observer temperature perception", "running the red light", "pedaling in the wrong way", "zigzag between vehicles", "using pedestrian-only sidewalk", "own infrastructure available and used" and "parked vehicles" exhibit as an option more than two responses with possibility of a single result, and the other variables have more than two responses options with multiple results. The multiple response procedure was used to record the different situations occurring within the 30 seconds range.

Sampling of cyclists

Four universities located in the city of Curitiba-PR were intentionally selected for the sample of cyclists' recruitment. The recruitment took place at the bike racks installed at the universities' outbuilding. All individuals who would go to the parking rack area in order to park or take a bicycle were approached. The inclusion criteria were: a) being a university student at one of the four universities; b) minimum age of 18 years; c) using the bicycle for transportation at least once a week and d) taking routes at least 5 minutes long.

Box 1. Structure of the instrument

Section	Variable name	Variable type	Response type
Route identification	Date of route	Nominal	-
	Time of the day	Nominal	-
	Video period	Nominal	-
	Day of the week	Nominal	-
	Max./min. temperature	Continuous	Numerical
	Perception of observer temperature	Categorical	Single answer
Behavioral	Location of the cyclist on the road	Categorical	Multiple answer
	Cyclist's direction	Categorical	Multiple answer
	Crossing track	Categorical	Dichotomous
	Run the red light	Categorical	Single answer
	Pedaling the wrong way	Categorical	Single answer
	Perform zigzag between vehicles	Categorical	Single answer
	Pedaling on the pedestrians sidewalk	Categorical	Single answer
	Own infrastructure available and used	Categorical	Single answer
Environmental	Location of the road used	Categorical	Multiple answer
	Type of bicycle infrastructure	Categorical	Multiple answer
	Presence of parked vehicles	Categorical	Single answer
	Mandatory stop	Categorical	Dichotomous
	Preferential	Categorical	Dichotomous
	Traffic light for vehicles	Categorical	Dichotomous
	There is no traffic control	Categorical	Dichotomous
	Perception of observer topography	Categorical	Multiple answer
	Number of vehicles	Continuous	Numerical
	Number of pedestrians	Continuous	Numerical
	Number of cyclists	Continuous	Numerical

Data collection procedures

In order to record the videos, was given to the participant a portable camera, the used brand was GoPro® (San Mateo, United States) in the following available models: "Hero3 + Silver Edition", "Hero4 Silver Edition" and "Hero4 Black Edition". Following the cameras was an acrylic protective box which allows the equipment attachment to the helmet surfaces through brackets. The cameras were fixed on the highest point of the helmet by the researcher. Helmets with supports were lent to participants who did not have it or whose helmet did not allow the camera to be fixed. The cameras were set to shoot at a rate of 30 frames per second (30fps) at a resolution of 720p ("p" indicates the "progressive" picture format). Figure 1 shows an image obtained during data collection.

Figure 1. Example of footage taken through the recording of the cyclist participant on the route.

For each taken route, the participant was requested to keep a route diary to record details of the trip (date, time of day, origin and destination, use of headset) and indicate any critical event, being this defined as a situation based on the perception of insecurity or discomfort in relation to traffic during travel. The participants were instructed to record all the routes made during seven consecutive days.

Altogether, 76 critical events were indicated. Of these, 54 (71.1%) were considered valid and occurred over 34 routes. These routes were divided in period of 30 seconds and were classified as eligible and ineligible. It was considered ineligible the period in which the cyclist: 1) was on private ground, 2) was off the bicycle or pushing it or 3) it was not possible to visualize the variables of interest (for example: poor lighting).

In order to achieve concordance, a sample of 100 periods was chosen. First, all the periods with critical events were selected. Afterwards, a systematic draw was carried out among the eligible periods of 30 seconds without the presence of critical events. For each critical event identified in the previous step, a sample of five periods from the same route was drawn. The periods were drawn dividing the total number of valid periods without the presence of critical events by the total number of periods that would be used in the route. The result was used as a "leap" from the first period.

