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Are Latin American cycling commuters "at risk"? A comparative study on cycling patterns, behaviors, and crashes with non-commuter cyclists

Sergio A. Useche, Ph.D. [a,b,*], Cristina Esteban, Ph.D. [a], Francisco Alonso, Ph.D. [a], Luis Montoro, Ph.D. [b]

[a] DATS (Development and Advising in Traffic Safety) Research Group, INTRAS (Research Institute on Traffic and Road Safety), University of Valencia, Carrer del Serpis 29, 3rd Floor, DATS. 46022, Valencia, Spain

[b] FACTHUM.Lab (Human Factor and Road Safety) Research Group, INTRAS (Research Institute on Traffic and Road Safety), University of Valencia, Spain

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ABSTRACT

Introduction: As part of the transformation of urban transportation dynamics, commuter cycling has acquired a high relevance as an alternative mode of transport in different countries, and Latin America seems to be one of the main focus of this worldwide "revolution". However, the high rates of crashes and injuries suffered by commuters have become a relevant issue in the field of road safety, especially in emerging regions with low cycling tradition, where social and infrastructural gaps may endanger the cyclists' safety.

Objectives: This study had two objectives. First, to compare key safe cycling-related variables between cycling commuters and non-commuters; and second, to differentially asses the effect of individual and cycling-related variables on their self-reported crash rates. Method: For this cross-sectional research, the data provided by 577 Latin American urban cyclists from three countries (Argentina, Colombia and Mexico) with a mean age of 32.7 years was used. They answered a questionnaire on cycling habits, risk perception, rule knowledge, cycling behaviors and riding crashes.

Results: The outcomes of this study showed that, despite having a higher risk perception, cycling commuters perform deliberate risky cycling behaviors (traffic violations) more frequently, and they suffer more crashes; cycling commuters report higher rates of psychological distress, and a lower degree of rule knowledge and protective behaviors than non-commuters. Furthermore, structural similarities and differences in the explanation of cycling crashes were found across commuters and non-commuters.

Conclusion: The results of this study suggest that non-commuters, whose purposes for cycling are more aimed at leisure and occasional trips, perform less risky behaviors but suffer more cycling distractions, whereas commuters are comparatively more exposed to behavioral-based safety risks, and suffer more frequent crashes. Since recent evidence forecasts that urban cycling will keep growing in Latin American cities, it is necessary to implement policies and educational/training improvements that may enhance the safety and health of cyclists in these countries.

1. Introduction

During the last decade, different Latin American cities have promoted bicycle commuting, that can be understood as a regular use of the bicycle for everyday trips, e.g., commuting trips from and to work or school (Stewart et al., 2015; de Geus et al., 2007).

Commuting cycling has a long tradition in several countries around the world, but especially in Europe, where it has turned in a sustainable, cheaper, healthy and useful alternative for daily travel. Some of the most exemplary cases regarding the implementation of commuter cycling are cities such as Copenhagen, Amsterdam, Oslo, Paris, Vienna and Barcelona, all them included in the "Copenhagenize Index", that ranks the most bicycle-friendly cities around the world (Copenhagenize.eu, 2020). After many efforts put throughout time in terms of infrastructure, transformation of transport dynamics and road user behavior, these cities have managed to effectively promote bicycle use, and the evidence suggests that this set of actions has had a positive impact on the lifestyle and health of both cyclists and the general population, since (among

* Corresponding author.
E-mail addresses: sergio.useche@uv.es (S.A. Useche), cristina.esteban@uv.es (C. Esteban), francisco.alonso@uv.es (F. Alonso), luis.montoro@uv.es (L. Montoro).

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other potential benefits) it also contributes to reducing the pollution and congestion caused by motorized modes of transport (Schmidt, 2018; Fishman et al., 2015).

Furthermore, cycling commuting seems to be the most beneficial (although not the only one) active commuting mode for health and lifestyle gains (Ogilvie et al., 2016; Veisten et al., 2011). Compared to walking commuting, which is a healthy activity itself, bicycle commuting has a higher physiological intensity, and it is likely to provide, for instance, cardiovascular stimulation and many other health and lifestyle-related improvements, even for young users (Shephard, 2008; Oja et al., 1991). Moreover, systematic reviews of the health benefits of cycling, such as the one performed by Oja et al. (2011), have found that commuting through physical activity -including cycling commuting- is related to a decreased risk of suffering illnesses such as colon cancer (also in Hou et al., 2004) and type 2 diabetes (Rasmussen et al., 2016), and it provides a significantly better fitness for young cycling commuters of both sexes (Aparicio-Ugarriza et al., 2020; Cooper et al., 2006). Commuter cycling has also been shown to have positive effects on job-related and welfare issues; as a relevant precedent, Oja et al. (1998) stated that physically active commuting may have a considerable potential as a health-enhancing element for the working-age population. Furthermore, Hendriksen et al. (2010) found that individuals using bicycles as a means of transport for daily commuting present a lower rate of sickness leaves than those using other modes of transport (typically cars and public service vehicles). Also, the longer and more regular the distance commonly traveled by bike, the fewer the days of absenteeism reported during a period of one year, also related to the fact that a constant and prolonged physical activity in everyday life is a relevant contributor for the reduction of cardiovascular mortality (Shephard, 2008). Finally, in a recent study carried out on Spanish cyclists, Avila-Palencia et al. (2017) found that Bicycle commuters had significantly lower risk of being stressed than non-commuters, supporting the assumption that active transportation may also contribute to the improvement of the psychological health of its users.

1.1. Non-traditional, but promising: cycling commuting is rising in Latin America

In the Latin American case, integrating daily trips with active transportation modes such as cycling represents an opportunity to promote physical activity as a part of transport dynamics, with the aim of improving – in addition to community health-, new cultural values, positive behaviors and societal development goals through sustainable transportation (Ramírez-Vélez et al., 2016; Reis et al., 2013). Among the most iconic examples of policymaking and strengthening of bicycle commuting used in Latin America, it is possible to highlight the cases of Mexico, Argentina, and Colombia (Gomez et al., 2015; Taddei et al., 2015; Baumann et al., 2013; Cervero et al., 2003; COHA, 2014), whose urban transportation systems and infrastructures have tried to progressively incorporate more and better social environmental elements for the enhancement of daily commuting; they have also attempted to integrate active transportation as a core strategy for the reduction of non-communicable diseases and the optimization of transportation dynamics (Steell et al., 2018; Page and Nilsson, 2017; Mosquera et al., 2012). Although these outcomes could rather be expected in the mid and long term, they are still needed for a safer active transportation (Guzman and Bocarejo, 2017); it is worth highlighting the case of Bogotá (Colombia), that, thanks to several investments in built environment and a growing number of daily cyclists, has recently been introduced in the Copenhagenize Index (Copenhagenize.eu, 2020; Torres et al., 2013). In comparison with other cities in Latin America, Bogotá has the highest number of bike-trips a day (Rosas-Satizábal and Rodríguez-Valencia, 2019).

