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Evaluating cyclist ride quality on different bicycle streets

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Abstract

The ride quality is considered essential for the acceptance of bicycles as a mode of transportation. The quality of the ride for a cyclist can be affected by several different variables. In addition, the ride quality on a bicycle path or street can vary from person to person. Hence, this research investigates the ride quality along different bicycle paths, considering the perception of cyclists. Thirteen bicycle paths and streets were selected around the city of Hasselt, Belgium, to measure ride quality. The bicycle paths and streets were chosen to represent different conditions. They were selected based on infrastructure types, scenery along the path, bicycle path width, and unevenness. Twenty volunteer cyclists were recruited and asked to complete a questionnaire and rate the selected factors and ride quality after the completion of the ride. A linear mixed model was used to predict bicycle ride quality. The results suggest a significant correlation between the variables and overall ride quality. The infrastructure type was a critical variable (Estimate = 0.342, $p < 0.001$), showing that higher infrastructure scores were connected with a better ride experience. Cyclists reported that the scenery along bike lanes had the most negligible impact on the quality of their rides. In addition, a comparison of the ride quality across various types of infrastructure was carried out. Asphalt-paved bicycle pathways provide the highest riding quality for bikers.

Keywords: ride quality; perception of bicyclists; bicycle planning

1. Introduction

Traffic problems are a major concern in many cities around the world. Congestion, long commute times, air pollution, and road traffic crashes are the most critical issues arising from traffic problems (Ul-Abdin et al., 2018). In

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addition, it impacts the economy, environment, and people's daily lives. Cities are implementing solutions such as better public transport, new roads, and alternative modes of transportation to solve these problems (Ahmed et al., 2023). Recently, there has been a global push to make cities more amenable to pedestrians and cyclists (Ahmed et al., 2021; Sobhani et al., 2019). Cycling is a widely used sustainable means of transportation and is a crucial component of any urban mobility strategy in terms of policy and implementation that aims to enhance urban living standards (Karolemeas et al., 2022).

Cycling is also beneficial in addressing traffic and environmental problems. For example, cycling can help reduce traffic congestion, improve air quality, and lower carbon emissions (Buehler and Pucher, 2021). Moreover, cycling as a mode of transportation can also lead to more liveable and sustainable cities (Podgórniak-Krzykacz and Trippner-Hrabi, 2021). For instance, increasing the number of people cycling in a city can help improve traffic flow, reduce air pollution, and increase sustainability (Komadina, 2021). Worldwide, the number of cyclists is rising in many cities and countries, i.e., EU countries and regions of the USA and Canada (Castells-Graells et al., 2020). In order to develop attractive, pleasant, secure, and healthy communities, many stakeholders agree that cycling should be prioritized alongside other active means of transportation like walking (Wahlgren and Schantz, 2014). By providing safe and convenient infrastructure, financial incentives, and promoting a positive culture and attitude towards cycling, governments can encourage more people to take cycling as a regular mode of transportation. Also, the modal shift towards bicycle use, safety, and comfort remain the most critical factors for the increased adoption of a bicycle as a mode. Although governments are making legislation to encourage cycling, a variety of other factors, including psychological ones, location, employer, income, etc., affect whether people choose to use bicycles as a mode of transportation daily (Ul-Abdin et al., 2018).

Bicycle ride quality and comfort levels for cyclists on various infrastructures can considerably impact their chosen transportation mode. In addition, Pavement roughness potentially influences the bicycle ride quality (Thigpen et al., 2015). Researchers argue that inadequately maintained bicycle path pavement, such as rough or uneven surfaces, can cause bikers discomfort and fatigue, reducing the likelihood of using their bikes as a mode of transportation (Bíl et al., 2015). Therefore, bike lanes and roads designated explicitly for cyclists should be flat and smooth, allowing cyclists to experience a good bicycle ride. The surface pavement type is one of the components of bicycle network assessment that is considered (together with other factors, such as traffic volumes, bicycle scenery, infrastructure type, and road width) when determining which routes offer the most favorable conditions for cyclists (Gao et al., 2018). Thus, bicycle ride quality is becoming increasingly important for cyclists and city planners.

