**Yes, size does matter (for cycling safety)!**

**Assessing self-reported cycling behavioral factors and crash outcomes among S, M, L, and XL cities from 18 countries**

**Abstract**

Although most actions aimed at promoting the use of active transport means have been conducted in ‘large’ cities, recent studies suggest that their cycling dynamics could hinder the efforts put into infrastructural, modal share, and cycling culture improvements. **Aim:** The present study aimed to assess the role of city sizes on riding behavioral and crash-related cycling outcomes in an extensive sample of urban bicycle users. **Methods:** For this purpose, a full sample of 5,705 cyclists from >300 cities in 18 countries responded to the Cycling Behavior Questionnaire (CBQ), one of the most widely used behavioral questionnaires to assess risky and positive riding behaviors. Following objective criteria, data were grouped according to small cities (S; population of 50,000 or fewer), medium cities (M; population between 50,000 and 200,000), large cities (L; population between 200,000 and one million), and megacities (XL; population larger than one million). **Results:** Descriptive analyses endorsed the associations between city size, cycling behavioral patterns, and mid-term self-reported crash outcomes. Also, it was observed a significant effect of the city size on cyclists’ traffic violations and errors (all *p* < .001). However, no significant effects of the city size on positive behaviors were found. Also, it stands out that cyclists from megacities self-reported significantly more violations and errors than any of the other groups. Further, the outcomes of this study suggest that city sizes account for cycling safety outcomes through statistical associations, differences, and confirmatory predictive relationships by means of the mediation of risky cycling behavioral patterns. **Conclusion:** The results of the present study highlight the need for authorities to promote road safety education and awareness plans aimed at cyclists in larger cities. Furthermore, path analysis suggests that “size does matter”, and it statistically accounts for cycling crashes, but only through the mediation of riders’ risky behaviors.

*Keywords:* Urban cycling; city size; riding behavior; cycling crashes; safety outcomes.

**Introduction**

While cycling and walking remain the most promoted active means of transport due to their sustainable, inexpensive, and health-related features, some studies have suggested that these benefits might vary considerably alongside infrastructural factors. Indeed, nowadays it is frequent to find references to urban environments as being closely related to transportation development under both environmental and human-based approaches (Brüchert et al., 2022; Mertens et al., 2017; Winters et al., 2010). In other words, it could be that road environmental dynamics, behavioral and safety outcomes might largely vary in accordance with typical differentiating factors of cities, such as their size and modal share patterns (Gao et al., 2018; Useche et al., 2022; Winters et al., 2010).

Regarding cycling safety, the behavior of cyclists is a major factor that can increase the chances of having a crash (Alavi et al., 2017; O’Hern et al., 2021; Useche, Alonso, et al., 2018a; Useche, Alonso, Sanmartin, et al., 2019; Wang et al., 2020; Zheng et al., 2019). Risky and positive road behaviors are assessed through behavioral questionnaires (Granié et al., 2013; Hezaveh et al., 2018; Reason et al., 1990). More specifically, the Cycling Behavior Questionnaire (CBQ) has proven to be useful in assessing self-reported cycling behavior through the identification of risky (deliberate and non-deliberate ) and positive behaviors. The questionnaire has proven to be sensitive to age and gender-based differences (Useche, Alonso, Montoro, et al., 2019; Useche, Alonso, Sanmartin, et al., 2019; Useche, Gene-Morales, et al., 2021; Useche, Montoro, Alonso, et al., 2018c; Useche et al., 2022), and it has shown correlations between risk perception, psychological distress, road distractions, and traffic-rule knowledge (Useche, Alonso, Montoro, et al., 2019; Useche, Alonso, Sanmartin, et al., 2019; Useche, Montoro, Alonso, et al., 2018).

Moreover, another strength of this self-report method to assess cycling behaviors has been its statistical consistency when crossed with theoretically related third variables. For instance, the CBQ has been dimensionally correlated with other psychosocial issues, such as cycling anger, sensation seeking, impulsiveness, and defiance of norms in previous studies (Zheng et al., 2019). However, to the best of our knowledge, no previous research has analyzed the potential effect that the built environment and city size may have on the results of this questionnaire. Therefore, the question arises as to whether self-reported cycling behaviors and crashes may be conditioned by the size of the city.

Traditionally, studies have mostly been conducted in one city or one country (Gao et al., 2018; Winters et al., 2016, 2018). However, a recent longitudinal study analyzed cyclist crash rates and risk factors in seven European cities, representing a range of environments in terms of size, population characteristics, mode shares, built environments, and culture (Branion-Calles et al., 2020). These authors encountered differences in crash rates between cities, neighborhoods, and population groups, and concluded that future research should focus on representative datasets that can integrate the most policy-relevant crash risk factors (Branion-Calles et al., 2020). A potential approach to bridge this gap could be to conduct self-reported behavioral analysis, such as that included in the CBQ. Furthermore, a study covering different city sizes around the world could provide the scientific body of knowledge with more insight into the interplay of municipality size and cycling behaviors and crashes (Gao et al., 2018).