As for the cases of Argentina and Mexico, the statistics also demonstrate how urban cycling is also rapidly gaining ground as a transportation mode in their main cities (Pucher and Buehler, 2017; World Bank, 2015). Indeed, recent sources forecast that the social distancing and avoidance of crowded transport means, measures adopted as a response to the recent COVID-19 pandemic, might potentiate even more the expansion of bike commuting in the large cities of these three countries (Americas Quarterly, 2020).

Furthermore, and although the empirical evidence is still very scarce in this regard, most of the daily cycling trips in some big Latin American cities, such as Bogotá and Mexico D.F., are related to commuting trips, especially for workers (most of them with a low-middle income) and students (secondary/high school and universities), while leisure bicycling can be observed particularly among middle- and higher- income residents, whose mean age tends to be higher (C40 Cities Finance Facility, 2018; Guerra et al., 2018; Alonso, 2017). Also, it has been found that Latin American bicycle commuting seems to be still *gendered*, since most of its daily users are adult and young-adult males; women seem to cycle less because of security and safety reasons, and female active commuters are more likely to perform walking trips (C40 Cities Finance Facility, 2018; de Sá et al., 2017).

However, and even though bike commuting might have several benefits for its users, there is a “flip side” of the coin. Bicycle commuting, especially in countries that lack a long tradition of cycling culture, implies a series of risks and burdens that should be mentioned: a high prevalence of cycling crashes implies a high cost for both health care systems and private organizations, increases the years of potential life lost (YPLL) of the population (Isaksson-Hellman, 2012), and produces severe injuries that may lead to the disability of both cyclists and other road users involved in their crashes (Ramalho et al., 2015). In societal terms, the absence of a cycling culture may impair the safety, sustainability, and feasibility of alternative transportation modes (Useche et al., 2019a,b,c; Alveano-Aguerrebere et al., 2017; Macmillan et al., 2014), putting more frequent bike users at special risk.

In behavioral settings, an insufficient education and training in road safety issues may expose cyclists to a major risk of cycling crashes (Winters et al., 2012). In this regard, Hezaveh et al. (2018) found significant differences in both errors and traffic violations committed by regular cyclists of both genders, which accounts for the fact that there are specific groups of users with particular training needs (e.g., more risk perception, rule knowledge, and protective behaviors) that should be addressed as part of the strengthening of safe urban cycling. As for other risk patterns, different studies have established that, for instance, cycling velocity, that is linked to the severity of crashes, is positively associated with the length and the distance of trips; it could therefore be higher among commuters (Schantz, 2017). Also, it has been found that cycling distractions seem to be a relevant predictor of cycling crashes, through the enhancement of risky behaviors (errors and traffic violations) that mediate this statistical relationship (Useche et al., 2018a). Precisely, this study follows a behavioral perspective, in which risky behaviors are taxonomically differentiated: firstly, *errors* refer to undeliberate or unintended behaviors that increase the risk of suffering a traffic crash (e.g., not realizing that a pedestrian is approaching when passing a crosswalk), while *violations* consist of deliberate transgressions of the traffic norms and/or safe riding features (e.g., running a traffic light that turned red), also increasing the likelihood of suffering a traffic accident (Zheng et al., 2019; Useche et al., 2018b).

1.2. Objectives and hypotheses

This study had two main objectives. First, to compare key safe cycling-related variables (i.e., riding habits, risk perception, rule knowledge, distractions, risky and positive behaviors, and cycling crashes) between commuter and non-commuter cyclists. Secondly, this study aimed to evaluate the differential impact of the study variables on the traffic crashes suffered by the cyclists from a multi-group perspective (*How similarly or differently do they work across commuters and non-commuters?*).

For this research we hypothesized: in regard to the first objective, that, although they commonly present more regular and intense cycling habits, Latin American commuting cyclists may comparatively show more adverse outcomes than non-commuters, considering their higher exposure to potentially unfriendly cycling environments and adverse conditions that do not affect non-commuters to the same degree. As for the second study aim, and as we have already mentioned, recent evidence shows that, together with cycling behaviors, cycling exposure and motives (e.g., commuting, or not) may explain differences in road risks; so, we hypothesized that, although keeping a similar structure (psychosocial variables, distractions, and risky behaviors would similarly affect their crash rates), the mechanisms through which cycling crashes are influenced may vary between commuters and non-commuters.

2. Methods and materials

2.1. Sample

The data were collected from a full sample of 577 Latin American bicyclists from three countries in which, as mentioned above, urban cycling has substantially increased during the last years: Argentina (n = 127), Colombia (n = 372), and Mexico (n = 78). 228 (39.5 %) of them were females, and 349 (60.5 %) were males, all of them aged between 17 and 71, with a mean age of M=32.69 (SD = 12.40) years.

In accordance with the aim of the study, we collected data from cyclists who were then divided into two groups. The first group (n = 389) consisted of commuter cyclists with a mean age of M=29.66 (SD=10.85). Regarding their cycling habits, commuters reported a mean number of M=7.72 (SD=5.93) cycling hours a week, and average bicycle journeys of M = 35.25 (SD=17.86) minutes. 39.7 % were females and 60.3 % males, coherently with the fact that cycling commuters in Latin American are predominantly males and their mean age tends to be lower than non-commuters, as we have mentioned in the introduction.

The second group was composed of non-commuter cyclists (n = 188; 40.4 % females and 59.6 % males), with a mean age of M=38.47 (SD=13.23) years. As for their cycling habits, this group reported an average number of M=5.03 (SD=5.13) cycling hours a week, and bicycle journeys of M = 65.27 (SD=44.39) minutes. Key comparisons between the groups for individual and cycling trip-related variables are presented in section "*3.2 Comparative Analyses*".

2.2. Study design and procedure

This was a cross-sectional study based on the self-reported data provided by cyclists from three Latin American countries in which commuter cycling has experienced a substantial growth and policy enforcement along the last decade: Argentina, Colombia, and Mexico. The data was collected during the years 2016−2019. In order to participate in the study, participants were directly contacted by means of an e-mail invitation, that also encouraged them to share the invitation with other potential partakers. This information was available thanks to the existence of an inter-institutional verified mailing list, shared with some other universities, research centers and foundations/associations based or working in these three countries.

