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Article

Exploring Cyclists Behavior, Traffic Safety Literacy, and Crash Occurrence in Latvia

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Abstract: While the role of safe riding behavior as a safety contributor for cyclists has been increasingly studied in recent years, there have been few studies analysing cycling behavior in relation to crash-related outcomes in Baltic countries. Indeed, to the best of our knowledge, this is the first time this issue has been addressed in the case of Latvia. **Aim:** The objective of this study was to assess the relationships among self-reported cyclists' behavior, traffic safety literacy, and their cycling crash involvement rates. **Method:** A total of 299 cyclists aged M=32.8 from across Latvia (42% females) participated in an online survey, which comprised questions regarding respondents' demographics, frequency of riding, and the number of crashes in the past five years. The Cycling Behavior Questionnaire (CBQ) and the Cyclist Risk Perception and Regulation Scale (RPRS) were applied to assess cyclists' behavior patterns and traffic safety literacy. **Results:** According to the findings, it can be inferred that cyclists frequently engage in riding errors and traffic violations while cycling. Those who exhibit more antisocial behavior patterns are also more likely to be involved in road crashes. Conversely, cyclists with greater positive behavior rates more often also tend to possess better knowledge of traffic rules and exhibit a heightened risk perception, indicating a greater awareness of road traffic safety. **Conclusion:** All in sum, this study underscores key age differences, with older individuals significantly less involved in riding crashes, exhibiting fewer driving errors and a higher level of risk perception, which serves as a crucial factor in road safety. At the practical level, these results stress the need to address both traffic safety literacy and protective cycling factors of cyclists, in a manner to improve overall road safety and promote active transport modes in Latvia.

Keywords: cycling; behavior; risk perception; traffic safety; crash occurrence

1. Introduction

For many residents of Latvia, cycling to work is becoming increasingly popular each year, offering a range of benefits. Cycling is widely recognized for promoting physical activity, being environmentally friendly, contributing to sustainability, and being cost-effective, while also improving individuals' health [1]. Recent studies highlight the significance of ensuring sufficient and safe infrastructure as well as user-friendly environments in both smaller, middle, and larger urban areas to foster the sustained growth of cycling as a transportation mode and ensure its longevity in the mid- and long-term [2,3]. However, the safety of cyclists on Latvia's roads remains a significant concern, just as it does in most countries around the world.

At a global level, and despite countless previous widespread actions (most of them predominantly infrastructural, though) conducted over the last two decades, safety outcomes of cyclists remain considerably concerning. According to data compiled by the World Health Organization (WHO) in 2018, approximately 41,000 cyclists die in road crashes annually [4]. Based on the existing body of applied research, the main causes of these crashes include, in addition to inadequate infrastructure issues, a range of behavioral factors: cycling under the influence of alcohol or other substances, disregarding road traffic regulations, engaging in distracting dynamics, often

related to emerging technologies, and neglecting to wear protective helmets, which, while not preventing crashes, exacerbates their severity.

Overall, the high prevalence of all the aforementioned user behavior-related issues have made growingly evident unaddressed connections between infrastructure quality and cyclist behavior on the road, both of which significantly impact cycling safety outcomes [2]. Consequently, in recent years researchers have shown an increasing interest in understanding the roles of both risky and protective behavior of cyclists and how the increases or reductions of traffic crashes involving them contribute to promoting this sustainable but sometimes “feared” means of transport [5].

1.1. Cycling Safety-Related Discouragers, Challenges, and Behavioral Affairs

As aforementioned, an elevated crash risk (or a perception of it) associated with cycling as a mode of transportation might increase people’s discouragement from using bicycles, especially on a regular basis [5,6]. Some studies highlight that when comparing accident rates and outcomes between cyclists and car drivers, cyclists face a higher risk of fatal crashes [7,8]. Therefore, addressing crash-related perceptions causes, and dynamics, as well as developing solutions to mitigate them, has been argued as a beneficial action to both enhance cyclists’ safety on the roads and promote non-cyclists’ engagement in active transportation means. However, it must be acknowledged that researchers still highlight a lack of empirical research on the most significant factors influencing self-governance for the promotion of cyclists’ safety [9–11]. This includes not only infrastructure but also other influential factors.

Also, and as pointed out in systematic review papers such as Oja et al. [1], it is undeniable that cycling safety depends not only on external factors, such as infrastructure but also on the behavior and actions of bicycle riders themselves. It’s crucial in research to focus on variables directly influencing cyclists’ behavior and related aspects. This has led researchers to increasingly pay attention to the study of these factors and the association of various variables with the likelihood of road crashes involving cyclists, as recent studies show that a significant proportion of them are directly caused by risky or reckless behaviors performed by the users themselves [12,13].