Therefore, the main aim of this study was to compare the self-reported risky and protective cycling behaviors and crashes among cyclists riding in cities of different sizes. A second aim was to study the association between deliberate and non-deliberate risky cycling behaviors according to the city size. Based on the theoretical assumptions presented in the literature review, we hypothesized that cyclists riding in larger cities would present more negative results in terms of the aforementioned phenomena. Rather than a direct effect, we hypothesized that the effect of city size on cyclists’ crash-related outcomes is mediated by their self-reported behaviors.

**2. Methods**

**2.1 Study design**

This cross-sectional and questionnaire-based study (Ethical IRB: HE0002170921) compared the outcomes of different questionnaires on cycling behavioral issues among bicycle riders from small (S), medium (M), and large (L) cities, and megacities (XL). The city classification chosen for this study was based on both the guidelines advised by the Organization for Economic Co-operation and Development (OECD, 2022) and previous research with bicycle users (Brüchert et al., 2022; Winters et al., 2018). Namely, the splitting criteria were as follows: cities were considered ‘small’ if they had a population of fewer than or equal to 50,000 inhabitants; ‘medium’ if their population ranged between 50,000 and 200,000 people; ‘large’ cities when their population ranged between 200,000 and one million; and ‘megacities’ if the number of inhabitants was larger than one million.

As for sample size calculation, a priori power analysis (G\*Power 3.0; Faul et al., 2007) was conducted. It showed an initial minimum sample size of approximately n= 1,424 individuals, if an effect size (f) of .11, a power (1-ß) of 0.95, and a maximum margin of error/confidence interval (CI) of 5% are assumed. However, bearing in mind the potential population heterogeneity, which suggested the need for collecting greater amounts of data, and its beneficial effect of decreasing the margin of error, the number of surveys was higher, enhanced by the relatively elevated response rate (estimated at about 60-70%). Moreover, once the data had been collected, the subsequent post hoc statistical power analysis endorsed the assumption that an optimum statistical power had been achieved.

**2.2 Participants**

The full study sample was composed of *n* = 5,705 urban cyclists (51.2% female) from > 350 urban locations in 18 countries (4 continents) around the world. Groups were balanced in terms of gender and age (which ranged from 18 to 80). Descriptive socio-demographic data and basic bicycle journey features of the sample are presented in Table 1.

**2.3 Description of the Questionnaire**

Participants answered an online-based questionnaire structured into two core sections. The first addressed socio-demographic features (i.e., age, gender, country and city of origin, educational level, occupation) and basic cycling information (frequency, trip length, motives). The second section aimed at assessing behavioral and safety-related cycling outcomes from a self-report approach. The Cycling Behavior Questionnaire (CBQ) is a Likert-type research form composed of 29 questions related to both risky and protective riding behaviors (see Useche et al. [2022] and McIlroy et al. [2021] for further information). Its dimensional structure, composed of three core factors, aims to allow cyclists to self-report their cycling behaviors according to three categories: deliberate risky behaviors (traffic violations; 8 items; = .777/= .779), non-deliberate risky behaviors (riding errors; 15 items; = .920/= .932), and protective/positive behaviors (6 items; = .798/= .801).