Once the online questionnaire was accessed, an Informed Consent Statement containing ethical principles and data treatment details was presented, explaining the objective of the study, the mean duration of the survey, the treatment of the personal data, and the voluntary participation; this Statement was always provided to the participants before they completed the questionnaire. Considering the scope of the study (aimed at frequent urban cyclists), and as an exclusion criteria, electronic surveys from participants that were not regular bicycle users (less than "*at least a few times a month*") and/or with less than 5 years of experience in bike use (in order to uniformly retrieve cycling crash rates), were automatically considered finished after collecting demographic data; even though they were acknowledged for their willingness to collaborate, the information they provided was dismissed from the database of the study.

The overall response rate (valid surveys) was around 69 %, considering that around 820 subjects were initially invited to partake in the study. In order to carry out this research, the study was evaluated by the Social Science in Health Research Ethics Committee of the University of Valencia, certifying that our research responded to the general ethical principles, in accordance with the Declaration of Helsinki (IRB approval number H1517828884105).

2.3. Study variables and description of the questionnaire

For this study, an electronic four-section questionnaire was used, and it was structured as follows:

The first part of the instrument addressed the demographic information of participants, such as age, gender, education, country of residence, and occupation. Furthermore, it presented a brief questionnaire about cycling habits, including the types of journey, and their regular trip length and frequency (measured in minutes and times per week, that were computed to calculate cycling intensity) reasons for cycling (i.e., *do you regularly use the bicycle to commute from/to a fixed location, (e.g.) your job or educational center?*), and traffic crashes suffered while cycling during the last five (5) years.

The second part of the questionnaire included the validated version of the Cycling Behavior Questionnaire – CBQ (Useche et al., 2018a), that is available in the Appendix I of this paper. This 5-level Likert scale (0=never; 1=hardly ever; 2=sometimes; 3=frequently; 4=almost always) based on the Behavioral Questionnaire paradigm (BQ; Hezaveh et al., 2018; Reason et al., 1990) is made up of 29 items assessing the frequency by which, commonly, cyclists perform risky and protective behaviors, and it is divided into three factors: *Traffic Violations*, defined as deliberate deviations from those practices believed to be necessary for maintaining the safe operation of the system, including traffic rules and social conventions (Useche et al., 2018a; Reason et al., 1990). This consists of 8 items (Cronbach's Alpha, α = .704; example item: *Crossing what appears to be a clear crossing, even if the traffic light is red*); *Errors*, that can be understood as the operational failure of planned actions meant to achieve their intended consequence (Reason et al., 1990), consisting of 15 items (α = .841; example item: *Unintentionally hitting a parked vehicle*); and *Positive Behaviors*, defined as the set of preventive and prosocial actions that may strengthen the road safety of cyclists, consisting of 6 items (α = .702; example item: *I yield to other vehicles that come very close to me, although I might have the priority*).

Thirdly, three short scales were included in order to measure supplementary variables: the Cyclist Risk Perception and Regulation Scale – RPRS (Useche et al., 2018a) was used to assess the cyclists' risk perception (the degree to which they perceive risks in potentially hazardous situations) and the knowledge of the most general traffic norms (the degree to which they consider to know and understand cycling traffic rules), through a 5-level Likert scale made up of 12 items: 7 for risk perception (α = .703; example item: *I perceive potentially higher risks for my integrity when I ride a bicycle than when I am on board of a motorized vehicle*) and 5 for the knowledge of general norms in cycling (α = .721; example item: *I believe that pedestrians should always have the priority, even more than cyclists*), in which the degree of risk perceived in objective risk factors and the knowledge of general road regulations were assessed in a 0 (no knowledge/risk perceived) to 4 (highest knowledge/risk perceived) scale.

Cycling distractions, that can be understood as deviations of attention, which shifts from tasks critical to safe driving, riding or walking, to another marginal activity (Useche et al., 2018a; Anstey and Wood, 2011) were measured through the Cycling Distraction Scale – CDS (Useche et al., 2018a). This is an 8-item binomial scale created to assess the impact of different potential road distracting sources on cycling performance (α = .643; example item: *The behavior of other users of the road*).

Finally, psychological distress was measured using the short version of the Goldberg's General Health Questionnaire (GHQ; Goldberg, 1992), a 12-item Likert scale (α = .714) that is meant to assess different potential symptoms which may have affected the mental health of the subject in the form of *psychological distress* during the previous month. This instrument was included for comparative purposes, bearing in mind two essential facts: first, that cycling has been linked to positive results for the subject's mental health (Pucher et al., 2010; Cavill and Davis, 2007), and second, that mental health is related to road safety behavior (McDonald et al., 2014).

2.4. Data processing

After data curation, basic descriptive analyses were performed in order to obtain scores for the three dimensions of the Cyclist Behavior Questionnaire (CBQ) and the supplementary scales. Cronbach's Alpha (α) analyses were used to assess the internal test reliability of the subscales composing the study questionnaire. Typically, an α = .50 is required to accept a subscale, and values close/superior to α = .70 suggest a very good fit (Morera and Stokes, 2016). Furthermore, descriptive statistics (means, standard deviations) were calculated.

Spearman's *rho* (or r_s) bivariate correlational analyses, performed using the full sample, were used to establish the measures of association among study variables, considering their robustness over Pearson's (r) correlations when ordinal values are measured (Liu et al., 2016; Mukaka, 2012). To accomplish the first study aim, and after basic comparability parameters were met, a Chi-square (x^2) analysis was used to assess the possible gender differences in cycling commuting, and one-way analysis of variance (ANOVA) tests were performed in order to compare the mean scores obtained by both commuters and non-commuters for the different study variables.

In regard to the second objective, Multi-group Structural Equation Modeling (MGSEM) with maximum likelihood analyses (MLA) and differential criteria - significance levels of $p < 0.05$, $p < .01$, $p < .001$, was applied in order to differentially study the effect of the study variables on cycling crashes in a period of five (5) years throughout cycling commuters and non-commuters.

Descriptive, correlational, and comparative (ANOVA) statistical tests or analyses were carried out using ©IBM SPSS (Statistical Package for Social Sciences), version 24.0, and MGSEM modeling was performed using ©IBM AMOS, version 26.0.