The importance of bicycle pavement type and its condition, safety, and ride quality cannot be overstated (Thigpen et al., 2015). It is well-recognized that pavement surface profile characteristics, such as roughness and texture, influence the ride quality of motor vehicles (Li et al., 2013). Given the similarities between the physical interactions between a bicycle and a road surface, it is clear that pavement surface profile characteristics also significantly affect the quality of a bicycle ride (Thigpen et al., 2015). It should be noted that factors that make a street appealing for bicycling, such as the presence of trees, landscaping, and street setbacks, are also considered important by researchers as they can be positively associated with bicyclist preferences (Namgung and Jun, 2019). One study showed that aesthetics or greenery are encouraging factors for bicycle commuting in suburban areas, while motor vehicle flows, noise, and low directness of the route are discouraging factors, emphasizing the importance of these factors in urban or built-up areas (Zukowska et al., 2022).

Various methods have been used to assess the bicycle environment, such as the Dynamic Comfort Index (DCI), Pavement Condition Index (PCI), and the International Roughness Index (IRI) (Ul-Abdin et al., 2018). The methods have made it possible to quantify the roughness of a road surface and evaluate its effect on comfort (Bíl et al., 2015). These indices account for frequent and dynamic acceleration readings, which are crucial in establishing the comfort level of a road surface (Gao et al., 2018). The PCI, DCI, and IRI are widely used to evaluate the pavement condition of bicycle surfaces and to determine bicyclist comfort. Some methods have also tried to predict the ride quality for bicyclists. One study predicted ride quality on various pavement surfaces based on a sensor-based statistical model with only one variable, i.e., pavement types (Qian et al., 2020).

Similarly, another study focused on modeling the impact of pavement roughness on bicycle ride quality and presented a multilevel binomial pavement acceptability model (Thigpen et al., 2015). However, it did not consider other potential factors, such as the width of the bicycle path and the scenery along the bicycle path. Other studies on bicycle ride quality have also considered pavement conditions, i.e., bicycle vibration and road roughness values (Ul-

Abdin et al., 2018). Although numerous studies have been conducted on bicycle ride quality, most methods have used pavement conditions to assess this. Multiple factors can influence ride quality, encompassing pavement roughness and other crucial factors such as lane width or aesthetics around the bicycle path (Gao et al., 2018; Ul-Abdin et al., 2018). Therefore, this study has considered these factors, i.e., bicycle lane width, type of bicycle infrastructure, and scenery, that could influence the ride quality of bicyclists. Also, the vibration resulting from the pavement is considered. This study developed a linear mixed model that demonstrates a correlation between various factors subjectively assessed for the ride quality of bicyclists.

2. Methodology

2.1. Case Study Area

The study was conducted in Hasselt, Belgium, a city in the province of Limburg. Hasselt is well known for its bicycle-friendly infrastructure. Fig. 1 shows the bicycle streets and paths chosen for this study. Hasselt was selected as a case study for several reasons. First, Hasselt is a small city, making it ideal for a study that aims to evaluate the ride quality of cyclists. Second, Hasselt is considered a bikeable city with a well-developed bicycle infrastructure that includes a variety of pavement types, such as asphalt, concrete, cobblestone, and paving slabs. This variety of pavement types meets the study's objective to evaluate the ride quality for cyclists on different types of pavements.