**Table 1.** Socio-demographic and riding characteristics of the sample according to city size (OECD-based criteria).

|  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- |
| **Feature** | **Category** | **Fewer than 50,000** | **50,000 to 200,000** | **200,000 to 1 million** | **More than 1 million** | **Total** |
| Gender | Female | 51.2 | 44.7 | 39.4 | 30.9 | 39.7 |
| Male | 48.5 | 54.7 | 59.2 | 68.6 | 59.6 |
| Other | .3 | .6 | 1.4 | .6 | .7 |
| Occupation | Student | 36.8 | 39.1 | 32.1 | 35.5 | 35.4 |
| Employed  | 44.7 | 43.6 | 48.0 | 40.4 | 44.0 |
| Self-employed | 7.7 | 8.2 | 9.4 | 14.8 | 10.7 |
| Unemployed | 1.0 | 2.2 | 3.3 | 4.5 | 3.1 |
| Retired | 5.5 | 3.8 | 2.9 | 2.1 | 3.3 |
| Homemaker | .8 | .7 | 1.3 | .9 | .9 |
| Other | 3.4 | 2.5 | 3.0 | 1.7 | 2.5 |
| Education | Primary or lower | 5.5 | 2.5 | 1.3 | 1.4 | 2.4 |
| Secondary/ high school | 18.5 | 17.5 | 15.2 | 13.8 | 15.8 |
| Technical/intermediate training | 17.7 | 11.4 | 10.8 | 23.6 | 16.7 |
| Undergraduate degree | 40.2 | 43.1 | 48.7 | 38.9 | 42.7 |
| **Variable** | **City-size group** | **N** | **M** | **SD** | **95% CI** |
| **Lower** | **Upper** |
| Age(years) | 1 | S - Small cities | 1,100 | 35.75 | 15.10 | 34.86 | 36.64 |
| 2 | M - Medium cities | 1,016 | 34.54 | 14.76 | 33.63 | 35.45 |
| 3 | L - Large cities | 1,622 | 35.13 | 13.91 | 34.45 | 35.80 |
| 4 | XL - Megacities | 1,967 | 31.21 | 11.07 | 30.72 | 31.70 |
| Total | 5,705 | 33.79 | 13.55 | 33.44 | 34.14 |
|  Weekly cycling hours | 1 | S - Small cities | 1,100 | 4.78 | 4.94 | 4.48 | 5.07 |
| 2 | M - Medium cities | 1,016 | 5.01 | 4.88 | 4.72 | 5.32 |
| 3 | L - Large cities | 1,622 | 5.80 | 5.89 | 5.50 | 6.08 |
| 4 | XL - Megacities | 1,967 | 5.62 | 5.83 | 5.36 | 5.88 |
| Total | 5,705 | 5.40 | 5.54 | 5.26 | 5.54 |
| Typical journey length (minutes) | 1 | S - Small cities | 1,100 | 49.42 | 40.50 | 47.12 | 51.96 |
| 2 | M - Medium cities | 1,016 | 45.98 | 41.93 | 43.50 | 48.72 |
| 3 | L - Large cities | 1,622 | 47.12 | 41.36 | 45.18 | 49.23 |
| 4 | XL - Megacities | 1,967 | 44.10 | 35.75 | 42.66 | 45.87 |
| Total | 5,705 | 46.33 | 39.50 | 45.42 | 47.49 |
| *Notes:* aSD= Standard Deviation; bCI= Confidence Interval (at the level 95%); OECD criteria= small cities [S population < 50,000], medium cities [M population between 50,000 and 200,000], large cities [L population between 200,000 and 1,000,000], and megacities [XL population > 1,000,000]. |

This questionnaire was applied using a self-report methodology in its validated language versions (i.e., Chinese [Zheng et al., 2019], Dutch and French [Useche et al., 2021], English [O’Hern et al., 2021], and Spanish [Useche et al., 2018a]). Additionally, further versions in German, Portuguese, Danish, Finnish, Malay, Polish, Russian, and Slovak were also used to cover the countries appended in the study composing its recent cross-cultural validation (Useche et al., 2022). Concerning the specific application of the questionnaire, it evaluated the riding behaviors (risky and protective) on a frequency-based Likert scale with five levels (0= never; 1= hardly ever; 2= sometimes; 3= frequently; 4= almost always) through the basic instruction: “Estimate how often you do the following when cycling”. Finally, a supplementary question inquired about the crashes suffered by participants during the previous five years, regardless of their severity. This was uniformly used as a self-reported cycling crash indicator.

**2.4 Data Analysis**

After a careful coding process, the database was curated, and study variables were scored in accordance with the directions provided by the authors of each scale/instrument applied. After applying a (Log10-based) logarithmic transformation to statistically correct continuous variables, participants were organized into four groups, depending on the size of their city/town. In a first analysis step and given the ordinal nature of some of the study variables, the association between city sizes and the self-reported frequency of deliberate and non-deliberate risky cycling behaviors was assessed through Spearman (non-parametric and bivariate) correlations.

As for inter-group comparisons, a one-way analysis of variance (ANOVA) was conducted in order to test potential differences in terms of different cycling outcomes among the four city sizes included in this study. Effect sizes (ES) were evaluated with eta partial squared (ηp2), where .01 < ηp2 < .06 constitutes a small effect, .06 ≤ ηp2 ≤ .14 constitutes a medium effect, and ηp2 > .14 constitutes a large effect. The post hoc testing for the age group was applied using the Bonferroni adjustment. The effect size (ES) was calculated as Cohen’s d with Hedges corrections (Lakens, 2013). This value is reported as unbiased Cohen’s d (dunb; Cumming, 2014), with dunb < .50 constituting a small effect, .50 ≤ dunb ≤ .79 moderate, and dunb ≥ .80 a large effect (Cohen, 1988).