3. Results

3.1. Descriptive outcomes

Table 1 summarizes the descriptive data of the study, including mean values, standard deviations, and association measures found between pairs of variables. The Spearman's bivariate correlation analysis (r_s coefficients and significances are also shown in Table 1), performed on the full study sample (n = 577) allowed us to identify significant associations between these study variables:

Cycling intensity and both risky behaviors [+] and traffic crashes [+]. In other words, and consistently with the existing literature on risk exposure, the more time spent cycling, the higher the rate of risky cycling behaviors and the higher the number of reported crashes.

Cycling distractions were not significantly correlated with traffic crash rates, but they were associated with risky cycling behaviors [+]. Also, age and cycling distractions were correlated [+] as well. **Risk perception** and **rule knowledge** were associated with age [+], educational level [+] and positive behaviors and, on the other hand, with psychological distress [-] and risky road behaviors [-]. This means that more risk perception and rule knowledge are associated with lower scores in risky behaviors, and vice versa. However, and unlike the case of risk perception (not significant), **traffic-rule knowledge** was significantly [-] associated with cycling crash rates.

As for **positive cycling behaviors**, they were positively are associated with age [+], education [+], risk perception [+] and rule knowledge [+], and negatively with hourly intensity [-], psychological distress [-], risky behaviors [-], and cycling crashes [-].

On the other hand, **risky behaviors were** significantly and negatively correlated with age [-], education [-], risk perception [-], rule knowledge [-] and positive cycling behavior [-], and positively correlated with cycling hours a week [+; but only in the case of *violations*], psychological distress [+], cycling distractions [+; but only for *errors*] and cycling crashes [+].

3.2. Comparative analyses

First of all, a Chi-square analysis was carried out, in order to determine whether cycling commuting showed (or not) significant gender-based differences: we found that there were no differences between male and female cyclists in this regard ($x^2_{(1)} = .097$, $p = .412$). Secondly, ANOVA tests were performed to assess differences in the study variables between cycling commuters and non-commuters. Table 2 reports significant differences, descriptive data for each group and confidence intervals (95 %). Specifically, it was found that commuter cyclists present a significantly higher average number of hours traveled per week than those reporting other reasons (recreational, leisure) for using bicycles as a transport mode (around 2.7 weekly hours more than non-commuters). Also, commuters report a higher risk perception and a lower rate of cycling distractions than non-commuters.

Nevertheless, we also found a set of significant differences in which commuters present unfavorable scores when compared to non-commuter cyclists: a greater mean of psychological distress (mental health measured through the GHQ-12), and lower mean scores of traffic rule knowledge in cycling. It is also striking that the average of cycling crashes suffered by commuter cyclists in the last 5 years is almost two times higher than the one reported by non-commuter cyclists (M = .43 non-commuter, versus M = .74 for commuters).

As for behavioral issues, comparisons show that cycling commuters perform deliberate risky behaviors (violations) with higher frequency, in comparison with non-commuters, and the latter report a significantly

Table 1
Bivariate Spearman's correlations (r_s) among study variables.

Study Variable		2	3	4	5	6	7	8	9	10	11
1	Age (years)	.505**	−.114*	−.307**	.092*	.287**	.423**	.203**	−.182**	−.270**	−.196**
2	Educational Level	–	−.202**	−.196**	.021	.167**	.205**	.156**	−.117**	−.182**	−.182**
3	Weekly Cycling Intensity		–	.040	−.115**	−.070	.004	−.092*	.067	.255**	.239**
4	Psychological Distress			–	−.037	−.196**	−.320**	−.169**	.187**	.139**	.131**
5	Cycling distractions				–	.059	−.001	−.044	.139**	.055	−.058
6	Risk Perception					–	.354**	. 359**	−.222*	−.253*	−.040
7	Knowledge of Traffic Norms						–	.272**	−.320**	−.240**	−.098*
8	Positive Behaviors							–	−.319**	−.466**	−.187**
9	Errors								–	.429**	.269**
10	Traffic Violations									–	.298**
11	Cycling Crashes (5 years)										–

Notes for the Table: *Correlation is significant at 0.05 level (2-tailed); **Correlation is significant at 0.01 level (2-tailed).

Table 2
Specific descriptive data and mean comparisons (One-way ANOVA) between commuter and non-commuter cyclists.

Study Variable	Group	N	Mean	SD	SE	95 % CI		Min	Max	ANOVA	
						Lower	Upper			F	Sig.
Age	Non-commuter	188	38.87	13.36	.97	36.94	40.79	17	70	78.172	.000 (***)
	Commuter	389	29.70	10.76	.54	28.63	30.77	17	71		
Weekly Cycling Intensity	Non-commuter	172	5.03	5.13	.39	4.26	5.80	.00	50.00	26.504	.000 (***)
	Commuter	378	7.72	5.93	.31	7.13	8.32	1.00	50.00		
Psychological Distress	Non-commuter	184	22.01	4.73	.35	21.32	22.70	13.00	33.00	12.700	.000 (***)
	Commuter	368	23.62	5.14	.27	23.10	24.15	12.00	45.00		
Cycling Distractions	Non-commuter	188	4.98	1.80	.13	4.72	5.24	.00	8.00	7.011	.008 (**)
	Commuter	389	4.57	1.77	.09	4.39	4.74	.00	8.00		
Risk Perception	Non-commuter	188	.98	.71	.05	0.88	1.09	.00	3.62	20.585	.000 (***)
	Commuter	389	1.28	.73	.04	1.20	1.35	.00	4.76		
Knowledge of Traffic Norms	Non-commuter	188	3.50	.57	.04	3.42	3.59	.29	4.00	7.256	.007 (**)
	Commuter	389	3.38	.49	.02	3.33	3.43	1.57	4.00		
Positive Behaviors	Non-commuter	188	3.27	.67	.05	3.18	3.37	.60	4.00	24.942	.000 (***)
	Commuter	389	2.96	.71	.04	2.89	3.03	.60	4.00		
Errors	Non-commuter	188	.48	.41	.03	.41	.53	.00	1.87	1.643	.200 (N/S)
	Commuter	389	.52	.36	.02	.48	.55	.00	2.13		
Traffic Violations	Non-commuter	188	.51	.40	.02	.41	.53	.00	2.13	7.896	.000 (***)
	Commuter	389	.76	.49	.03	.48	.57	.00	2.00		
Cycling Crashes	Non-commuter	188	.43	.90	.07	0.30	.55	.00	5.00	14.645	.000 (***)
	Commuter	389	.74	.93	.05	0.65	.83	.00	5.00		

Notes: SD = Standard Deviation; SE = Standard Error; CI = Confidence Interval; *** Significant at level 0.001; ** Significant at level 0.01; * Significant at level 0.05; (N/S) Non-significant

Table 3
Multi-group Structural Equation model (MGSEM) used to predict the cycling crashes suffered in the last five years.