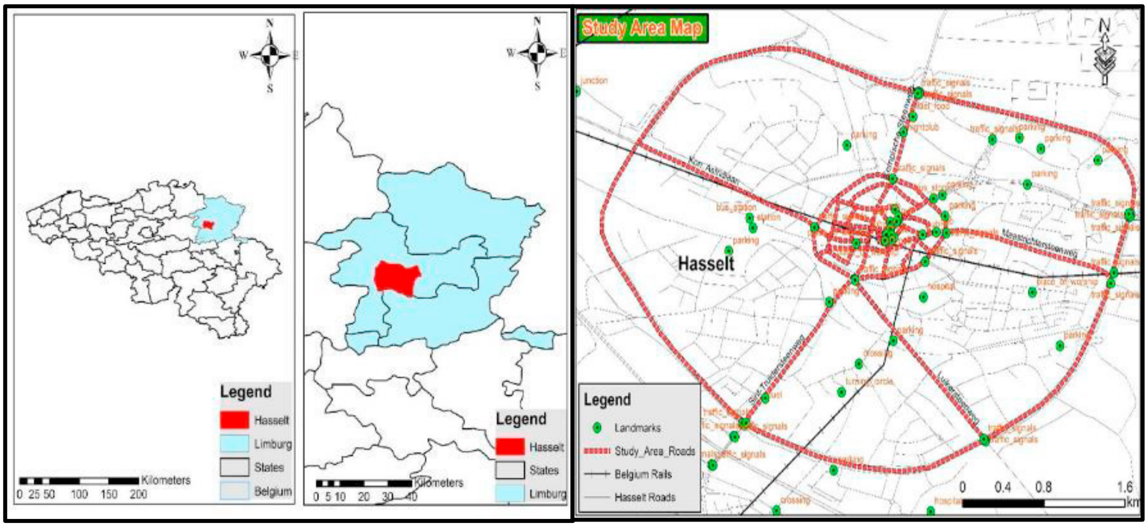

Fig. 1. Study area map.

2.2. Cyclist perception test

The ride quality on a bicycle path varies among bicyclists and is subjective. We carefully selected thirteen streets in Hasselt to represent a wide range of bicycle paths, streets, or lanes. As part of the selection process, we considered infrastructure types, scenery along the path, bicycle path width, and unevenness or roughness to assess ride quality. Twenty volunteer cyclists were recruited to evaluate the ride quality of each bicycle street or segment. The volunteer cyclists filled out a questionnaire and provided a rating for the selected variables and overall ride quality after completing the ride. The recruited volunteers completed the rating for all the selected streets for the study. The questionnaire includes pre-ride and post-ride questions. Pre-ride questions aimed to gather information on participants' gender, age, education, reasons for riding, daily cycling distances, and cycling frequency. In the post-ride survey, riders were asked to score each section and rate their riding experience from 1-5. The five-point scale was "very poor," "poor," "average," "good," and "excellent," where 1 represents "very poor" and 5 shows "excellent." Additionally, riders were asked to rate their experience for four indicators, scenery, vibration, road width, and type of bicycle pavement, using a rating scale of 1 to 5, with 1 being "very poor" and 5 being "excellent."

2.3. Reliability Assessment of Questionnaire Results

The Cronbach's test was conducted to determine whether the questionnaire responses could be relied upon. The value of Cronbach's a may be determined using Equation 1.

$$\alpha = x = \frac{K}{K-1}\left(1 - \frac{\sum_{i=1}^{k} \sigma_{y_1}^2}{\sigma_x^2}\right) \qquad \text{Eq.1}$$

Whereas k is the number of items in the test, $\sigma_{y_1}^2$ is the variance of the scores on items i and σ_x^2 is the variance of the observed test scores.

The Cronbach's Alpha coefficient test encompassed the ratings for infrastructure type, scenery, vibration, and bicycle path width, which was 0.791. Including all five items in this reliability test aligns with our aim to evaluate the overall ride quality by considering all the relevant factors. In addition, these items collectively contribute to the overall perception of ride quality for bicyclists. Cronbach's alpha coefficient of more than 0.7 indicates consistency, indicating that the questionnaire replies can be relied on (de Vet et al., 2017). This level of dependability suggests that the questionnaire's responses are consistent. In addition, a high level of dependability also implies that the study's findings are likely to be robust and reliable, providing confidence for the formulated conclusions.