A review of risky cycling behaviors among cyclists includes illegal occupancy of vehicle lanes, speeding, running red lights, illegal carrying, and riding in the opposite direction [14]. It has been established that the behavior of road users is among the foremost factors posing a potential threat and serving as a predictor of road traffic accidents for cyclists [15]. Studies indicate that accidents on the road are often linked to negative and risky behaviors among cyclists, such as cycling in the opposite direction, disregarding road signs or signals, and distracted cycling [11,16].

In research, traffic safety literacy is often more emphasized and applied to car drivers, yet it holds equal importance among cyclists. In the context of this study, traffic safety literacy refers to cyclists’ knowledge of traffic rules and their perception of risks. Chen et al. (2022) [17] highlight the significance of enhancing literacy to address traffic issues and note that much of the research on traffic literacy primarily investigates factors influencing traffic accidents and safety. For instance, in a recent study by Useche et al. (2023) [18], which compared the behavior and safety aspects of cyclists across urban environments of varying sizes, it was discovered that city size positively correlated with instances of traffic violations, cycling errors, and cycling crashes. This implies that in cities with more extensive and complex infrastructure, cyclists’ traffic safety literacy becomes an especially crucial factor in safety assessments.

Similarly, previous research conducted in other countries supports the role of knowing road rules and developing a suitable risk perception as key safety-related factors. For instance, a recent study examining perceived risk levels among cyclists and motorists concludes that cyclists’ perceived risk is closely linked to both errors of ignorance and the consequences of violations themselves. According to the findings, inattention was associated with the perceived risk level, while cyclist traffic violations were linked to a tendency toward risky behavior [18]. All in all, the results of previous studies support the critical significance of cyclists’ traffic safety literacy in increasing their riding safety. From a theoretical point of view, it can be translated to the assumption that understanding and knowing the traffic rules, as well as being aware of potential risks, apart from

strengthening cyclists' safety, may reduce the statistical likelihood of getting involved in both cycling and non-cycling traffic crashes [15,19].

Nevertheless, the number of empirical studies addressing these variables and inter-relations remains scarce in geographical zones such as Baltic countries, still receiving insufficient attention, policymaking, or intervention in general, even though the broader context concerning cyclists' behavior on the road and its correlation with road traffic crashes, a fact that could raise awareness among cyclists and the public regarding the gravity of this issue [20,21].

1.2. Study Aim and Hypothesis

Bearing in mind the aforementioned considerations, the scarcity of similar empirical research in the region, and the possible contribution of a cycling safety-related case study in Latvia for both road safety practitioners and policymakers, this study aimed to assess the relationships among self-reported cyclists' behavior, traffic safety literacy, and their cycling crash involvement rates.

As for what is hypothesizeable on the basis of the existing literature, it is expected to find significant and positive relationships among risky cycling behaviors and safety outcomes self-reported by Latvian cyclists, as well as a lesser rate of safety-related cycling incidents among those bicycle riders with greater indexes of traffic safety literacy and positive cycling behaviors.

2. Materials and Methods

2.1. Participants

This study, conducted across different regions of Latvia, involved a sample of 299 cyclists who filled out an online survey. The sample of the study consisted of cyclists aged between 18 and 76 years with mean age $M=32.80$ ($SD=13.21$) from the following Latvian cities: Riga (52.5%), Jurmala (4.3%), Jelgava (3.3%), Liepaja 3.3%), Ventspils (3.0%), Sigulda (2.7%), Ogre (2.7%), Valmiera (2.7%), and other cities (25.4%). Among the 299 participants, 124 identified as female (41.5%), 173 as male (57.9%), and 2 as non-binary (0.7%).

As for educational attainment features, the majority of the participants had higher education (61.5%), while some had secondary school education (24.4%), and professional education (13.4%). Only 2 participants had primary school education or lower, representing 0.7% of the study sample. Regarding current occupation, the research respondents reported being employed (47.2%) or students (35.5%). The remaining participants were self-employed (8.0%), unemployed (2.3%), retired (2.0%), householders (1.3%), or categorized as other (3.7%).

Regarding cycling intensity, participants reported spending approximately $M=5.23$ ($SD=5.48$) hours per week cycling, with an average trip length of $M=61.84$ ($SD=42.77$) minutes. Over the past five years, 156 cyclists (52.2%) reported no accidents while riding a bicycle, while 142 participants (47.5%) indicated they had been involved in at least one crash.

2.2. Data Collection Procedure

This cross-sectional study was conducted using a web-based questionnaire administered via Google Forms to a convenience (pseudo-probabilistic) sample of Latvian cyclists. The target population, as defined by the sampling strategy, consisted of cyclists aged 18 and over who regularly use bicycles for various purposes daily. Therefore, and regarding inclusion criteria, every possible adult with basic literacy, able to respond to an e-form, and using a bicycle at least once a month (regardless of the motive(s) associated with it) was considered a possible research partaker, as long as they willed to respond to the electronic survey once received the invitation.