Video data training and collecting

In order to perform the inter-rater agreement, two evaluators (A and B) received six-hour theoretical-practical training. Concerning the identification of the factors, the procedure of splitting the routes in period of 30 seconds was adopted, a process also used in a study with similar subject matter[11]. There after each evaluator observed 100 samples of periods independently, and, when needed, there was a possibility of reviewing the records individually and without previous communication with the other evaluators. Purposing to perform the intra-rater agreement, the volunteer A carry out the data collection in two distinct moments, using a time gap of 7 days between the evaluations.

Statistical analysis

For the categorical variables of the instrument, the relative frequency of observations per evaluator was calculated in each category of variables. The reliability between evaluators and intra-evaluators was tested by general agreement (% C) and kappa index (K) per variable category. Regarding the dichotomous categorical variables, the values were calculated per variable. Relating to the continuous variables, mean and standard deviation of each variable were calculated and the reliability was tested through the intraclass correlation coefficient (IC) and 95% confidence interval. Values of general agreement ≥70.0%, kappa index ≥0.70 and intraclass correlation coefficient ≥0.70 were considered suitable reproducibility values[13]. The analyzes were performed in SPSS (Armonk, United States) 20.0 software and the significance level adopted was 5%.

RESULTS

Among the dichotomous variables, there was a high inter-general (97.0 - 99.0%) and intra-rater (95.0 - 97.0%) agreement observed. Values of the kappa index revealed concordances higher than 0.80. The intra-rater "there is no traffic control" variable had the lowest kappa value (0.869) among these variables (table 1).

Table 1. Frequency distribution, general agreement (%C) and Kappa (K) index inter and intra-rater of dichotomous variables of the instrument

	A1	B	%C	K	p	A1	A2	%C	K	p
Variables and categories	%	%				%	%			
Crossing track										
Yes	64	63	97.0	0.935	<0.001	64	64	96.0	0.913	<0.001
Not	36	37				36	36			
"mandatory stop" traffic control										
Yes	29	29	98.0	0.951	<0.001	29	25	96.0	0.899	<0.001
Not	71	71				71	75			
"Preferential" traffic control										
Yes	0	0	100	-	-	0	0	100	-	-
Not	100	100				100	100			
"traffic light for vehicles" traffic control										
Yes	53	52	99.0	0.980	<0.001	53	47	97.0	0.940	<0.001
Not	47	48				47	50			
There is no traffic control										
Yes	77	76	99.0	0.972	<0.001	77	72	95.0	0.869	<0.001
Not	23	24				23	28			

Note. A1%: frequency of observations evaluator A1; B%: frequency of observations evaluator B; A2%: frequency of observations evaluator A2; % C: general agreement; K: Kappa index, p: level of significance; it was not possible to calculate concordance values in the variable "preferential traffic control" because the categories were constant.

Overall agreement values for single response variables were similarly high inter (94.0 - 100.0%) and intra-rater (88.0 - 97.0%). All variables had kappa index values higher than 0.80, and the "own and available infrastructure" variable presented perfect agreement (table 2).

Table 2. Frequency distribution, general agreement (% C) and Kappa (K) index inter and intra-rater of single answer variables of the instrument

	A1	B	%C	K	p	A1	A2	%C	K	p
Variables and categories	%	%				%	%			
Perception of observer temperature										
Sun between the clouds	50	47	97.0	0.940	<0.001	50	47	95.0	0.900	<0.001
Cloudy	50	53				50	53			
Running the red light										
Yes	10	10	94.0	0.897	<0.001	10	10	91.0	0.843	<0.001
Not	40	42				40	35			
There is no traffic light	50	48				50	55			
Pedaling the wrong way										
Yes	19	18	96.0	0.936	<0.001	19	19	96.0	0.937	<0.001
Not	47	47				47	43			
Did not pedal on the track	34	35				34	38			
Perform zigzag between vehicles										
Yes	0	0	97.0	0.934	<0.001	0	1	95.0	0.893	<0.001
Not	66	65				66	61			
Did not pedal on the track	34	35				34	38			
Pedaling on the pedestrians sidewalk										
Yes	22	23	96.0	0.928	<0.001	22	20	94.0	0.890	<0.001
Not	61	59				61	62			
There is no sidewalk	17	18				17	18			
Own infrastructure available and used										
Yes	40	40	100.0	1.000	<0.001	40	41	97.0	0.939	<0.001
Not	1	1				1	0			
There is no own infrastructure	59	59				59	59			
Parked vehicles										
From both sides of the road	15	16	98.0	0.971	<0.001	15	13	88.0	0.823	<0.001
On the same side as the cyclist	20	20				20	14			
On the opposite side of the cyclist	19	20				19	22			
There are no parked vehicles	46	44				46	51			