3. Results

3.1. Summary of Descriptive Statistics

Twenty participants took part in the study, thirteen male and seven female. Table 1 provides information about the descriptive statistics of the participants. The age range of participants was between 18 and 54 years. The majority fell into the 25-34 age group, which accounted for 50% of the sample. The second most common age group was 18-24, which accounted for 25% of the sample. The age group with the smallest representation in the sample was 45-54, which accounted for only 5%. Half of the participants have a Bachelor's degree, with Master's degrees being the second most common level of education (25%). Regarding weekly cycling frequency, the most common response was 3 and 5 times per week (25%), while most participants reported cycling a distance of 2-5 km per day (30%).

Table 1. Descriptive statistics of the participants (n = 20)

Variable	Group	Frequency	Percent
Gender	Male	13	65.0
	Female	7	35.0
Age	18 - 24	5	25.0
	25 - 34	10	50.0
	35 - 44	4	20.0
	45 - 54	1	5.0
Education	High school graduate	1	5.0
	Bachelor degree	10	50.0
	Master degree	5	25.0
	Doctorate	4	20.0
Weekly cycling frequency (days per week)	1	1	5.0
	2	3	15.0
	3	5	25.0
	4	4	20.0
	5	5	25.0

	7	2	10.0
Daily	Less than 1 km	3	15.0
	1-2 km	4	20.0
	2-5 km	6	30.0
	5-7 km	5	25.0
	More than 7 km	2	10.0

3.2. Ride Quality on Different Pavement Types

The results of multiple comparisons using Tukey's HSD test are shown in Table 2. These comparisons were carried out based on the dependent variable, overall ride quality, and asphalt, concrete, small paving slabs, paving slabs, and cobblestone were the various types of infrastructure pavement types analyzed. The findings represent how different types of infrastructure pavement affect the ride quality of bicyclists.

Table 2. Post hoc Tukey method for ride quality on different pavement types

Multiple Comparisons						
Tukey HSD						
		Mean Difference			95% Confidence Interval	
(I) Infra_type	(J) Infra_type	(I-J)	Std. Error	Sig.	Lower Bound	Upper Bound
Asphalt	Concrete	.895*	.220	<.001	.29	1.50
	Small paving slabs	.472	.212	.171	-.11	1.05
	Paving slabs	1.719*	.225	<.001	1.10	2.34
	Cobblestone	2.317*	.128	<.001	1.97	2.67
Concrete	Asphalt	-.895*	.220	<.001	-1.50	-.29
	Small paving slabs	-.423	.278	.550	-1.19	.34
	Paving slabs	.824*	.288	.037	.03	1.62
	Cobblestone	1.422*	.221	<.001	.81	2.03
Small paving slabs	Asphalt	-.472	.212	.171	-1.05	.11
	Concrete	.423	.278	.550	-.34	1.19
	Paving slabs	1.246*	.282	<.001	.47	2.02
	Cobblestone	1.845*	.213	<.001	1.26	2.43
Paving slabs	Asphalt	-1.719*	.225	<.001	-2.34	-1.10
	Concrete	-.824*	.288	.037	-1.62	-.03
	Small paving slabs	-1.246*	.282	<.001	-2.02	-.47
	Cobblestone	.598	.226	.064	-.02	1.22
Cobblestone	Asphalt	-2.317*	.128	<.001	-2.67	-1.97
	Concrete	-1.422*	.221	<.001	-2.03	-.81
	Small paving slabs	-1.845*	.213	<.001	-2.43	-1.26
	Paving slabs	-.598	.226	.064	-1.22	.02

*. The mean difference is significant at the 0.05 level.

The results in Table 2 demonstrate a statistically significant difference between the ride quality of streets with asphalt-paved and concrete-paved (p = .001), with asphalt-paved streets providing a better overall ride quality for cyclists. There is no statistically significant variation in ride quality along streets with asphalt paved and small paving slabs, as there is no significant difference in the mean difference between the two types of pavement (p =.171).