The data collection window covered a period of approximately 9 months, as data collection was started in May 2023 and concluded in February 2024. The survey was distributed through social media platforms (such as Facebook) and targeted emails to reach the specific research demographic. Participation in the study was voluntary, and participants were assured of the anonymity of their data and its use solely for research purposes within the scope of this study.

2.3. Study Variable Measurement

Through the online survey, data were collected on respondents' demographic information, cycling habits, and frequency, as well as the number of traffic crashes experienced while cycling. Additionally, two questionnaires were included in the electronic survey: the Cycling Behavior Questionnaire [19] and the Cyclist Risk Perception and Regulation Scale [15].

2.3.1. The Cycling Behavior Questionnaire

Nowadays, the Cycling Behavior Questionnaire (CBQ) constitutes the most widely used tool to assess cyclists' behavior, focusing on self-reported both risky and positive behaviors. Developed and cross-culturally validated by Useche et al. [19], the CBQ aims to explore the interrelationship between cyclists' behavior and its outcomes. Initially, the questionnaire consisted of 29 items. The CBQ is structured into three scales: 1) Traffic Violations; 2) Errors, and 3) Positive Behaviors. The traffic violations scale assesses deliberate risky behaviors, such as cycling against traffic flow or exceeding speed limits. The second factor, i.e., riding errors scale, identifies unintentional behavior patterns that heighten the risk of accidents, such as failure to assess surrounding conditions leading to potential crashes. Conversely, the positive behaviors scale highlights safety-promoting habits like cycling under adverse conditions, helmet usage, and cautious approaching when crossing streets. All across the scale, respondents are required to rate each questionnaire question on a five-point scale ranging from 1 (never) to 5 (almost always). The full version of the CBQ is available in the Appendix of its multi-national validation study [19].

At a practical level, the CBQ is increasingly being used in the latest scientific research that addresses critical issues surrounding cyclist safety and strategies for its enhancement globally. Previous studies conducted in the five continents have systematically shown that, apart from cross-cultural validity, the questionnaire has a high reliability and internal consistency [2,19], as well as coherent relationships to similar questionnaires used in behavioral research for active transport users, including the Bicycle Rider Behavior Questionnaire (BRBQ) [22], or the Walking Behavior Questionnaire (WBQ) [9].

2.3.2. Cyclist Risk Perception and Regulation Scale (RPRS)

The Cyclist Risk Perception and Regulation Scale (RPRS) was employed to assess cyclists' perception and knowledge of traffic regulations. The scale was developed and constructed by Useche et al. (2019) [15] and it consists of 12 items distributed into two scales: 1) Risk perception and 2) Knowledge of traffic rules. The RPRS measures cyclists' perceived risk levels concerning common safety issues, such as their ability to identify road surface irregularities or potential obstacles along their route. Meanwhile, the knowledge of traffic rules scale evaluates cyclists' familiarity with essential traffic regulations, including the recognition of very basic road conventions. Respondents must rate each of the items on a five-point scale ranging from 1 (strongly disagree) to 5 (strongly agree) [15]. Previous studies have consistently endorsed the RPRS scale's reliability and validity, underscoring its value in exploring the factors impacting cyclist safety concerns.

2.4. Statical Analysis

The full set of statistical analyses conducted with this study's data were carried out using the Statistical Package for Social Sciences (SPSS) software (Armonk, New York), version 28.0 for Windows operative systems.

In the first step, data were carefully curated in order to check their quality, dismiss any potential duplicates, and calculate the study variables as advised in their original source validation studies or manuals. Subsequently, descriptive statistics were analysed for all survey data, including results from the CBQ and RPRS questionnaires.

In the further analysis, statistical methods were selected according to the research objectives. Namely, the internal consistency of the CBQ and RPRS questionnaires was assessed using Cronbach's alpha coefficient and the value of the coefficient is acceptable if it is 0.6 and higher. To explore

correlations between respondents' demographics, weekly cycling duration, accident history, and questionnaire scales, bivariate Pearson's correlation tests were utilized.

Regarding multivariate analyses, two relevant tests were utilized to examine the study hypothesis: firstly, Multivariate Analysis of Covariance (MANCOVA) was employed, with recent crash involvement (within the last five years) serving as a fixed factor. Apart from controlling for basic demographics such as age, gender, and education, the specific factors or sub-scales from the CBQ and RPRS questionnaires were considered dependent variables, while age and average weekly cycling duration were included as covariates. This analytical approach was selected based on previous studies [12]. Secondly, in the final stage of result analysis, Binary Logistic Regression was employed to investigate the relationship between crash occurrence and the specific indicators from the CBQ and RPRS scales, having previously dichotomized the study sample between those Latvian cyclists self-reporting having suffered (or not) at least one cycling safety-related incident studying the five last years.