A1%: frequency of observations evaluator A1; B%: frequency of observations evaluator B; A2%: frequency of observations evaluator A2; % C: general agreement; k: kappa index and p: significance level

For the variables with the possibility of multiple answers, the concordance values were presented per category of variable. Among all categories, the overall agreement results were higher than 90.0% inter and intra-rater. Among the kappa index values, the categories showed values greater than 0.80, except the categories "lateral lane on the left" and "flat surface" considering the inter-rater analysis and "pedaling ahead" considering the intra-rater analysis (table 3). Finally, all continuous variables presented intraclass correlation values higher than 0.90 (table 4).

Table 3. Frequency distribution, general agreement (% C) and Kappa (K) index inter and intra-rater of multiple answers variables of the instrument

	A1	B	%C	K	p	A1	A2	%C	K	p
Variables and categories	%	%				%	%			
Location of the cyclist on the road										
Right side of lane	23	25	98.0	0.945	<0.001	23	25	96.0	0.890	<0.001
Left side of lane	11	11	96.0	0.796	<0.001	11	10	97.0	0.840	<0.001
In the middle of the lane	22	21	99.0	0.970	<0.001	22	22	96.0	0.883	<0.001
Shoreline	0	0	-	-	-	0	0	-	-	-
Sidewalk	21	22	99.0	0.970	<0.001	21	19	98.0	0.938	<0.001
Own infrastructure	41	40	99.0	0.979	<0.001	41	42	99.0	0.979	<0.001
Cyclist's direction										
Pedaling ahead	98	98	100.0	1.000	<0.001	98	97	99.0	0.795	<0.001
Turning right	6	8	98.0	0.847	<0.001	6	5	99.0	0.904	<0.001
Turning left	5	4	99.0	0.884	<0.001	5	5	100.0	1.000	<0.001
Stopped	21	20	95.0	0.847	<0.001	21	23	96.0	0.884	<0.001
Location of the road used										
Track	37	37	98.0	0.957	<0.001	37	39	96.0	0.915	<0.001
BRT (Bus Corridors)	13	12	99.0	0.954	<0.001	13	11	98.0	0.905	<0.001
Shoreline	0	0	-	-	-	0	0	-	-	-
Sidewalk	21	22	99.0	0.970	<0.001	21	19	98.0	0.938	<0.001
Own infrastructure	40	40	100.0	1.000	<0.001	40	42	98.0	0.959	<0.001
Type of own infrastructure										
Bicycle path	12	12	100.0	1.000	<0.001	12	13	99.0	0.954	<0.001
Cycle Track	3	4	99.0	0.852	<0.001	3	3	100.0	1.000	<0.001
Calm way (low speed limit streets)	11	10	99.0	0.947	<0.001	11	12	99.1	0.951	<0.001
Shared sidewalk	14	14	100.0	1.000	<0.001	14	14	98.0	0.917	<0.001
Cycle route	0	0	-	-	-	0	0	-	-	-
Available and unused own infrastructure	1	1	100.0	1.000	<0.001	1	0	99.0		
There is no own infrastructure	59	59	100.0	1.000	<0.001	59	58	99.0	0.979	<0.001
Perception of observer topography										
Aclive	28	25	93.0	0.821	<0.001	28	33	95.0	0.882	<0.001
Plan Surface	62	67	89.0	0.760	<0.001	62	63	91.0	0.808	<0.001
Slope	20	18	96.0	0.870	<0.001	20	15	85.0	0.828	<0.001

Note. A1%: frequency of observations evaluator A1; B%: frequency of observations evaluator B; A2%: frequency of observations evaluator A2; % C: general agreement; k: kappa index and p: significance level; it was not possible to calculate concordance values in the categories "coasting", "ciclorrota" and "own available and unused infrastructure" (intra raters) because the categories were constant.