MGSEM (Group 1): Commuters			SPC[1]	SE[2]	CR [3]	p^4	Sig.
Age	→	Cycling Distractions	.132	.005	2.606	.009	**
Cycling Intensity	→	Cycling Distractions	.040	.090	.803	.422	N/S
Risk Perception	→	Cycling Distractions	.074	.054	1.444	.149	N/S
Knowledge of Traffic Norms	→	Cycling Distractions	−.009	.029	−.293	.769	N/S
Age	→	Errors	−.085	.002	−.1669	.095	N/S
Cycling Intensity	→	Errors	−.015	.032	−.304	.761	N/S
Risk Perception	→	Errors	−.119	.190	−.2.379	.017	*
Knowledge of Traffic Norms	→	Errors	−.190	.019	−.3664	<.001	***
Cycling Distractions	→	Errors	.183	.018	3.756	<.001	***
Age	→	Traffic Violations	−.174	.002	−.3.402	<.001	***
Cycling Intensity	→	Traffic Violations	.021	.044	.425	.671	N/S
Risk Perception	→	Traffic Violations	−.196	.026	−3.882	<.001	***
Knowledge of Traffic Norms	→	Traffic Violations	−.005	.026	−.088	.930	N/S
Cycling Distractions	→	Traffic Violations	.143	.025	2.910	.004	**
Age	→	Cycling Crashes	−.325	.016	−.1766	.077	N/S
Cycling Intensity	→	Cycling Crashes	.049	.174	.474	.635	N/S
Cycling Distractions	→	Cycling Crashes	1.565	1.169	1.260	.209	N/S
Errors	→	Cycling Crashes	.157	.138	2.906	.004	**
Traffic Violations	→	Cycling Crashes	.182	.101	3.397	<.001	***
MGSEM (Group 2): Non-commuters			**S.P.C.[1]**	**S.E. [2]**	**C.R. [3]**	**p^4**	**Sig.**
Age	→	Cycling Distractions	117	.006	1.444	.149	N/S
Cycling Intensity	→	Cycling Distractions	−.019	.053	−.263	.792	N/S
Risk Perception	→	Cycling Distractions	.087	.065	1.235	.217	N/S
Knowledge of Traffic Norms	→	Cycling Distractions	−.196	.094	−.2.293	.022	*
Age	→	Errors	.035	.002	.543	.651	N/S
Cycling Intensity	→	Errors	.013	.021	.190	.849	N/S
Risk Perception	→	Errors	−.081	.028	−1.097	.273	N/S
Knowledge of Traffic Norms	→	Errors	−.266	.037	−.3223	<.001	***
Cycling Distractions	→	Errors	.095	.027	1.384	.166	N/S
Age	→	Traffic Violations	−.115	.002	−.1.499	.134	N/S
Cycling Intensity	→	Traffic Violations	.188	.020	2.761	.006	**
Risk Perception	→	Traffic Violations	−.047	.027	−.650	.516	N/S
Knowledge of Traffic Norms	→	Traffic Violations	−.212	.036	−2.590	.010	**
Cycling Distractions	→	Traffic Violations	.177	.070	1.534	.125	**
Age	→	Cycling Crashes	.048	.006	.570	.569	N/S
Cycling Intensity	→	Cycling Crashes	−.041	.054	−.498	.619	N/S
Cycling Distractions	→	Cycling Crashes	−.488	−.438	−.992	.321	N/S
Errors	→	Cycling Crashes	.064	.185	.752	.452	N/S
Traffic Violations	→	Cycling Crashes	.231	.194	2.670	.008	**

Notes: [1]SPC = Standardized Path Coefficients (can be interpreted as linear regression weights; β). [2]SE = Standard Error. [3]CR = Critical Ratio. [4]Raw *p*-values. N/S Non-significant path; ***Significant at level 0.001; **Significant at level 0.01; *Significant at level 0.05.

higher rate of positive behaviors. Differences in errors were not significant (see Table 2).

3.3. Multi-Group structural (MGSEM) analysis

Based on the theoretical assumptions presented in the introduction, the mechanisms explaining cycling crashes of commuter and non-commuter cyclists were simultaneously assessed by means of the MGSEM approach: this is extensively different from separately modeling both groups in two different structural models, and it allows for the detailed study of the differences and similarities between groups of individuals. Thus, the data were split into two groups (**Group 1:** Commuter cyclists; **Group 2:** Non-commuter cyclists), presenting an acceptable sample size and good conditions for comparability. Using the AMOS multi-group comparison analysis, the hypothesized structural model (see "*Objectives and hypotheses*") was adjusted following a multi-group invariance-testing strategy.

The MGSEM model was specified in a sequence similar to the one recommended in the expert literature (Marsh et al., 2004). As a baseline model it did fit the data relatively good, but not optimally ($x^2_{(12)}$ = 105.05, $p < .001$; NFI=.794; CFI=.795; RMSEA=.116 - IC(90 %) [.096–.137]; CMIN/DF = 8.754); therefore, structural modifications were applied to constrain the model through controlling the hypothesized covariances. The resulting MGSEM better fit coefficients ($x^2_{(10)}$ = 30.965, $p < .001$; NFI=.939; CFI=.954; RMSEA=.060 - IC$_{(90\ \%)}$[.037–.085]; CMIN/DF = 3.096), and it is presented in Table 3 and, graphically, in Fig. 1. In addition to the multi-group invariance test, indicating that the model works similarly well for both of them, the RMSEA (<.08), NFI/CFI (>0.90) coefficients suggested an optimal fit for the final model (Yuan and Chan, 2016; Marsh et al., 2004; Hu and Bentler, 1999), showing that factor loadings, intercepts and residual covariances were similarly operating in both groups.

3.3.1. Group 1: cycling commuters

As depicted in Fig. 1 (left), for cycling commuters nine **direct effects** were significant. Age positively predicted cycling distractions and negatively predicted traffic violations. Risk perception negatively predicted both errors and traffic violations. Rule knowledge was negatively related to errors. Cycling distractions positively predicted errors and violations. Regarding risky cycling behaviors, errors and violations predicted self-reported cycling crashes. As for **indirect effects** of the study variables on cycling crashes, errors have shown to exert full mediations between three variables, (*i*) risk perception, (*ii*) rule knowledge and (*iii*) distractions and cycling crashes. On the other hand, violations fully mediate the relationship between (*i*) risk perception, (*ii*) age and (*iii*) distractions and self-reported crashes.