3. Results

Table 1 summarizes the means and standard deviations of CBQ and RPRS questionnaires, collected from a sample of cyclists. The mean scores provide insight into the frequency of negative behavior patterns reported on the CBQ scales Traffic violations and riding errors. That means that lower scores indicate less often negative behavior is reported. Higher scores on the CBQ questionnaire scales for the positive behaviors sub-scale and the RPRS questionnaire scales for knowledge of traffic rules and risk perception scales indicate a more positive outcome. Overall, the descriptive statistics suggest that Latvian cyclists' risky behavioral indicators are not particularly high, if compared with other countries of the region included in previous multi-national studies using the CBQ [19].

Moreover, the reliability analysis, carried out using Cronbach's alpha coefficients, showed high internal consistency indexes across all questionnaire scales, with coefficients ranging from 0.814 to 0.904, all of them over the commonly accepted cut-off point of $\alpha=0.70$ in traffic psychology studies [23,24]. This indicates strong reliability and consistency in the measurement of constructs assessed by the CBQ and RPRS questionnaire scales.

Table 1. Descriptive statistics and internal consistency results of CBQ and RPRS scales (n=299).

Factor	Descriptive scores		Cronbach's Alpha (α)
	M	SD	
<i>CBQ</i>			
F1: Traffic violations	1.11	.87	.904
F2: Riding errors	.75	.75	.965
F3: Positive behaviors	2.37	.90	.836
<i>RPRS</i>			
F1: Knowledge of traffic rules	3.16	.66	.780
F2: Risk perception	3.38	.71	.814

Notes: CBQ= Cycling Behavior Questionnaire; RPRS= Regulation and Perception of Risks Scale; M= Arithmetic Mean; SD= Standard Deviation.

3.1. Traffic Violations

By closer examination of the CBQ questionnaire items concerning specific activities carried out while cycling, which may pose potential dangers according to respondents' analysis, it is worth pointing out that certain activities are practiced more frequently. Among the most typically reported cycling behavioral patterns, the following activities are most commonly reported: 71.24% of cyclists reported listening to music while cycling ($M=1.83$; $SD=1.51$); 68.56% reported talking on the phone or sending text messages while riding a bike ($M=1.35$; $SD=1.21$); and crossing what appears to be a clear crossing, even if the traffic light is red ($M=1.34$; $SD=1.22$), which is practiced by 68.56% of cyclists.

It should be mentioned that even though with a low frequency, a large part of the respondents self-reported that they also engage in potentially dangerous activities, such as cycling against the flow of traffic ($M=1.03$; $SD=1.11$; 57% of cyclists), handling potentially obstructive objects while riding a bicycle (food, packs, cigarettes etc.) ($M=1.12$; $SD=1.15$; 63.54% of cyclists) and going at a higher speed than they should be going at ($M=1.27$; $SD=1.22$; 66.56% of cyclists). Furthermore, other risky behavior include carrying passengers on the bicycle without it being adapted for such a purpose ($M=0.67$; $SD=1.05$; 43.48% of cyclists), cycling under the influence of alcohol and/or drugs or hallucinogens ($M=0.74$; $SD=1.02$; 47.16% of cyclists), zigzagging between (weaving in and out of) vehicles using a mixed lane ($M=0.88$; $SD=1.16$; 36.12% of cyclists), and having a dispute in speed or "race" with another cyclist or driver ($M=0.85$; $SD=1.14$; 45.15% of cyclists) are less commonly reported by cyclists.

3.2. Riding Errors

As for non-deliberate risky road behaviors (i.e., errors) performed by Latvian cyclists, it was found that the most common road misbehavior of this nature consisted of failing to be aware of the road conditions and falling over bumps, hole or obstacle present on the road ($M=1.02$; $SD=0.99$; 63.55% of cyclists), as well as braking very abruptly on slippery surfaces (something very expectable, given the weather conditions of the country; $M=0.87$; $SD=0.97$; 54.51% of cyclists), and not properly assessing the surrounding traffic situation, leading to failure in noticing another vehicle and causing it to brake sharply to avoid a collision ($M=0.83$; $SD=0.88$; 58.19% of participating cyclists).

3.3. Positive Behaviors

All items of the Positive behavior scale of the CBQ questionnaire received relatively similar ratings among the surveyed cyclists. However, upon closer analysis of positive behavior expressions, it becomes evident that Latvian cyclists exhibit insufficient and relatively low indicators concerning the consistent use of a helmet while riding ($M=1.61$; $SD=1.51$), with only 64.55% reporting regular helmet usage. Nevertheless, cyclists suggest positive actions that contribute to reducing the risk of injury and enhancing safety in various activities. These include: using designated bicycle paths ($M=2.79$; $SD=1.17$; 95.99%); keeping a safe distance from other cyclists or vehicles ($M=2.68$; $SD=1.17$; 94.98%); stopping and looking at both sides before crossing a corner or intersection ($M=2.67$; $SD=1.25$; 95.32%); selecting appropriate speeds ($M=2.59$; $SD=1.21$; 93.65%); avoiding from cycling when feeling fatigued, ill ($M=2.17$; $SD=1.25$; 89.3%) and, or under adverse weather conditions ($M=2.07$; $SD=1.27$; 87.63%, respectively). These positive behaviors, despite variations in helmet usage, indicate a generally responsible approach to cycling safety among Latvian cyclists.