However, ride quality significantly differs between streets with asphalt-paved and paving slabs (p = .001) and between asphalt-paved streets and cobblestone streets (p = .001), with asphalt-paved streets having a higher ride quality in both cases. The p-value for this difference is significantly lower than the p-value for the difference in ride quality between streets paved with asphalt and cobblestone paved streets.

Based on the results, the mean difference is insignificant (p =.550) for ride quality between concrete paved streets and small paving slab streets. The mean difference in ride quality between concrete paved streets and paving slab streets (p =.037) and between concrete paved streets and cobblestone paved streets (p = .001) is significant, with concrete paved streets having a lower ride quality in both instances. Notably, the mean difference in ride quality between small paving slab streets and paving slab streets (p = .001) and between small paving slab streets and cobblestone streets (p = .001) is considerable, with small paving slab streets having a worse ride quality in both instances. Moreover, there is no significant difference in ride quality between paving slab streets and cobblestone streets, as the mean difference between the two is insignificant (p =.064).

The pavement's roughness or smoothness can affect bicyclists' feelings, as rougher pavement creates vibrations that impact the ride quality (Thigpen et al., 2015). It is reported by various studies that asphalt-paved bicycle paths produced lesser vibration than other pavement types, i.e., cobblestone paved or paving slabs (Ahmed et al., 2023; Gao et al., 2018). Also, studies suggest that asphalt-paved bicycle path provides better bicycling comfort (Bíl et al., 2015). In addition, there is a strong correlation between the evenness or vibration and the ride quality (Ul-Abdin et al., 2018). The results of this study are consistent with those reported in the literature, suggesting that asphalt provides the best riding quality for cyclists. Moreover, a Pearson's correlation analysis was performed, which revealed a strong negative correlation (r=-0.746) between cyclists' ride quality and vibration.

Studies testify that concrete paved bicycle paths are more comfortable or have better ride quality (Bíl et al., 2015; Wu et al., 2015). Interestingly, based on the Tukey HSD test results, the bicycling ride quality was second best on paving slabs and was better than concrete paving. It was because the concrete paved bicycle path had more vibration in the selected streets. In addition, it should be noted that the overall ride quality also depends on other factors selected in the study, such as the width of the streets and scenery along the bicycle path.

3.3. Linear Mixed Model for Bicycle Ride Quality

A linear mixed model was employed to investigate the factors influencing overall ride quality, a critical aspect of the bicyclist experience. The dependent variable, overall ride quality, was evaluated with four covariates: vibration on the bicycle street, scenery along bicycle path/streets, bicycle path width, and infrastructure type. The data was collected from 20 bicycle riders who repeatedly gave their opinion on various bicycle streets selected for this study by filling out the questionnaire. This model comprehensively analyzes ride quality by incorporating both fixed effects, representing the four covariates, random effects associated with Street IDs, and accounting for repeated measures associated with individual riders.

Table 3 shows the Type III test that assesses the significance of each covariate infrastructure type, scenery along bicycle paths/streets, vibration on the street, and width of the bicycle path in the context of the overall linear mixed model. It accounts for the combined effect of all the covariates. It evaluates the unique contribution of each one in explaining the variability in the dependent variable, which is the overall ride quality for this study. Based on the results, infrastructure type emerges as a prominent determinant, showcasing a highly significant effect (F = 31.392, $p < 0.001$). Also, vibration on the bicycle street or lanes indicates a significant influence (F = 22.172, $p < 0.001$). Moreover, the width of a bicycle path significantly impacts ride quality (F = 9.146, p = 0.003). However, the scenery along bicycle paths/streets does not show a statistically significant effect (F = 2.979, p = 0.086).

Table 4 shows the estimates of the fixed effects. The fixed effects analysis demonstrated significant relationships between the covariates and overall ride quality. Infrastructure type emerged as a highly influential factor (Estimate = 0.342, $p < 0.001$), indicating that better infrastructure ratings were associated with improved ride quality. Vibration on the street/path also showcased a notable positive effect (Estimate = 0.257, $p < 0.001$), suggesting that smoother surfaces positively impacted overall ride quality. Similarly, the width of the bicycle path had a significant positive effect (Estimate = 0.173, p = 0.003), underscoring the importance of wider bicycle paths in enhancing ride quality. On the other hand, scenery along bicycle paths/streets did not reach statistical significance (Estimate = 0.121, p = 0.086).