3.3.2. Group 2: non-commuters

As shown in Fig. 1 (right), six **direct effects** were significant for non-commuters. Cycling intensity was positively associated with traffic violations. Rule knowledge negatively predicted cycling distractions, riding errors and traffic violations. Cycling distractions positively predicted traffic violations. In regard to risky cycling behaviors, violations (but not errors) predicted self-reported cycling crashes. As for **indirect effects** on cycling crashes, traffic violations have shown to exert full mediations between three variables, (*i*) cycling intensity, (*ii*) rule knowledge and (*iii*) distractions and cycling crashes.

3.3.3. Differences and similarities between commuter and non-commuter cyclists

The MGSEM model shows that, although both analyzed groups keep some key similar characteristics, there are some key structural differences regarding the differential effect of the variables (included in the significant model) on cycling crashes, expressed in both (*i*) the significance of the relationships and (*ii*) their magnitude. Firstly, and regarding the observed similarities, it was found that: the knowledge of traffic norms has a significant effect on the cycling errors of both groups, although the magnitude of the effect is higher for the second group ($\beta = -.190$***commuters; β=-.266***non-commuters). Also, cycling distractions have a significant effect on violations, keeping similar magnitudes for both groups, although slightly lower in the case of group 1 ($\beta = .143$***commuters; $\beta = .177$***non-commuters). Finally, traffic violations are a shared predictor for cycling crash rates in both groups, with the magnitude of the effect being relatively higher for group 2 ($\beta =$ .182***commuters; $\beta = .231$**non-commuters).

Regarding differential factors, key structural differences were found between the two groups: unlike non-commuters, in the case of commuting cyclists age has a significant effect on cycling distractions ($\beta = .132$**) and traffic violations ($\beta = -.174$***).

Also, in the case of **commuters**, risk perception has a significant effect on errors (β=-.119*) and traffic violations ($\beta = -.196$***), while errors significantly influence cycling crash rates ($\beta = 0.157$**). On the other hand, and as a specific finding for the case of **non-commuters**, the knowledge of traffic norms has a significant effect cycling distractions ($\beta = -.196$*) and traffic violations ($\beta = .212$***), while cycling crashes are significantly influenced by traffic violations ($\beta = -.231$**), but not by cycling errors. The aforementioned mediations, found in both groups (even though with some slight differences), allow us to support the hypothesis that, according to the model, cycling distractions may not directly predict the traffic crashes of urban cyclists for both commuters

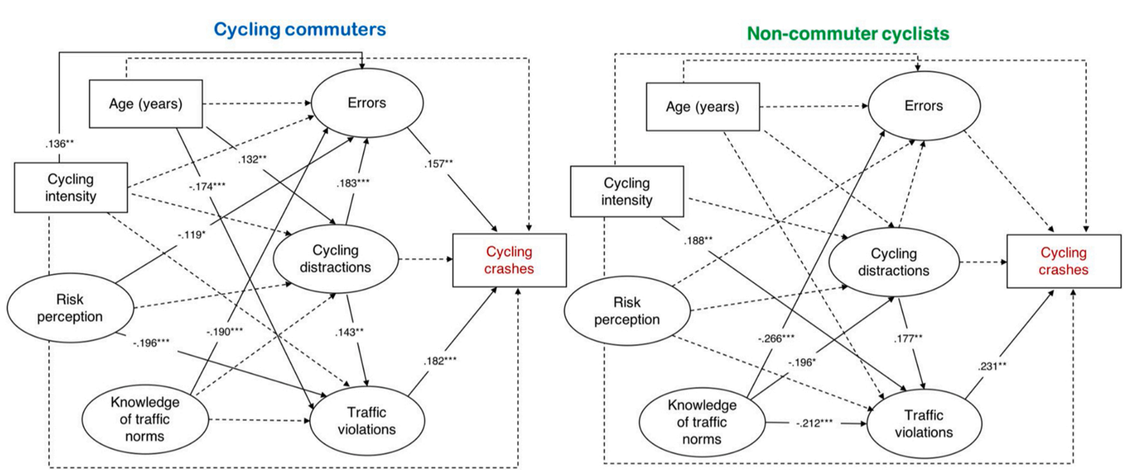

Fig. 1. Two-group (MGSEM) structural model showing standardized path coefficients and significant paths (solid lines). Categories: commuters (left) and non-commuters (right). *$p < 0.05$; **$p < 0.01$; ***$p < 0.001$.

and non-commuters. They might rather be mediated by risky behaviors (errors and traffic violations in the case of commuters, and traffic violations in the case of non-commuters) in the explanation of cycling crashes.

4. Discussion

The first objective of this study was to comparatively assess key cycling safety-related variables (i.e., riding habits, risk perception, rule knowledge, distractions, risky and positive behaviors, and cycling crashes) between commuter and non-commuter cyclists. In brief, our results support the idea that, although commuters cyclists present some "advantages" over non-commuters in what concerns some study variables, such as comparatively higher risk perception and lower rates of cycling distractions, other concerning outcomes were identified regarding mental health issues (psychological distress), rule knowledge, deliberate risky behaviors (violations) and higher rates of crashes suffered in a period of five years. It is worth pointing out, however, that commuter cycling does not have a long tradition in Latin America, and its growth has taken place under several societal and structural shortcomings (Useche et al., 2019a, 2019b, 2019c; Guzman and Bocarejo, 2017; Torres et al., 2013; de Hartog et al., 2010). Thus, this can be a key factor to understand why, under certain conditions, and although commuter cycling has been empirically linked to a huge set of improvements for health and lifestyle (Steell et al., 2018; Ramírez-Vélez et al., 2016; Pucher and Buehler, 2016; Reynolds et al., 2009), its risks might be overcoming the benefits in different spheres, including behavioral and safety settings.

Concretely in the Latin American context, we can observe -even when considering the issue of underreporting - the relative growth of urban cycling aimed at activities other than leisure and fitness. This can be related to the fact that cycling often cheapens the daily trips of (e.g.) low- and middle- income workers and students (C40 Cities Finance Facility, 2018; World Bank, 2015). However, it has been accompanied by (*i*) an increasing rate of injured cyclists (International Transport Forum, 2017) and (*ii*) the absence of adequate directions in policymaking to protect users of alternative transportation modes (Bösehans and Martineli, 2018; Becerra et al., 2013). In other words, the issue is not just strengthening the positive perception of cycling as a cheap, useful, healthy, and environmental-friendly activity for encouraging individuals to commute by bike, but also to systematically perform different necessary enhancements to (e.g.) cycling infrastructure, road safety education, and cycling culture, that may contribute to make commuter cycling safer and more sustainable (Florindo et al., 2018; Reis et al., 2013). In this regard, the findings of this study also suggest that key issues such as risk perception, rule knowledge, and protective behaviors are negatively linked to both traffic violations and errors, remarking the relevance of performing better interventions on road training for cyclists; this especially applies to those performing the activity more regularly who are, thus, more exposed to certain road risks, that is the case of commuters.