Table 4. Mean, standard deviation and inter and intra-rater intraclass correlation coefficient of the continuous variables of the instrument

Variables	Inter-raters				Intra-rater			
	A1	B			A1	A2		
	M±DP	M±DP	CCI ($IC_{95\%}$)	p	M±DP	M±DP	CCI ($IC_{95\%}$)	p
# vehicles	12.8 ± 10.3	13.5 ±10.5	0.989 (0.983 – 0.992)	<0.001	12.8 ± 10.3	12.2 ± 9.7	0.961 (0.942 – 0.974)	<0.001
# pedestrians	8.1 ±19.5	8.5 ± 20.8	0.997 (0.996 – 0.998)	<0.001	8.1 ±19.5	8.3 ± 19.0	0.996 (0.995 – 0.998)	<0.001
# cyclists	0.3 ± 0.6	0.3 ± 0.6	0.960 (0.940 – 0.973)	<0.001	0.3 ± 0.6	0.3 ± 0.6	0.988 (0.981-0.992)	<0.001

Note. #: number of observations; M: mean; SD: standard deviation; ICC: intraclass correlation coefficient; IC 95%: 95% confidence interval and p: significance value

DISCUSSION

The present study was the first one in Brazil to develop a specific instrument to determine aspects related to the safety of universities cyclists when traveling on public roads. Behavioral and environmental aspects observed through cameras fixed to the cyclist's helmet were observed. The instrument presented adequate reproducibility values.

Overall intra and inter-rater concordance percentages were elevated for all categorical variables (88.0 - 100.0%), in the same way kappa index presented values of high coefficients (0.760 - 1.000). Among the continuous variables, we observed equally high values of intraclass correlation coefficient (0.960 - 0.997). In a previous study that aimed to identify the type and characteristics of critical events between cyclists and drivers, it was observed that the lowest inter-rater concordance values were adequate and similar to those of the present study (0, 667 and 0.769, respectively).

The lowest concordance values were observed in three categories of multi-response variables, being them the "left side of the lane" and "flat surface" when considering the inter-rater analysis and "pedaling ahead" when considering the intra-rater analysis. This may have happened due to the possibility of indicating more than one response option, which, although it allows the identification of particularities, may require better established protocols and a more refined training with the evaluators, in order to avoid observation nuances gathering.

Until this moment, an instrument that allows a more detailed evaluation of the characteristics of these accidents has not been found in the literature. This study represents a contribution in the area of control and prevention of bicycle accidents on public roads, since the information obtained through this instrument would be able to help the targeting of public policies focused on this subject. The development of the instrument followed recommended steps[13] and evaluated separately each component of the instrument, which made it possible to identify in details the quality of each item of the instrument.

However, some limitations must be considered in order to extrapolate the results. The instrument evaluates samples of a 30 seconds range route, which may not represent the different situations along the trip. In addition, the instrument was developed through trips made in the city of Curitiba, and adaptations may be necessary when applied in different cities. Some conditions may complicate the variables collect of interest, such as rainy days or periods of the day without natural light, limiting the results of this study to exceed other periods and in different climatic conditions.

CONCLUSION

The developed instrument showed adequate reproducibility to determine behavioral and environmental aspects in public roads.

COMPLIANCE WITH ETHICAL STANDARDS

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Ethical approval

Ethical approval was obtained from the Human Research Ethics Committee of the Pontifical Catholic University of Paraná, and the protocol was written according to the standards established by the Declaration of Helsinki.

Conflict of interest statement

The authors have no conflict of interests to declare.

Author Contributions

Elaboration and design of the experiment: TC and AH. Experiments: CT and IC. Data analysis: CT and AH. Article Writing: TC, IC and AH. All authors read and approved the final version of the manuscript.

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