3.4. Traffic Safety Literacy

An analysis of the RPRS questionnaire items has provided valuable insights into cyclists' knowledge of traffic rules and their perception of risks. The results indicate a positive and satisfying level of understanding among respondents regarding traffic signs and signals ($M=3.61$; $SD=0.80$), with 74% affirming their full familiarity with road signs and basic road rules ($M=3.61$; $SD=0.80$). Moreover, the questionnaire reveals a reasonable knowledge of the bicycle safety regulations of one's city/town ($M=3.35$; $SD=0.87$), with 52.52% of cyclists indicating full familiarity. Additionally, a large part of respondents (59.19%) scored considerably high in the awareness of the potential consequences of being involved in a traffic accident, for example, with another vehicle ($M=3.34$; $SD=0.94$). While slightly lower, several indicators still reflect adequate levels of knowledge and awareness. Cyclists exhibit a moderate ability to identify areas prohibited for traffic or bicycle parking ($M=2.98$; $SD=1.04$, 40.8%). Furthermore, there's recognition that pedestrians should always have priority, even over cyclists ($M=2.65$; $SD=1.22$, 32.77%) and acknowledges the higher risks for their safety while riding a bicycle compared to riding a motorized vehicle ($M=2.55$; $SD=1.30$, 33.78%).

Analysing the perception of risks from a comparative approach to previous studies using the RPRS [15,19], it is noteworthy that the surveyed cyclists have a consistently high level of awareness regarding the various safety risks associated with riding a bicycle: 70.57% of respondents suggest

high awareness of other vehicles that surround them on the road ($M=3.55$; $SD=0.83$), 62.87% acknowledge the impact that cycling under the influence of certain substances (alcohol, illegal and/or prescribed drugs) affects the ability to ride well ($M=3.49$; $SD=0.94$), 71.91% realize that there are signalling and infrastructure problems that can affect their safety ($M=3.41$; $SD=0.93$), 63.87% recognize the risks associated with using headphones and mobile phones while riding bicycle ($M=3.42$; $SD=0.91$). Additionally, 42.48% recognize that urban areas are especially risky, considering the number of vehicles and the complexity of the roads ($M=3.01$; $SD=1.08$).

3.5. Correlational Analysis

The Pearson correlation results in Table 2 exhibited a significant relationship among factors included in the analysis. The magnitude of the relationship in Pearson correlation results was considered either weak ($r>0.1$), moderate ($r>0.3$), or strong ($r>0.5$), in accordance with the standard suggestions provided by Cohen (1988), which can be applied in behavioral science [25]. According to the obtained results, it can be stated that there is a significant negative relationship between age and both traffic violations ($r= -0.232$, $p<0.01$) and riding errors ($r= -0.257$, $p<0.01$), suggesting that older participants are less likely to commit traffic violations or make riding errors while riding a bicycle. Age showed positive significant correlations with weekly cycling ($r= 0.215$, $p<0.01$), positive behavior ($r= 0.343$, $p<0.01$), knowledge of traffic rules ($r= 0.115$, $p<0.05$), and risk perception ($r= 0.213$, $p<0.01$), indicating that older cyclists tend to spend more time cycling weekly, exhibit more positive behavior on the road, and have greater knowledge of traffic rules and perception of possible risk. No significant relationship was found between age and the total number of crashes.

The weekly time spent cycling had positive significant relationships with positive behavior ($r= 0.152$, $p<0.01$), knowledge of traffic rules ($r= 0.117$, $p<0.05$), and risk perception ($r= 0.115$, $p<0.05$) factors. This suggests that cyclists who spend more time riding a bicycle each week tend to exhibit more positive behavior, possess greater knowledge of traffic rules, and are more aware of risk perception. Additionally, the traffic violations factor exhibited a negative significant relationship with positive behavior ($r= -0.184$, $p<0.01$). In other words, this indicates that participants who commit fewer traffic violations tend to exhibit more positive behaviors while being on the road. There are also positive significant relationships between traffic violations and both riding errors ($r= 0.646$, $p<0.01$) and crashes ($r= 0.149$, $p<0.05$) factors, suggesting that cyclists who tend to violate traffic laws more frequently also tend to make more riding errors and consequently experience more crashes.