Also, and regarding the other key outcomes of this study, it is worth highlighting the absence of a significant correlation between cycling distractions and traffic crashes suffered while cycling. In this regard, previous studies have stated that, on the contrary to what may be assumed, distractions on the road do not directly predict the traffic crashes of urban cyclists. Cycling distractions -that are still highly prevalent in most countries- are (although differentially between groups) rather mediated by errors and traffic violations, as it will be discussed in the next section (Useche et al., 2018a; Terzano, 2013).

Furthermore, it is worth mentioning that, although the group of commuters who participated in this study reported lower rates of positive behaviors (which suggests the need of strengthening protective cycling habits, especially in the case of frequent users) and more frequent deliberate risky ones (traffic violations), non-commuters are more prone to cycling distractions and to a lower risk perception. This may explain differential risks for them (Useche et al., 2019a, 2019b, 2019c; Oehl et al., 2019)

4.1. Generalities and particularities between commuters and non-commuters, and insights for intervention

Regarding the second aim of the study (i.e., to evaluate the differential impact of the study variables on the traffic crashes suffered by cyclists from a multi-group perspective), and comparing the structural models presented in Fig. 1 with the hypothesized assumption that key structural similarities (but also differences) exist between commuters (Group 1) and non-commuters (Group 2), we found an interesting set of outcomes.

Initially, the findings support the importance of strengthening key issues such as the knowledge of cycling norms (that predicted errors among commuters and both violations and errors among non-commuters) and cycling distractions (since they explained both errors and violations of Group 1 and violations of Group 2). Regarding the first point, previous studies have endorsed the need of increasing the rule knowledge of traffic norms for cycling among urban cyclists through road safety education, as a way of reducing their likelihood to be involved in risky behaviors and traffic causalities (Useche et al., 2019a, 2019b, 2019c; Twisk et al., 2015; McLaughlin and Glang, 2010). On the other hand, cycling distractions are emerging as a relevant issue for the risky behavior and safety of non-motorized users. This is especially relevant because -apart from the "traditional" sources of distraction -emerging handheld devices are increasingly present during urban trips, increasing the cyclists' risk of getting involved in either a pre-crash scenario or a traffic crash (Useche et al., 2020; Oviedo-Trespalacios et al., 2019; Useche et al., 2018a; Wolfe et al., 2016)

Furthermore, some essential differences in the mechanisms explaining cycling crashes of commuters and non-commuters, that suggest the need of developing specific interventive components for more intensive urban cyclists, were noticeable: firstly, age seems to influence cycling distractions and deliberate violations, and risk perception seems to influence errors, but only in the case of more regular (commuter) cyclists. On the other hand, and unlike commuters, the non-commuters' degree of norm knowledge has a significant effect on their cycling distractions. Apart from the significant difference that can be assumed in terms of intensity and exposure between commuters and non-commuters, the following point is particularly attention-worthy: from a multigroup-based perspective, in the case of commuters, risk perception - that influences not only travel choices, but also risky behaviors (Bösehans and Martineli, 2018; Oviedo-Trespalacios and Scott-Parker, 2017; Sanders, 2013) - and norm knowledge (in the case of non-commuters; McLaughlin and Glang, 2010, in a study performed with young cyclists) may play a critical role in reducing risky behaviors, if they are strengthened through focused interventions.

Regarding the hypothesized mediation of risky behaviors (errors and violations) between cycling distractions and suffered crashes, both groups present a similar structure, with the key difference that cycling crashes can be explained by both errors and violations for the most exposed cyclists (Group 1), while only errors have a significant effect for non-commuters (Group 2). This finding allows us to support the hypothesized paths (i.e., cycling distractions do not directly predict the traffic crashes of urban cyclists, in the case of both commuters and non-commuters), but it also remarks that, while crashes of non-commuters seem to be only explained by unintentional risky behaviors (i.e. *errors*), commuter cyclists' crashes are significantly influenced by both deliberate and non-deliberate risky cycling behaviors.

As for the structural role of distractions in relation to risky road behaviors and suffered crashes (both of which, although differentially, are only linked through indirect effects in the two groups), the results of this and other previous studies support the idea that, while they did not necessarily explain crashes themselves, distractions enhance the risky behaviors that precede them (Useche et al., 2020, 2018). Thus, actions aimed at the prevention of on-road distractors (e.g. billboards, mobile phones and headphones) would be beneficial for reducing distraction-related risky behaviors (Oviedo-Trespalacios et al., 2019; Dukic et al., 2013). This is the reason why some studies have emphasized the value of incorporating cycle training as a transversal strategy for the prevention of maladaptive behaviors of riders in different scenarios (Ji et al., 2017; Goodman et al., 2016). This especially applies if we consider that the tradition of urban cycling is still "young" in most of Latin American countries; also, the legislation on urban cycling issues, including mandatory formation, use of passive safety elements and traffic sanctions for offenders who use non-motorized vehicles remains scarce (Bösehans and Martineli, 2018; Becerra et al., 2013).

Furthermore, apart from highlighting the various advantages of increasing commuter cycling (principally related to economic, health, and social benefits), the accumulated evidence has shown the need of developing interventions to integrate physical activity in everyday transportation (Stewart et al., 2015), through the systematic involvement of different population groups in a more "healthy and sustainable" transportation; this includes active workers and students that may improve their mental and physical health via active daily commuting in Latin American countries, by means of promoting active transportation based on physical activity (Hoehner et al., 2013; Cervero et al., 2003).

Although different barriers are still visible, it is true that some improvements in walking and cycling culture, that may protect road users such as bicycle commuters, have been applied during the last years (Lemoine et al., 2016; Reis et al., 2013). However, more training and legislation accompanying the promotion of sustainable transportation are much needed, considering the benefits they may carry for community and public health.