Finally, the confirmatory associations between city size and (*i*) traffic violations; (*ii*) riding errors; and (*iii*) self-reported crashes of cyclists were assessed through path analysis, controlling for basic confounders (i.e., age and cycling exposure). This type of test, understood in specialized literature as a subset of structural equation modeling procedures, constitutes a useful method to determine and differentially assess the effects of a set of variables acting on a specified outcome via multiple causal (but theoretically-based) confirmatory pathways (Streiner, 2005).

All the analysis was performed with IBM® Statistical Package for Social Sciences (SPSS, version 28; IBM Corp., Armonk, NY, US), except for the path analysis, which was carried out with IBM SPSS AMOS, version 28.0.

**3. Results**

**3.1 City size in relation to cycling behaviors and safety outcomes**

The initial descriptive analysis of the relationships between study variables (i.e., bivariate correlation coefficients) showed significant correlations between city size (ordinalized factor) and the whole set of continuous variables appended in the study (all of them *p* < .001). More specifically, city size positively correlated with self-reported traffic violations (σ= .159\*\*), cycling errors (σ= .170\*\*), and cycling crashes (σ= .079\*\*). On the other hand, a negative correlation suggests that the bigger the city size, the less self-reported cycling-positive behaviors (σ= -.050\*\*), despite having a considerably low magnitude. The full set of correlations is available in Table 2.

**Table 2.** Bivariate (Spearman) non-parametric correlations between the study variables

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
|  | **Variable** | **2** | **3** | **4** | **5** |
| 1 | City sizea | .159\*\* | .170\*\* | -.050\*\* | .079\*\* |
| 2 | Traffic violations | 1 | .537\*\* | -.351\*\* | .290\*\* |
| 3 | Riding errors |  | 1 | -.316\*\* | .286\*\* |
| 4 | Positive behaviors |  |  | 1 | -.167\*\* |
| 5 | Cycling crashes (last 5 years) |  |  |  | 1 |
| *Notes:* aOrdinal variable; \*\*The correlation is statistically significant at the level *p* < .001.  |

Also, correlational facts previously endorsed by cycling safety literature stand out, such as the highly consistent correlation between self-reported violations with both riding errors (σ= .537\*\*) and cycling crashes (σ= .290\*\*). Furthermore, the relationship between violations and positive behaviors remains negative and significant (σ= -.351\*\*). In contrast to the case of traffic violations, the more self-reported positive behaviors there were, the fewer crashes were reported by the study participants (σ= -.167\*\*).

**3.2 Between-groups and among-groups (Post Hoc) comparisons**

Comparative analysis has shown a set of significant effects of the city size on risky behavioral and safety-related outcomes, namely on cycling violations (F [3,5701] = 40.14, *p* < .001, ηp2 = .021), errors (F [3,5701] = 37.85, *p* < .001, ηp2 = .020), and cycling crashes (F [3,5701] = 5.69, *p* < .001, ηp2 = .003) . No significant effects of the city size on the positive behaviors were highlighted (F [3,5701] = 2.33, *p* = .072, ηp2 = .001). Descriptive statistics and post-hoc analysis can be found in Tables 3 and 4, respectively.

**Table 3.** Behavioral questionnaire factor scores for city population group-based comparisons.

|  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- |
| **Variable** | **Gr** | **City size** | **N** | **M** | **M-D**a | **SD**b | **95% CI** |
| **Lower** | **Upper** |
| Traffic violations | 1 | Small | 1,100 | .56 | 2,3,4 | .51 | .53 | .60 |
| 2 | Medium | 1,016 | .68 | 1,4 | .59 | .65 | .72 |
| 3 | Large | 1,622 | .71 | 1,4 | .66 | .68 | .74 |
| 4 | Megacity | 1,967 | .81 | 1,2,3 | .63 | .78 | .84 |
| Total | 5,705 | .71 |  | .61 | .70 | .73 |
| Riding errors | 1 | Small | 1,100 | .41 | 2,3,4 | .48 | .38 | .44 |
| 2 | Medium | 1,016 | .47 | 1,4 | .55 | .44 | .51 |
| 3 | Large | 1,622 | .49 | 1,4 | .63 | .46 | .52 |
| 4 | Megacity | 1,967 | .62 | 1,2,3 | .57 | .60 | .65 |
| Total | 5,705 | .52 |  | .57 | .50 | .53 |
| Positive behaviors | 1 | Small | 1,100 | 3.04 |  | .83 | 2.99 | 3.09 |
| 2 | Medium | 1,016 | 3.00 |  | .86 | 2.95 | 3.06 |
| 3 | Large | 1,622 | 2.99 |  | .83 | 2.95 | 3.03 |
| 4 | Megacity | 1,967 | 2.96 |  | .82 | 2.92 | 2.99 |
| Total | 5,705 | 2.99 |  | .83 | 2.97 | 3.01 |
| Cycling crashes | 1 | Small | 1,100 | .65 | 3,4 | 1.29 | .58 | .73 |
| 2 | Medium | 1,016 | .70 |  | 1.21 | .63 | .77 |
| 3 | Large | 1,622 | .83 | 1 | 1.43 | .76 | .90 |
| 4 | Megacity | 1,967 | .81 | 1 | 1.28 | .75 | .86 |
| Total | 5,705 | .77 |  | 1.31 | .73 | .80 |
| *Notes:* 1,2,3,4: Statistically significant differences with groups 1,2,3, or 4, respectively; Gr.: Groups being compared; aM-D= Mean differences between groups; bSD= Standard deviation of the mean; CI: Confidence interval; CBQ: Cycling Behavior Questionnaire; OECD criteria= small cities [S population < 50,000], medium cities [M population between 50,000 and 200,000], large cities [L population between 200,000 and 1,000,000], and megacities [XL population > 1,000,000].  |

