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IMPACT OF ENVIRONMENTAL AND DEMOGRAPHIC FACTORS ON URBAN CYCLING

Alireza Abdolrazaghi, Babak Mirbaha
Imam Khomeini International University, Qazvin, Iran

Abstract: Little is known about the importance of different variables in shaping cyclists' risk perception when cycling in urban areas. We evaluate the effects of environmental and demographic factors on cyclists' perception of risk in urban cycling, by conducting a study in the central area of a large city, Qazvin, Iran. We develop a linear mixed model to predict the cyclists' angular movement. With twenty-six cyclists included in this study, the outcome variable is the change in the cyclists' angular movement as a surrogate for risk perception, while the predictors are the personal characteristics and environmental features. Cycling through residential and commercial areas, one-way routes, routes with speed limits, wide routes ≥ 12 m, existing bike lanes, traffic volume, and path elevation (all P≤0.001) are associated with angular movement. However, sex, age, cycling history, psychological distress score, and presence of parks are not significant predictors of the angular movement. While the cyclist characteristics do not show significant correlations with the angular movement, environmental factors have significant effects on the cyclists' risk perception. This study, therefore, highlights the critical role of cycling infrastructure in shaping the cyclists' risk perception and it provides implications for urban planners and policymakers.

Keywords:

risk perception;
angular movement;
cycling;
psychological distress;
environmental features;
Iran

Email: alireza.abdolrazaghi@edu.ikiu.ac.ir

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Introduction

Urban environments, inhabited by more than two-thirds of the world's population, pose significant health challenges due to multiple factors that influence the well-being of their inhabitants (Gavrilidis et al. 2023). Over the past thirty years, research has focused on understanding and addressing the complex causes of deteriorating health status in large cities, emphasising the importance of urban design, regulations in promoting human health, and preventing randomness in urban development processes (Ortiz et al. 2021, Gavrilidis et al. 2023). Research conducted during the COVID-19 pandemic led to the implementation of non-pharmaceutical interventions and the dissemination of detailed data to understand and mitigate the spread of the pandemic. Geospatial analysis of the data was considered essential to support decision-making by health authorities and policymakers at various levels (Miramontes Carballada and Balsa-Barreiro 2021). In addition, urban planning plays a critical role in managing social movements associated with environmental risks, which requires an examination of location patterns and their impact on regional development, including socio-economic and political aspects (Crețan et al. 2005).

The growing popularity of cycling as a mode of transport can be attributed to its inherent advantages over alternative modes (Blondiau et al. 2016). The attractiveness of cycling is based on its cost-effectiveness, accessibility, health benefits, and ability to reduce travel time within urban areas (Oja et al. 2011, Blondiau et al. 2016). Nevertheless, cycling exposes riders to various risks, such as accidents resulting from interactions with other road users, poor infrastructure, and environmental factors (Reynolds et al. 2009). To reduce these risks and to promote cycling as a sustainable transport mode, researchers have conducted studies where various models have been formulated to capture the effects of environmental conditions and the cyclist-specific variables on cyclist safety (De Hartog et al. 2010). The environmental factors included air quality, road surface conditions, weather, and lighting conditions; while the personal factors included age, gender, experience level, and cycling frequency (Reynolds et al. 2009).

Studies have highlighted the importance of risk perception in shaping people's behaviour and their acceptance of technologies, policies, and standards (Siegrist and Árvai 2020). Current research on risk perception revolves around three main perspectives: the characteristics of hazards, the characteristics of risk aspects, and the use of heuristics in forming risk judgments (Siegrist and Árvai 2020). While psychometric research focuses on how hazard characteristics influence perceptions, there's a notable gap in understanding how individual differences affect risk perception (Siegrist and Árvai 2020). Factors such as demographics, psychological traits, and knowledge levels contribute to diverse risk perceptions, underscoring the need for a deeper understanding to improve communication, decision-making, and risk management capabilities. For instance, a study in Germany showed that heat risk perception is primarily influenced by factors such as awareness of heat risks, sensitivity to such risks, and an external locus of control (Beckmann and Hiete 2020). Descriptive statistics revealed significant effects of health implication scores, chronic diseases, and young age on heat perception.