Moreover, riding errors showed negative significant correlations with positive behavior ($r= -0.184$, $p<0.01$), knowledge of traffic rules ($r= -0.183$, $p<0.01$), and risk perception ($r= -0.233$, $p<0.01$) factors, meaning that cyclists with greater knowledge about traffic rules, higher risk perception, and more positive behaviors tend to make fewer riding errors. Additionally, positive behavior outcomes suggest a strong and significant positive relationship with both knowledge of traffic rules ($r= 0.177$, $p<0.01$) and risk perception ($r= 0.302$, $p<0.01$) factors independently of previously mentioned correlations. Finally, and as for traffic safety literacy factors, the self-reported level of knowledge of traffic rules shows a significant positive correlation with risk perception ($r= 0.631$, $p<0.01$) factors, which indicates that cyclists with better knowledge of traffic rules also tend to have higher levels of perception of potential road risks.

Table 2. Pearson correlation matrix between age, spent time weekly, total crashes, CBQ and RPRS scales.

Factor	1	2	3	4	5	6	7	9
1 Age	1							
2 Weekly cycling (min.)	.215**	1						
3 Traffic violations	-.232**	-.015	1					
4 Riding errors	-.257**	-.024	.646**	1				

5	Positive behaviors	.343**	.152**	-.139*	-.184**	1			
6	Knowledge of traffic rules	.115*	.117*	-.079	-.183**	.177**	1		
7	Risk perception	.213**	.115*	-.111	-.233**	.302**	.631**	1	
8	Self-reported cycling crashes (5 years)	.094	.050	.149*	.134*	.039	-.031	.027	1

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

3.6. Multiple Analysis of Covariance (MANCOVA)

Table 3 represents the results of a Multivariate Analysis of Covariance (MANCOVA) examining the relationship between crash occurrence and various factors related to cycling behavior. The Wilks' Lambda of the MANCOVA was 0.961 ($F=2.36$, $p<0.05$), indicating that the overall main effect of crash occurrence reached statistical significance. This suggests that the crash occurrence significantly influenced the combined dependent variables. Among the 299 cyclists composing the study sample, 47.49% ($n=142$) of them reported experiencing at least one crash in the past five years, while the remaining 52.51% ($n=157$) reported no crashes during the past five years.

As for cycling safety outcomes, both risk-related factors, i.e., traffic violations ($F=9.29$, $p<0.05$) and riding errors ($F=6.26$, $p<0.05$), showed significant differences between the non-crashed and crashed groups of riders suggesting that, as hypothesized, these behaviors may increase the likelihood to suffer road crashes of cyclists. On the other hand, positive riding behaviors, knowledge of traffic rules, and risk perception did not show significant differences between the two groups, implying that these factors might not be as strongly associated with crash occurrence.

Table 3. Multivariate Analysis of Covariance of CBQ and RPRS scales and crash occurrence.

Factor	No crashes (n=157)	Crashes (n=142)	F	η^2
Traffic violations	1 (.88)	1.23 (.84)	9.29*	.031
Riding errors	.68 (.73)	.82 (.76)	6.26*	.021
Positive behaviors	2.30 (.95)	2.44 (.84)	.33	.001
Knowledge of traffic rules	3.19 (.72)	3.11 (.60)	1.31	.004
Risk perception	3.37 (.75)	3.38 (.67)	.14	.000

Notes: Wilks' Lambda = 0.961, $F=2.36$ $p<0.05$. Age and weekly distance riding a bicycle are included as covariates; *Correlation is significant at the 0.05 level (2-tailed).

3.7. Logit Analysis

With the aim to confirm the observed in the MANCOVA analyses through a directional analysis procedure, a Binary Logistic Regression (*Logit*) was used to predict the relationship between crash occurrence and CBQ and RPRS scale indicators (see Table 4). The Binary Logistic Regression model identified a significant directional relationship between self-reported crash involvement and two of the study variables: traffic violations (behavioral factor) and age (demographic factor).

For each logarithmic unit increase in traffic violations, the expectancy of a crash occurrence was increased by 0.352 ($\beta = 0.352$; $p<0.05$), indicating that cyclists with more frequent traffic violations have 1.421 times higher odds of experiencing a crash compared to those with fewer deliberate risk-related behaviors. Additionally, the analysis outcomes imply that age is a statistically significant predictor of crash occurrence ($\beta = 0.030$, $p<0.05$). This suggests that for each one-year increase in age, cyclists are 1.031 times more likely to experience a crash. This finding implies that younger individuals are less involved in crashes compared to older individuals. However, variables such as riding errors, positive behavior, knowledge of traffic rules, risk perception, and weekly cycling (min)

duration did not show statistically significant coefficients ($p>0.05$). This indicates that these variables are not significant predictors of crash occurrence among cyclists.

Table 4. Results of the Binary Logistic Regression (*Logit*) Model for predicting crash involvement (dichotomic factor) among Latvian cyclists.