 Subsequent to the aforementioned descriptive comparisons, a set of Post Hoc (Bonferroni-adjusted) analysis was conducted, with the aim of highlighting specific differences between pairs of city sizes. Overall, the analysis outcomes (fully available in Table 4) show consistent differences between low-sized cities and their high-size counterparts, being in all (significant) cases the mean differences of a negative and significant character.

**Table 4.** Outcomes of Post Hoc (Bonferroni-adjusted) tests for specific city population group comparisons. Groups: (1) small city (2) medium city, (3) large city, (4) megacity.

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| **Variable** | **Groups compared** | **M-D**a | **SE**b | **Sig.** | **ES (Cohen’s *d*)** |
| Traffic violations | **1-2** | -.12\* | .03 | \*\*\* | .218 |
| **1-3** | -.15\* | .02 | \*\*\* | .248 |
| **1-4** | -.25\* | .02 | \*\*\* | .424 |
| **2-3** | -.03 | .02 | .627 | .047 |
| **2-4** | -.13\* | .02 | \*\*\* | .211 |
| **3-4** | -.10\* | .02 | \*\*\* | .147 |
| Riding errors | **1-2** | -.06\* | .03 | \* | .117 |
| **1-3** | -.08\* | .02 | \*\* | .139 |
| **1-4** | -.21\* | .02 | \*\*\* | .389 |
| **2-3** | -.01 | .02 | .924 | .033 |
| **2-4** | -.15\* | .02 | \*\*\* | .277 |
| **3-4** | -.13\* | .02 | \*\*\* | .217 |
| Positive behaviors | **1-2** | .03 | .04 | .794 | .047 |
| **1-3** | .05 | .03 | .429 | .060 |
| **1-4** | .08 | .03 | .050 | .097 |
| **2-3** | .02 | .03 | .964 | .012 |
| **2-4** | .05 | .03 | .456 | .048 |
| **3-4** | .03 | .03 | .676 | .036 |
| Cycling crashes | **1-2** | -.05 | .06 | .837 | .040 |
| **1-3** | -.18\* | .05 | \*\* | .131 |
| **1-4** | -.15\* | .05 | \*\* | .125 |
| **2-3** | -.14 | .05 | .051 | .096 |
| **2-4** | -.11 | .05 | .155 | .088 |
| **3-4** | .03 | .04 | .919 | .015 |
| *Notes:* aM-D= Mean Difference; bSE= Standard Error; cES= Effect Size; \*The difference is significant at the level *p*< .050; \*\*The difference is significant at the level *p*< .010; \*\*\*The difference is significant at the level *p*< .001. |



**Figure 1.** Density charts of the three dimensions of the Cycling Behavior Questionnaire (CBQ) and histogram of cycling crashes. Results are grouped according to the city population group.

Comparative analyses helped depict key city-size-based differences, especially among small and large areas, for which differences were of a greater magnitude. In other words, cyclists from bigger urban areas self-report comparatively increased rates of traffic violations, riding errors, and cycling crashes. On the other hand, no particular significant differences between specific categorical levels (i.e., city sizes) were found for positive behaviors. A further visual analysis of these Post Hoc-based outcomes allowed us to get further insights into these trends. The full set of graphical distributions for each dependent variable is available in Figure 1.

It is worth highlighting that the bigger the city, the more the distribution was tailed in the direction of more violations and errors, especially in cities with a population of more than one million. In particular, the distribution of positive cycling behaviors and crashes were the most similar among the four study groups.

**3.3 Association between deliberate and non-deliberate risky behaviors**

Bearing in mind both the theoretical considerations appended in the literature review, as well as the significant correlation found between deliberate (i.e., violations) and non-deliberate (i.e., errors) risky behaviors in the general sample (see Table 2), the potential effect of city size in this statistical relationship was also evaluated following a multi-group approach. As shown in Figure 2, significant correlations (*p* < .001) between violations and errors were observed in all the study groups, i.e., regardless of city sizes, even though the magnitude and consistency of such bivariate associations tended to strengthen in greater urban areas. Moreover, the city size-based group presenting the highest correlation coefficient (σ= .752) were riders in cities with a population between 200,000 and 1,000,000.