However, there is a scarcity of information on how environmental and behavioural factors affect the cyclists' perception of risk (Zhao et al. 2020). Objective risk factors, such as traffic volume and infrastructure quality, influence the estimation of risk associated with cycling. Individual characteristics, including prior experience and personal attitudes towards cycling safety, also play important roles in shaping the cyclists' risk perception (Branion-Calles et al. 2019, Zheng et al. 2019, Zhao et al. 2020). Risk perception involves the cyclist’s subjective assessment of both the expectation and severity of potential hazards in the cycling environment.

Cycling safety research has traditionally focused on objective crash risk, but there is growing interest in the cyclists' subjective risk perceptions (von Stülpnagel and Krukar 2018). Crash risk and subjective risk perception in urban cycling appear to be largely consistent. A study examined the relationship between bicycle crashes and subjective risk perception for different types of infrastructure and different speed limits, controlling for the local cycling volume (von Stülpnagel and Krukar 2018). The results showed that reporting absolute values can be misleading. Adjusting the absolute values for significant covariates (e.g. cycling volume) yields for more accurate models. Also, cyclists may misperceive crash risk in certain situations, suggesting the need for further research to understand these differences and to improve the cyclists' perceptions (von Stülpnagel and Krukar 2018). Individuals make decisions about preventive behaviours and response strategies by perceiving and assessing the risk, ultimately minimising the occurrence and impact of adverse events (Doorley et al. 2015).

Psychological traits have the potential to influence an individual's perception of risk in various situations (Anderson et al. 2013). Anxiety plays a central role in determining how individuals respond to conditions that may pose potential dangers to them (Doorley et al. 2015). Higher levels of psychological distress correlate with increased risk perception (Böhm and Brun 2008). Research suggests that people experiencing psychological distress are more likely to overestimate the level of risk, even in circumstances where the objective risk assessment suggests relatively safe conditions (Zheng et al. 2019). Integrating demographic and psychological characteristics into a predictive model provides an opportunity to evaluate their impact on risk perception.

Our objective was to provide insight into the importance of different characteristics in shaping the cyclists' risk perception. This would be valuable in designing interventions that promote cycling while ensuring the safety of cyclists. The change in gaze angle has been proposed as an indicator of risk perception for cyclists riding in urban areas, representing risk anticipation and reaction to potential hazards (Mantuano et al. 2017, Schmidt and von Stülpnagel 2018, von Stülpnagel 2020). It has been suggested that increasing the visual workload requires more concentration from the rider, leading to discomfort and changes in the movement preferences (e.g., angle of movement). Consequently, measuring the angular changes while adjusting for the internal state and external conditions has the potential to represent the cyclist's perceived risk. The effects of speed and path characteristics on the steering of professional cyclists have been previously investigated in research settings (Vansteenkiste et al. 2013, Schepers et al. 2014, Vansteenkiste et al. 2014a, Vansteenkiste et al. 2014b). Meanwhile, the assessment of angular movement in real-world environments among non-professional cyclists may also provide insight into cyclists' risk perception. Our investigation was focused on evaluating the angular movement of cyclists as a surrogate for the measurement of their ability to perceive risk. We hypothesised that both participants' and environmental characteristics would be associated with changes in the risk perception of cyclists.

Methodology

Study area

A single cohort of cyclists was studied from July 2022 to October 2022 in the urban areas of Qazvin, located in the Qazvin Province in Iran (Figure 1). The geographical location of Qazvin City is about 152 kilometres northwest of the capital of Iran (Tehran) and it borders Zanjan Province in the north, Alborz Province in the east, Markazi Province in the south, and Hamadan Province in the west. Qazvin is known as one of the historical cities of Iran and it has many historical, cultural, and natural monuments. This city has a semi-arid and cold climate.