Variables	β	SE(β)	Wald's χ^2	Exp(β)	95% CI for Odds Ratio	
					Lower	Upper
<i>Traffic violations</i>	.352*	.184	3.666	1.421	.992	2.037
<i>Riding errors</i>	.161	.217	.552	1.175	.768	1.797
<i>Positive behaviors</i>	.138	.152	.823	1.148	.852	1.546
<i>Knowledge of traffic rules</i>	-.249	.234	1.134	.780	.493	1.233
<i>Risk perception</i>	.098	.229	.183	1.103	.704	1.727
<i>Age</i>	.030*	.010	8.652	1.031	1.010	1.052
<i>Weekly cycling (min.)</i>	-.004	.003	1.611	.996	.991	1.002
<i>Constant</i>	-1.257	.763	2.712	.285		

Notes: Predicted variable: Involvement in ≥ 1 cycling crash. Time span: Last 5 years; SE= Standard Error; χ^2 = Chi-Square; 95% CI = Confidence Interval at the 95% level; Nagelkerke R Square of the significant model = 0.084; *Correlation is significant at the 0.05 level (2-tailed).

4. Discussion

This research analysed the relationship between cyclists' behavior, traffic safety literacy, and self-reported crash involvement among Latvian cyclists. In the context of the study, the Cycling Behavior Questionnaire [19] was utilized to measure the risk-related behavior patterns of cyclists, while the RPRS questionnaire [15] was employed to evaluate cyclists' traffic safety literacy, measuring both risk perception and road rule knowledge following a self-report approach.

4.1. Behavioral Correlates and Safety-Related Outcomes

Overall, the results of this study suggest significant correlations between self-reported cycling behavior and traffic safety literacy with cyclist crashes, considering a time window of five years. From a bivariate approach, the data provided by this Latvian sample show significant positive behavioral patterns of behavior among cyclists, as well as cases where road traffic violations are committed intentionally, and errors are due to lack of awareness or misjudgement of traffic situations.

Moreover, the findings show a correlation between the behavior of cyclists and the likelihood of traffic violations which are associated with crashes. Also, there is a significant positive correlation between traffic violations and riding errors ($p<0.01$). This suggests that cyclists who commit more intentional traffic violations also make more riding errors, potentially endangering their safety on the road. Similar findings have been reported in studies conducted in other countries, even though, from a comparative point of view, the results obtained in the study indicate that the frequency with which the surveyed cyclists commit both deliberate (i.e., traffic violations) and non-deliberate (i.e., errors) is comparatively greater than the mean concerning other countries of the region such as Finland (see [19]).

Building on further previous research conducted both within and outside the Baltic countries, it is noteworthy that O'Hern et al. (2021) conducted studies in Finland and Australia on cyclists' behavior and crash involvement, yielding similar results [13,26]. They concluded that cyclists who commit more traffic violations were, consistent with the findings of this initial study with the Latvian population, more prone to making more errors on the road, indicating risky behavior [13]. Similar results were found in research where traffic violations were associated with errors and multiple crashes [15,20,27]. According to our results, one of the most common and deliberate actions

performed by cyclists while riding a bicycle is using a phone; 68% of the respondents admitted to regularly engaging in this action.

At a hands-on level, the potential consequences and dangers of such activities have attracted the attention of several researchers and road traffic context analyses [28]. For instance, De Angelis et al. (2020) conducted a separate study on smartphone use and crash risk among cyclists [29]. Their results provide insight into how smartphone use contributes to an increased likelihood of being involved in near-crashes and actual crashes. Another common and deliberate action is listening to music, as reported by 71% of surveyed cyclists. Stelling-Konczak et al. (2018) carried out research proposing that not being able to hear traffic sounds may decrease cyclists' awareness of approaching vehicles and lead to unsafe situations sometimes acting as pre-crash scenarios [30].

4.2. Behavioral and Literacy-Related Predecessors of Crash Involvement History

Another important finding from the study is that cyclists with more frequent traffic violations also tend to uniformly show increased Odds Ratios of experiencing a crash compared to those with fewer self-reported frequency of traffic violations while riding. Apart from endorsing the core study hypothesis, this aligns with the results of previous research experiences with similar findings. For instance, a study conducted by Rad et al. (2024), suggests that different behavioral patterns of cyclists may influence cycling outcomes [16]. This study observed significant levels of risky behavior among cyclists, which were significantly associated with their history of previous traffic crash involvement.

Also, despite variations in helmet usage, Latvian cyclists exhibit generally positive behavior in aspects such as using designated bicycle paths, with stable trends in behaviors such as maintaining a safe distance from other cyclists or vehicles, practicing caution at intersections, selecting appropriate speeds, and avoiding cycling in unfavourable conditions, reflecting a responsible approach to cycling safety. Moreover, the negative correlations between traffic violations, risk perception, and positive habits or behavior is coherent with the observed in other studies addressing protective habits in addition to merely risky riding behavior [13,15].