**Figure 2.** Bivariate (XY) correlations of risky cycling behaviors (deliberate and non-deliberate), measured with the Cycling Behavior Questionnaire (CBQ) in different sized city . Each spot represents a cluster of ±5 cases.

**3.4 Path analysis**

To test the directional hypothesis on the effect of city size on both risky cycling behaviors and riding crashes, a theoretically based path model controlling for age and exposure variables was tested. The model development comprised two sequential steps. In step one, the model was drawn to assess the direct effects of city size on both risky riding behaviors (i.e., errors and violations) and self-reported cycling crashes. In the second step, two paths were added from both risky behavioral types to self-reported cycling crashes. The resulting model fit statistics were *x*2= 195.167, *p* <.001; NFI = .981; RFI= .903; CFI =.981; TLI = .906; IFI= .981; RMSEA = .074, 90% CI [.062 - .087].

The model was retained because of its theoretical plausibility and adequate fit indexes. However, as aforementioned in the data analysis section, statistical corrections (i.e., bootstrapping procedures) were applied to prevent biased results and type I errors on path significance. The path model and its standardized and bias-corrected parameter estimates are presented in Table 4 (detailed coefficients), as well as graphically in Figure 3. The solid lines or arrows indicate significant predictive relationships between variables.

The retained path model shows four direct and significant effects of the five paths drawn. Two of these paths coming from city size are significant (and positive): city size  traffic violations, and city size  riding errors. However, there is not a direct path or significant association between city size  cycling crashes suffered over a period of five years. On the other hand, the two behaviorally-based theoretical paths (i.e., traffic violations  cycling crashes, and riding errors  cycling crashes) were both significant and positively explained the endogenous variable. This suggests that the relationship between city size and self-reported cycling crashes may be mediated by users’ behavioral characteristics. The full set of paths, bias-corrected coefficients, and significance levels are graphically shown in Figure 3.

**Table 4.** Variables included in the model, estimates, significance levels, and 95% confidence intervals for bootstrap bias-corrected values of the path model.

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| **Study variable** | **SPCa** | **S.E.b** | **C.R.c** | ***p*d** | **Bootstrap bias-corrected valuese** |
| **Estf** | **S.E.b** | **95% CIg** | ***p*d** |
| ***Direct effects*** |
| City Size | → | Traffic Violations | .111 | .005 | 8.634 | \*\*\* | .112 | .004 | .087 | .137 | \*\* |
| City Size | → | Riding Errors | .107 | .004 | 7.710 | \*\*\* | .108 | .004 | .073 | .125 | \*\* |
| City Size | → | Cycling Crashes | -.003 | .010 | -.263 | .793 | -.003 | .001 | -.024 | .024 | .916 |
|

|  |
| --- |
| ***Mediated effects*** |

 |
| Traffic Violations | → | Cycling Crashes | .137 | .037 | 8.033 | \*\*\* | .138 | .039 | .103 | .173 | \*\* |
| Riding Errors | → | Cycling Crashes | .183 | .039 | 10.852 | \*\*\* | .184 | .040 | .147 | .210 | \*\* |
| *Notes:* a SPC= Standardized Path Coefficients (can be interpreted as b-linear regression weights); b S.E.= Standard Error; c CΡ= Critical Ratio; d p-value: \*significant at the level *p*< .050; \*\*significant at the level *p*< .010; \*\*\*significant at the level p< .001; e Bootstrapped (bias-corrected) model; f Bootstrapped (bias-corrected) model standardized estimates; g Confidence Interval at the level 95% (lower bound – left; upper bound – right). |



**Figure 3.** Path model- Bootstrap (bias-corrected) parameter estimates. Squares represent non-latent factors, and ellipses represent latent variables. Note: All listed estimates in solid lines are significant (as shown in Table 4).

**4. Discussion**

The present study assessed the role of city sizes on riding behavioral and crash-related cycling outcomes in an extensive sample of urban bicycle users. In this regard, it was initially hypothesized that these outcomes may largely differ, given that key literature-based issues suggest that larger cities can pose ‘additional’ threats to active transport users (Goel, 2023; Winters et al., 2018). Overall, and in accordance with the study hypothesis, the core findings of this research suggest that city sizes may play a critical role in both behavioral and safety-related outcomes of urban bicycle riders.