5. Conclusion

Regarding the first aim, the results of this study suggest that commuter cyclists from the three analyzed Latin American countries are comparatively more exposed to behavioral-based safety risks, and experience more cycling crashes than non-commuters. As for the second aim, structural similarities, but also particularities, can be observed across the two groups, suggesting the need of enforcing specific issues related to the reasons, frequency and exposure of cycling, in addition to the overall known variables that are proven to reduce risky cycling behaviors (when properly addressed). Finally, and as the evidence suggests that urban cycling is expected to keep growing in Latin America, it is necessary to implement policies and educational/training improvements that may enhance the safety and health of cyclists in these countries.

6. Limitations of the study and further research

Although this study presents considerable strengths as for its sample size, reliability, and the internal consistency of the research tools and analysis, there are some potential limitations that should be acknowledged. First, the data was collected through self-reports, which makes them vulnerable to common method and social desirability biases. In this regard, it could be suggested to use research methods with complementary information sources, such as observations, crash records, and in-depth interviews.

Secondly, and bearing in mind the nature of the study, we used a convenience sampling technique based on the accessibility to the data, and this may exclude some useful information that could have been provided by bicyclists who do not present a major involvement in electronic surveying and/or research dynamics. Moreover, and although a high homogeneity could be theoretically assumed to exist among the addressed countries, key country-based particularities could be taken into account, and future studies could consider studying similarities and differences among the geographical regions covered. Also, our subsamples proportionally differ, and the built environment presents substantial inequalities and gaps (Guzman and Bocarejo, 2017; COFA, 2014; Ziccardi, 2014), which prevented us from making country- or city-based comparisons. These could be performed through controlled trip and zone-based analyses (Hong et al., 2014; Ewing and Cervero, 2010). Of course, this implies the need of retrieving bigger sample sizes, in order to be able to properly represent the commuter and non-commuter population of cyclists of each one of the analyzed countries. Furthermore, the analysis of cyclists with more than one riding reasons (e.g., commuting and, also, regularly recreational/sports reasons) may contribute to enlightening the knowledge on this matter.

Finally, it is important to highlight that, although yet scarcely studied, the differences in terms of cycling exposure (higher in the case of commuters) may play a biasing role in the self-report of crashes. In this regard, those cyclists who are most exposed to suffering "more common" accidents may underestimate their least severe crashes. For instance, an accident such as *falling off the bike*, that is the most common event, is hardly likely to be reported as an accident, especially when retrospective designs, prone to recalling bias, are used (Shinar et al., 2018; de Geus et al., 2012). As an example, a previous cohort study carried out with Belgian cyclists has shown that underreporting minor crashes is even higher than expected among commuters (De Geus et al., 2012). This is is also suggested by another study performed in Australia, focused on the case of cyclist-driver incidents (Johnson et al., 2010).

Author contribution statement

For this study, F.A., L.M., and S.U. conceived, designed and supervised the research and performed the data collection; S.U. and L.M. analyzed the data; C.E. contributed reagents/materials/software/analysis tools; F.A. and S.U. wrote and revised the paper.

Conflicts of Interest

The authors declare no competing interests.

CRediT authorship contribution statement

Sergio A. Useche: Conceptualization, Methodology, Data curation, Investigation, Writing - original draft. **Cristina Esteban:** Data curation, Data curation, Writing - original draft, Writing - review & editing. **Francisco Alonso:** Visualization, Supervision, Software, Resources. **Luis Montoro:** Conceptualization, Investigation, Writing - review & editing.

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Appendix I. Cycling Behavior Questionnaire, CBQ (29 items)*

Instruction: Please estimate how often you do the following when cycling, using this scale: 0 = Never; 1 = Almost never; 2 = Sometimes; 3 = Frequently; 4 = Almost always / always.

Item content	Frequency				
Factor 1: Traffic Violations					
1 Cycling under the influence of alcohol and / or other drugs or hallucinogens.	0	1	2	3	4
2 Circulating against the traffic (wrong way).	0	1	2	3	4
3 Zigzagging between vehicles when using a mixed lane.	0	1	2	3	4
4 Handling potentially obstructive objects while riding a bicycle (food, packs, cigarettes …).	0	1	2	3	4
5 Feeling that sometimes I'm going at a higher speed than I should be going at.	0	1	2	3	4
6 Crossing what appears to be a clear crossing, even if the traffic light is red.	0	1	2	3	4
7 Carrying a passenger on my bicycle without it being adapted for such a purpose.	0	1	2	3	4
8 Having a dispute in speed or "race" with another cyclist or driver.	0	1	2	3	4
Factor 2: Errors					
9 Unintentionally crossing the street without looking properly, thus making another vehicle brake to avoid a crash.	0	1	2	3	4
10 Colliding (or being close to it) with a pedestrian or another cyclist while cycling distractedly.	0	1	2	3	4
11 Braking suddenly and being close to causing an accident.	0	1	2	3	4
12 Failing to notice the presence of pedestrians crossing when turning.	0	1	2	3	4
13 Not braking on a “Stop” or “Yield” sign and being close to colliding with another vehicle or pedestrian.	0	1	2	3	4
14 Braking very abruptly on a slippery surface.	0	1	2	3	4
15 While I am distracted, I do not realize that a pedestrian intends to cross a crosswalk, and therefore I do not stop to let him or her do so.	0	1	2	3	4
16 Not realizing that a parked vehicle intends to leave and consequently having to brake abruptly to avoid a collision.	0	1	2	3	4
17 When driving on the right side, not realizing that a passenger is getting out of a vehicle or bus, and thus being close to hitting him or her.	0	1	2	3	4
18 Trying to overtake a vehicle that had previously used its indicators to signal that it was going to turn, consequently having to brake.	0	1	2	3	4
19 Misjudging a turn and hitting something on the road, or being close to losing balance (or falling).	0	1	2	3	4
20 Unintentionally, hitting a parked vehicle.	0	1	2	3	4
21 Failing to be aware of the road conditions and falling over a bump or hole.	0	1	2	3	4
22 Confusing one traffic signal with another, and maneuvering according to the latter.	0	1	2	3	4
23 Trying to brake but not being able to use the brakes properly due to poor hand positioning.	0	1	2	3	4
Factor 3: Positive Behaviors					
24 I stop and look at both sides before crossing a corner or intersection.	0	1	2	3	4
25 I try to move at a prudent speed to avoid sudden mishaps or braking.	0	1	2	3	4
26 I usually keep a safe distance from other cyclists or vehicles.	0	1	2	3	4
27 When I use the bike path (or bike-lane), I always use the indicated lane.	0	1	2	3	4
28 I avoid circulating under adverse weather conditions.	0	1	2	3	4
29 I avoid circulating if I feel very tired or sick.	0	1	2	3	4

* The questionnaire can be used for research and educational purposes without permission request, as long as credits are properly given to the authors.

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