Due to its flat topography, with an average road gradient of 2.5% and an area of about 120 hectares, the historical city of Qazvin has a high potential for cycling as a mode of transportation. Since 2010, the Qazvin Deputy for Transport and Traffic has been seriously engaged in the development of clean and human-oriented transportation. As a first step, the topic of clean transportation was proposed and approved by the Ministry of Interior as one of the main objectives in the Transportation Master Plan (City of Qazvin 2013). In the second step, a professional committee was formed to plan and design new strategies to develop the infrastructure and to promote the culture of cycling in the city. During the investigation and research conducted by this committee, the issue of safety was identified as the most important factor responsible for the decreased adoption of cycling in Qazvin. Following the development of clean transportation, nearly 52 km of bicycle paths were constructed in the city. With regard to the Transportation Master Plan (City of Qazvin 2013), the deputy intends to develop bicycle lanes in busy streets through a medium-term plan and to establish a connected network between the existing lanes. Also, to provide the citizens with access to shared bicycles in the city, in cooperation with the private sector, the construction of mechanised stations for shared bicycles is on its agenda.

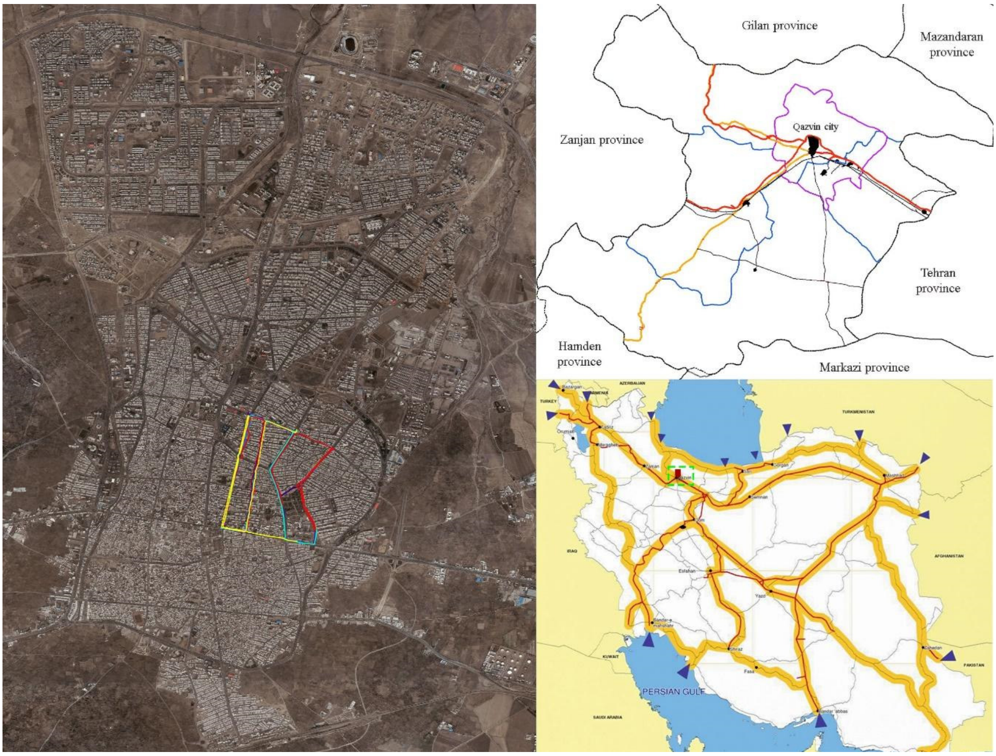

Figure 1. The research area and the cycling routes. Source: City of Qazvin (2013)

Ethical Considerations

The study was conducted in accordance with the Declaration of Helsinki. Ethical approval was obtained from the Institutional Review Board of Imam Khomeini International University, with the reference number 12018/1400/04/10, and all enrolled participants provided written informed consent. Participants were given verbal explanations of the study rationale, and they were informed that they could withdraw from the study at any time during the research.