**Do riders ‘match’ their behaviors to the context?**

The outcomes of this extensive data collection show that, in particular, cyclists from bigger urban areas (especially in the case of megacities) consistently self-report more frequent risky road behaviors, including both traffic violations and errors, than cyclists from any other city size-based group (see Tables 3 and 4). There were no such significant differences in self-reported positive behaviors between study groups, although a slight trend (p ≈ .050) was observed when comparing cyclists from small cities and those from megacities. Although this particular finding will be discussed further, it is worth anticipating that one of the common literature-endorsed assumptions supporting this goes beyond greater exposure rates.

Particularly, previous studies such as Gao et al. (2018), Graells-Garrido et al. (2021), Kraus & Koch (2021), and Useche et al. (2018b), support the key critical issues of large cities, such as the complexity of bike lane networks, stress-related factors, high environmental stimulation degrees, and the latency of road conflicts, as potential hindrances to both safe cycling patterns and outcomes. Regarding safety indicators (i.e., self-reported cycling crashes), cyclists from small cities self-reported significantly fewer cycling crashes than cyclists from cities with a population of 200,000 or more. In addition, it is worth highlighting the non-significant nature of the differences between cyclists from medium and large cities in all the behavioral and crash-related variables used in this study. Hereunder, this discussion is developed by first attending to the correlation between the study variables, both in the general sample and divided by city size, and afterwards, analyzing the main differences found between the groups.

**City size, riding behavior and crash involvement**

Firstly, the descriptive bivariate correlation analysis strengthens the findings of previous literature regarding cycling behavior and crash involvement. In this regard, the association between the three dimensions of the CBQ (positive correlation between risky behaviors and negative correlation with positive behaviors) has been reported in previous applied studies (Useche et al., 2022; Useche, Gene-Morales, et al., 2021), higher rates of risky behaviors correlate with higher self-reported involvement in cycling crashes, and higher rates of protective behaviors are associated with lower self-reported crash involvement (O’Hern et al., 2021; Useche, Alonso, et al., 2018; Useche, Alonso, Sanmartin, et al., 2019; Wang et al., 2020; Zheng et al., 2019).

The core independent variable referred in this study (i.e., city size) significantly correlated (p < .001) with all the study variables. More specifically, it was found that cyclists from bigger cities self-reported significantly (p < .001) higher rates of violations, errors, and the number of cycling crashes and lower rates of positive behaviors. After this bivariate analysis, the effect of the city size on the study-dependent variables is discussed. From a theoretical point of view, the great homogeneity found in terms of city size-based trends (see Figure 1) drives us to consider that, in broad terms, the right approach may not be that a group of cyclists is more or less ‘risky’ than the others, but that the environment in which one cycles pushes riders into performing behaviors considered risky.

**Could bigger cities get ‘riskier’ riders than the others?**

As mentioned in the introduction, interventions in support of active mobility have predominantly taken place in highly populated urban environments, where cycling infrastructure tends to be comparatively over-developed in comparison with most smaller cities (Brüchert et al., 2022; Mertens et al., 2017; Sharma et al., 2019). However, the infrastructure-based approach tends to remain reductionist in the absence of a multifactorial point of view. In addition, the raw effect of city size on behavior and the number of crashes remains under explored in the literature (Sharma et al., 2019; Winters et al., 2010; Zhang et al., 2022).

Bearing in mind the aforementioned, and regardless of having a relatively extensive sample size, a categorical response to this question might exceed the scope of the data provided by this study. However, the gathered data allow us to provide some insights in this regard. In the present study, which explores a single (but relevant) part of this question, cyclists from small cities (population of 50,000 or lower) have been shown to self-report the lowest rates of violations and errors compared with cyclists from the rest of the groups (i.e., 50,000 or more inhabitants) and fewer cycling crashes compared with cyclists from large cities and megacities (i.e., > 200,000 people; see Tables 3 and 4). This is despite research suggesting small cities to be more likely to favor cars over bikes (Brüchert et al., 2022).

Secondly, the ‘safety in numbers’ phenomenon should be considered (see further below; Jacobsen, 2003; Jacobsen et al., 2015; Macmillan & Woodcock, 2017; Winters et al., 2018), by which smaller cities would be a riskier environment to ride in. Some studies summarize this as ‘the more people cycling in a city, the safer cycling in that city’ (Jacobsen, 2003; Jacobsen et al., 2015). Consequently, many people may choose not to cycle due to a perception of unsafe cycling conditions (Branion-Calles et al., 2020; Macmillan & Woodcock, 2017). Additionally, individuals cycling in these hazardous environments might become more skillful, potentially preventing or regulating their influence on risky cycling behaviors and crash risk (Castro et al., 2018).