Table 3. Type III Tests of Fixed Effects

Source	Numerator df	Denominator df	F	Sig.
Intercept	1	31.334	.260	.614
Infrastructure type	1	122.597	31.392	<.001
Scenery along bicycle paths/streets	1	259.542	2.979	.086
Vibration on the street	1	210.216	22.172	<.001
Width of the bicycle path	1	231.816	9.146	.003
Dependent variable: overall ride quality				

Table 4. Estimates of Fixed Effects

						95% Confidence Interval	
Parameter	Estimate	Std. Error	df	t	Sig.	Lower Bound	Upper Bound
Intercept	.172	.337	31.334	.509	.614	-.516	.859
Infrastructure type	.342	.061	122.597	5.603	<.001	.221	.463
Scenery along bicycle paths/streets	.121	.070	259.542	1.726	.086	-.017	.258
Vibration on the street	.257	.055	210.216	4.709	<.001	.149	.364
Width of the bicycle path	.173	.057	231.816	3.024	.003	.060	.285
Dependent variable: overall ride quality							

The presence of bicycle infrastructure plays a role in deciding to use bicycles as a mode (Podgórniak-Krzykacz and Trippner-Hrabi, 2021). In addition, the type of bicycle infrastructure also plays a significant role in choosing the preferred route, as it appeared to be the most significant variable in our model. The separate bicycle lane received a higher ride rating for ride quality than shared bicycle streets. There have been contrasting claims regarding the scenery or aesthetics of the route's surroundings. One study suggests that aesthetics or route scenery has been identified as a more significant influence on leisure bicycle riding than transport cycling (Pikora et al., 2003). In contrast, others indicate that transport cycling for commuting reasons is encouraged by route aesthetics (Wahlgren and Schantz, 2014). Our study revealed that scenery along bicycle paths/streets did not significantly affect the ride quality of the bicyclist.

4. Conclusion

Cycling is a sustainable form of transportation and an essential part of any urban mobility strategy that seeks to improve urban living conditions. Poor cycling paths and on-road or off-road riding infrastructure may discourage cyclists. This research aimed to evaluate bicycle ride quality on various bicycle streets.

For this study, we evaluate the ride quality of bicycle paths with the help of four different criteria. Twenty volunteer cyclists completed a questionnaire on ride quality for the selected bicycle streets. Volunteer cyclists scored each section or a bicycle street/lane and rated their experience from "Very Poor" to "Excellent" in the post-ride survey. Riders also rated their experience on four indicators: Scenery, vibration, bicycle path width, infrastructure type, and overall ride quality. The Cronbach's Alpha value was 0.791, so the questionnaire responses are reliable.

This study conducted a preliminary investigation of the link between the ride quality of cycling and selected factors such as vibration, the scenery along the bicycle route, the kind of bicycle infrastructure, and the bicycle path width. Based on the Cronbach alpha test, the findings are considered accurate; nonetheless, there is space for improvement in the findings' accuracy and representativeness. Due to the limited resources available for this study, the number of volunteers who participated in the tests to determine their perceptions of the ride quality was relatively low. Also, we chose four variables for the model; nevertheless, other variables can influence the overall ride quality of a bicyclist on a specific route, and the model can be improved by adding more variables.

As suggested, there are limitations to this study. Increasing the sample size and including a more diverse group of participants can enhance the representativeness of the findings. Age, bicycling experience, fitness level, traffic intensity, weather conditions, and bicycle type could also be factors impacting ride quality, and considering them could provide a more comprehensive understanding. Nevertheless, the study provides an essential foundation for further research and has practical implications for urban planning and infrastructure development.

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