Recruitment and Eligibility

The cyclists were selected using a convenience sampling approach. We included individuals of both sexes who were willing to participate in the study and they were 18 years of age or older. Potential participants were initially invited to attend a screening visit, during which the study phases and rationale were fully explained. If an individual refused to participate, a subsequent candidate was recruited using the same process until the required sample was provided. During the screening visit, all participating cyclists completed questionnaires that asked about their demographics, cycling-related data, and medical history. A qualified physician conducted a comprehensive medical examination of the participants to ensure the absence of any health problems that could potentially introduce confounding variables to the study outcome. Particular attention was paid to the musculoskeletal, blood, and cardiovascular health (Callaghan 2005, Nordengen et al. 2019, Mohammadi and Mohammadi 2023a, Sharifkazemi et al. 2023). In parallel, a clinical psychologist conducted interviews with the cyclists and administered two validated psychological questionnaires. Individuals with a documented history of significant physical or psychological disorders and those with current medical conditions were excluded from the study.

Protocols and Measurements

All of the bike routes were located in the central city and all the participants cycled in this area at the same time of the day. Each study participant underwent a total of 60-minute assessments. It has been proposed that the cyclists' angular movement during urban cycling is related to their subjective perception of risk (von Stülpnagel 2020). The outcome of our study was the participants' angular movement which was measured by the Garmin Virb XE camera.

A number of predictors were also assessed during the study. Participants were given identical bicycles, each equipped with two GoPro Hero 7 compact video cameras (Van Cauwenberg et al. 2018). The first camera was mounted on the handlebars of the bike to video record the obstacles in the forward direction. The second camera, facing rearwards, was used to document the passage of other vehicles. In addition, environmental factors, subjective variables, and various cycling parameters (e.g., cycling history) were quantified. Participants were instructed to verbally report any instances of discomfort or anxiety during their cycling sessions. The cameras were able to store the data collected by the sensors. In addition, the Sydney Coordinated Adaptive Traffic System was installed on all routes and used for data collection.

A validated Persian-translated Beck Anxiety Inventory (BAI) was used to assess the levels of anxiety (Kaviani and Mousavi 2008). The BAI has good reliability and validity with coefficients of 0.72 and 0.83, respectively. In addition, the internal consistency of the instrument was remarkably high as evidenced by an alpha (Cronbach's alpha) coefficient of 0.92 (Kaviani and Mousavi 2008). The questionnaire consists of a total of 21 multiple-choice items designed to collect information about anxiety symptoms experienced during the previous week. Each item is scored on a scale of 0 to 3, with higher scores indicating greater severity of anxiety symptoms. The cumulative score on the Beck Anxiety Inventory (BAI) ranges from 0 to 63. In addition, a validated Persian translation of the Kessler Psychological Distress Scale (K10) was used to assess the psychological distress (Ataei et al. 2015). One study estimated an average content validity ratio and content validity index of 0.88 and 0.95, respectively, for the K10 questionnaire (Ataei et al. 2015). The questionnaire showed Cronbach's alpha coefficient of 0.84. In addition, the intra-class correlation coefficient was 0.77, indicating good agreement between the responses. The K10 questionnaire includes ten questions about emotional states, with a total score ranging from 10 to 50. A higher score corresponds to an increased level of psychological distress.