Back to the present study data, our participant cyclists from megacities self-reported more violations and errors compared with the other groups (see Tables 3 and 4). One potential explanation for this comparatively riskier behavior taking place in bigger cities could be linked to the fact that better infrastructure tends to provide a safer riding environment, giving sense to both the afore described ‘safety in numbers’ phenomenon (Macmillan & Woodcock, 2017; Winters et al., 2018), and risk management-related approaches such as the risk homeostasis theory. According to the last, cyclists may tend to adapt their behavior toward greater or lesser risk-taking on the basis of how they subjectively perceive the risk (Constant et al., 2012; Lardelli-Claret et al., 2003).

Back to the study data, and although not applicable to all cases, cyclists riding in larger cities are more likely to count on friendlier infrastructures which, in turn, might contribute to increased safe environmental perceptions generating a feeling of overconfidence and, therefore, enhance riskier behavioral patterns (Kelly et al., 2020; Winters et al., 2018). However, this seems not to apply to the case of positive behaviors (e.g., avoidance of riding under adverse weather conditions, helmet wearing) which, are perhaps more internally driven (Thompson, Rivara & Thompson, 2000). On the other hand, actual risky-riding behaviors, (e.g., running red lights, riding on the pavement) are driven more by external factors, like the physical and traffic environment (McIlroy et al., 2022; Useche et al., 2018b).

Additionally, and although they were not directly considered in this study, common distracting features (e.g., billboards, over-signalized paths) are more present in large cities and play a mediating role in risky behaviors (Dukic et al., 2013; Useche, Alonso, et al., 2018; Wolfe et al., 2016), which in turn influences the vehicle crash rates of cyclists (O’Hern et al., 2021; Useche, Alonso, et al., 2018; Useche, Alonso, Sanmartin, et al., 2019; Wang et al., 2020; Zheng et al., 2019). There is also research demonstrating higher crash risks for active transportation users in urban areas with higher compared to lower building densities (Branion-Calles et al., 2020). Coherently with previous literature, and unlike self-reported risky riding behaviors and crash outcomes, significant differences in positive behaviors are not commonly found (Alonso et al., 2021). However, there was still a pseudo-significant statistical difference (p≈ .050) between small cities and megacities, suggesting that the matter could not be definitely discarded (see Table 4).

**A ‘behaviorally-mediated’ effect**

One of the key features of the present research was to assess the statistical effects of city sizes and risky cycling behaviors on (self-reported) crash-related outcomes of urban cyclists. In brief, the findings suggest that, far from having found a direct statistical path/effect (p > .900), the relationship between city sizes and crash outcomes is mediated by bicycle riders’ propensity to perform risky riding behaviours.

This is, indeed, consistent with previous behavior questionnaire (BQ) studies using predictive techniques (e.g., Path, SEM, MGSEM, MLR methods) to assess the role of behavioral issues on cycling crashes, in which risky riding contributors remain the most relevant issue alongside demographic factors, such as age and gender (Hezaveh et al., 2018; Li et al., 2021). For instance, and after also controlling for demographics and exposure, multiple linear regression (MLR) based studies explaining cycling crashes have shown great predictive value for risky road behaviors (but especially for errors; McIlroy et al., 2022; O’Hern et al., 2021), and confirmatory modeling (i.e., path, SEM and MGSEM) procedures have systematically endorsed the predictive value of behavioral contributors to self-reported crashes across the five continents (Useche et al., 2022; Useche et al., 2018c; Zheng et al., 2019).

On the other hand, the role of city size on behavioral outcomes remains largely underexplored, despite providing broad and relatively consistent patterns suggesting the need for action to face the challenging ‘safety in density effect’ and other typical hindrances targeted in larger urban areas across the few studies so far conducted with cyclists (Thompson et al., 2019; Winters et al., 2018). Nevertheless, the statistically endorsed hypotheses of this study regarding cycling behavior as a potential mediator between infrastructural factors – city size being just one of them – and mid-term safety outcomes of cyclists (which are coherent with the limited empirical research that does exist) make us think about the need to further explore the matter ‘beyond numbers’.

**5. Conclusions**

The outcomes of this study analyzing the data provided by 5,705 cyclists from >300 urban areas in 18 countries suggest that city size account for cycling safety outcomes through statistical associations, differences, and confirmatory predictive relationships by means of mediation via cycling behavioral patterns.

Specifically, we found that cyclists from small cities (population of 50,000 or less) self-report significantly lower rates of risky behaviors, higher rates of positive behaviors, and fewer cycling crashes compared with cyclists from larger cities.

On the other hand, and beyond cyclists’ age and exposure, ‘riskier’ profiles were consistently found in larger cities in terms of both self-reported cycling crashes and risky riding behaviors (i.e., traffic violations and errors). No such differences were found not in terms of self-reported protective behaviors. The results of the present study highlight the need to target cycling safety-threatening dynamics of larger cities.

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