This suggests that cyclists with enhanced knowledge of traffic regulations, heightened risk perception, and a proactive approach towards safety tend to make fewer riding errors, emphasizing the significance of promoting positive behavior in cycling habits. Based on the results of Kummeneje and Rundmo (2020) study, risk perception was a significant factor in shaping the positive behavioral perspectives of cyclists in Norway. The study concluded that an individual's attitude, including behavior, is directly influenced by their perception of risk. When this perception is low, it may manifest in cycling behavior characterized by fewer positive attitudes towards road safety [31].

When evaluating cyclists' traffic knowledge and risk perception indicators, negative mutual relations between these factors and riding errors can be observed, indicating that as these indicators increase, riding errors decrease. Likewise, these indicators also have a positive interpersonal relationship with positive behavior on the road, as well as a positive relationship with self. These results are largely consistent with and support the findings of previous studies, such as Useche et al. (2019), where significant relationships were identified between involvement in reckless road behaviors, risk perception levels, and traffic knowledge [15]. Similar results were also found in the Australian study by O'Hern et al. (2021) [13]. By understanding the interplay between traffic knowledge, risk perception, and behavior on the road underscores the importance of promoting education and awareness among cyclists to foster safer and more responsible cycling practices [32].

One of the notable findings is the significant impact of cyclists' age on various factors, including weekly cycling intensity, traffic violations, riding errors, positive behavior, knowledge of traffic rules, and risk perception. This observation highlights a trend among Latvian cyclists, wherein individuals tend to exhibit greater caution and self-awareness as a function of age. Specifically, the study reveals that older cyclists show a tendency to engage in fewer traffic violations, consequently leading to a reduction in riding errors. While the research emphasizes the prevalence of intentional traffic rule violations among cyclists, it suggests a decline in such risky behavior as individuals age [15,20].

For example, although it relates to a passive safety issue rather than modulating post-crash severity figures, older cyclists exhibited a higher frequency of helmet usage, similarly to the observed

in previous studies conducted in other countries [16,33]. Moreover, older respondents demonstrate higher levels of positive behavior, knowledge of traffic rules, and risk perception, indicating a more informed and responsible approach to cycling safety. This is essential for fostering a culture of road awareness and reducing the likelihood of accidents among cyclists of all ages.

4.3. Limitations of the Study

While this study used validated research instruments and covered the different regions of Latvia, there are some essential limitations that should be acknowledged, in order to make a fair interpretation of the study results. One of them is the relatively large age range of the sample, which ranged from 18 to 76 years. Age is often correlated with factors such as maturity, experience, level of education, state of health, and others, which can complicate the formulation of clear conclusions, and understanding the influence of age on research results.

Another limitation is that the research data collection occurred in an online environment, which did not afford full control over the veracity of respondents' answers and the validity of the data. It's important to note that participation was voluntary, and responses were anonymous, which helped to decrease this limitation.

Furthermore, the research data collection spanned from May 2023 to February 2024. It's worth mentioning that the time of year during survey completion could potentially influence respondents' answers. For instance, during winter when road surfaces are often covered with snow, the number of cyclists on the road tends to decrease compared to warmer seasons. This factor should also be considered in future research.

Moving forward with the study on cyclists' road behavior, traffic safety literacy, and crash involvement in Latvia, it is critical to consider the aforementioned limitations and consider expanding the research sample to address potential biases and enhance the robustness of the findings.

5. Conclusions

At a general level, the evidence obtained in the study suggests significant interrelationships between cyclists' behavior, traffic safety literacy, and crash occurrences among Latvian cyclists over the past 5 years. In addition, and as for specific issues, there is a set of findings worth to be mentioned:

Firstly, in comparison to other countries in the Baltic region previously examined using the CBQ, cyclists in Latvia exhibit a slightly higher frequency of both traffic regulation violations and riding errors.

When it comes to cyclists' demographics, it's noteworthy that older cyclists consistently demonstrate greater knowledge of traffic rules and a heightened perception of potential road risks. This may explain their inclination towards exhibiting more positive behavior compared to younger individuals.

Regarding positive cycling behaviors, although no correlation was found between positive behavior and crashes, positive correlations were identified between total crashes in the past 5 years and both traffic violations and riding errors. This suggests that the more cyclists engage in traffic violations and riding errors, the higher the likelihood of being involved in cycling crashes.

At a practical level, and based on the results obtained, promoting cyclists' awareness of the potential risks and consequences of not adhering to safety traffic rules could enhance both safety and positive behavior among cyclists. Additionally, it could contribute to a reduction in traffic violations and riding errors, which is particularly relevant for strengthening the promotion of active and sustainable transportation methods in Baltic countries.

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