Statistical Analyses

Results are presented as mean (SD) for continuous variables and as absolute numbers (%) for categorical data. The normality of variables was assessed using the Shapiro-Wilk test. A linear mixed model was constructed to examine the effects of participant characteristics and environmental factors on the angular movement. It is a form of regression analysis that can account for both fixed and random effects within the data set and it is particularly useful for analysing repeated measures data. Given the ability of mixed models to handle missing data, imputation was not required to handle missing values. We included participant and environmental variables as predictors of angular movement, while also accounting for random intercepts and slopes associated with age, BAI, and cycling history in the model. This framework allowed us to examine not only the global effects of fixed variables but also the variance in both intercepts and slopes across participants. The level of significance was set at two-tailed $\alpha = 0.05$. Data analysis and visualisation were performed using the R software version 4.0.2. for Windows. We used the afex library (Singmann et al. 20246) of R to fit our mixed model. It estimates mixed models using the lme4 library, it calculates p-values for all fixed effects, and it tests the results with ANOVA.

Sample

A cohort of 26 cyclists, 20 (76.9%) of whom were men, were enrolled as participants in this study. The total number of trials in the entire cohort was 14,423. A minimal proportion of data (2.8%) was missing. We did not impute the missing data. The cohort characteristics, including both demographic and anthropometric aspects as well as environmental attributes, are shown in Table 1. In general, the participants were young to middle-aged individuals. Predominantly, the cohort consisted of single males with a healthy body mass index, cycling for either professional (serious) or recreational purposes.

The BAI scores ranged from 1 to 28, corresponding to minimal to severe anxiety. Similarly, the K10 scores ranged from 11 to 37, indicating a psychological distress from mild to severe. Referring to the routes used for this study, in general, the cycling participants travelled mostly within the commercial area of the city. The routes were representative of the prevailing cycling conditions during normal, non-holiday daytime hours.

Table 1. *The sample characteristics (N = 26) and the environmental features*

Characteristic	***Description***
Sample (N = 26 participants)	
Age (year)	*33.5 (10.6)*
Sex (male)	*20.0 (76.9%)*
BMI (kg/m²)	*24.1 (2.9)*
Marital status (married)	*10.0 (38.5%)*
Family size	*3.6 (1.8)*
Cycling purpose (serious)	*11.0 (47.8%)*
Cycling history (year)	*10.7 (8.0)*
History of cycling accident	*11.0 (47.8%)*
K10	*21.2 (7.6)*
BAI	*12.0 (8.0)*
Angular movement (degree)	*158.9 (12.1)*
Routes and Environment (N = 14423 trials)	
Residential area	*2162 (15.0%)*
Commercial area	*9410 (65.2%)*
Mixed area	*3689 (25.6%)*
Park	*2763 (19.2%)*
One-directional route	*4644 (32.2%)*
Posted speed limits ≤50 km/h	*4078 (28.3%)*
Path width ≥12 m	*4102 (28.4%)*
Bikeway	*4755 (33.0%)*
Traffic volume	*2435.1 (431.9)*
Elevation (m)	*1321.2 (7.2)*

The figures indicate the mean (SD) for continuous variables and the absolute number or share (%) for categorical variables BMI (Body Mass Index); K10 (the Kessler Psychological Distress Scale); and BAI (Beck Anxiety Inventory)

Results

Univariate Analysis

The Shapiro tests for normality implied that angular movement, K10, and BAI data were normally distributed, W = 0.940, 0.934, and 0.933 with the P-values of 0.135, 0.133, and 0.127, respectively. The univariate analysis did not show a significant linear relationship between the angular movement and the K10 score ($r = -0.20$, $P = 0.387$), and the angular movement and the BAI score ($r = -0.25$, $P = 0.251$). Plausibly, there was a significant correlation between K10 and BAI scores ($r = 0.76$, $P < 0.01$). We excluded K10 scores from further analysis. Figure 2 shows the association of psychological assessment scores with the angular movement and the variation of the angular movement for the study participants. Multivariable models were needed to assess more accurately the relationship between the BAI score and the angular movement. This required a mixed-effects model as the preferred analytical framework to examine the precise nature of the linear relationship between psychological scores and the angular movement observed in our cohort of cyclists. The mixed model effectively captured the inherent randomness of the variation in the participants' psychological scores.

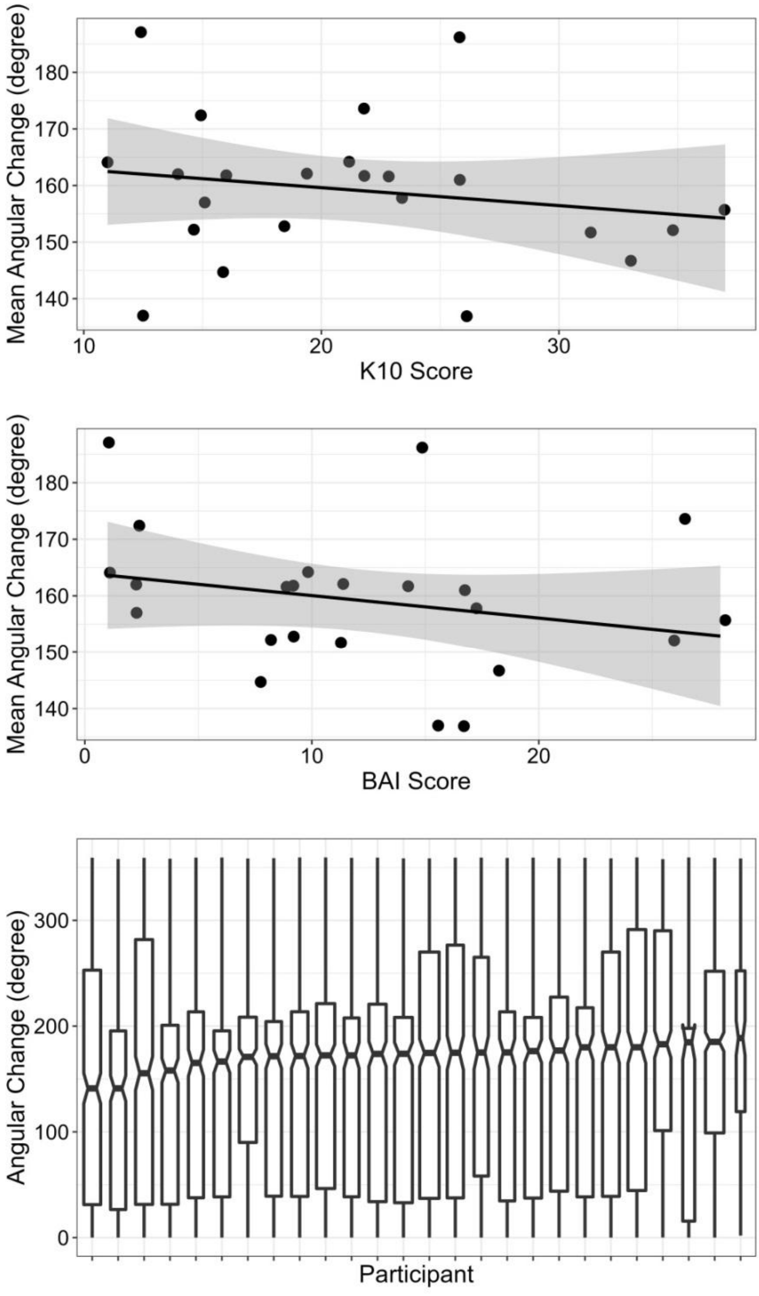

Figure 2. Scatter plots of K10 and BAI scores versus heart rate (in the upper row, the black lines represent linear regressions, and the shaded grey areas display the 95% confidence intervals around the regression line), and boxplots of heart rate variation within each participant (lower row)

Mixed Models

Participants' Characteristics and Environmental Features

The linear mixed model for predicting the angular movement did not show important associations of cyclists' characteristics with the angular movement (Table 2). Age, sex, and BAI scores were not significant predictors in changing the angle of movement. However, the environmental characteristics had statistically significant effects on the angular movement. Cycling through residential and commercial areas posted speed limits, and the existence of bikeways was negatively related to the angular movement. One-way streets or wide cycling paths were directly related to the angular movement. While traffic volume and route elevation were significantly associated with the angular movement, the degrees of association were not practically important. The model also included random intercepts and slopes for the cycling history, BAI, and age across the participants. The angular movement for the participants varied around the average intercept of 553 degrees by about 100 degrees. The SD for by-participant random slopes of cycling history, BAI, and age indicate that the participants' estimated slopes varied around the average slopes of -0.36, 0.14, and -0.58 by 55.25, 48.54, and 14.32, respectively. This implies that the random effects of cycling history, BAI, and age were controlled appropriately across participants. Meanwhile, the random effects of the participants' cycling history and BAI scores were higher than the effect of age. The model residual of 100.53 suggested a relatively accurate model.

Table 2. *The linear mixed model for predicting the angular movement using the cyclists' and environmental variables*

Characteristics	*Statistical Analysis Variables"*					*Likelihood Ratio Test Anova*	
	B	*SE*	*df*	*t*	*P*	*χ2(1)*	*P*
Intercept	*553.70*	*328.00*	*872.3*	*1.69*	*0.092*		
Residential area	*-23.39*	*3.58*	*1301.0*	*-6.53*	*<0.001**	*0.00*	*0.999*
Commercial area	*-70.92*	*3.03*	*1301.0*	*-23.42*	*<0.001**	*514.99*	*<0.001**
Park	*1.57*	*4.04*	*1301.0*	*0.39*	*0.698*	*11.62*	*<0.001**
One-directional route	*39.31*	*3.55*	*1301.0*	*11.06*	*<0.001**	*0.00*	*0.999*
Age	*-0.58*	*6.26*	*4008.0*	*-0.09*	*0.926*	*7.10*	*0.008**
Sex	*-26.12*	*91.52*	*376.2*	*-0.29*	*0.775*	*2.81*	*0.094*
BAI	*0.14*	*15.75*	*7203.0*	*0.01*	*0.993*	*20.75*	*<0.001**
Cycling history	*-0.36*	*16.90*	*4913.0*	*-0.02*	*0.983*	*18.41*	*<0.001**
Posted speed limits ≤50 km/h	*-26.04*	*2.79*	*1301.0*	*-9.34*	*<0.001**	*0.00*	*0.999*
Path width ≥12 m	*50.31*	*3.81*	*1301.0*	*13.22*	*<0.001**	*192.88*	*<0.001**
Bikeway	*-65.69*	*3.68*	*1301.0*	*-17.83*	*<0.001**	*326.64*	*<0.001**
Traffic volume	*0.07*	*0.003*	*1301.0*	*25.67*	*<0.001**	*504.98*	*<0.001**
Elevation	*-0.34*	*0.09*	*1301.0*	*-3.61*	*0.001**	*0.00*	*0.999*

**significant at p <0.05*

Discussion

The purpose of conducting this study was to assess the effects of various individual and environmental factors on the cyclists' angular movement, which served as an indicator of risk perception while cycling. Our study implied significant effects of environmental factors on the angular movement, however, it did not show a significant association of cyclists' personal characteristics with the angular movement. We recruited a representative sample of cyclists using identical bicycles on common urban terrain in a metropolitan area and performed multiple measurements on each participant. The results showed that environmental variables were significantly associated with changes in the cyclists' risk perception. We found that cycling through residential and commercial areas posted speed limits, and the existence of bikeways were negatively related, while one-way streets, or wide cycling paths were positively related to cycling risk perception. The effects of traffic volume and route elevation on risk perception were statistically significant but practically unimportant. Our results failed to show a statistically significant relationship between BAI scores and the angular movement.

Angular Movement

The human factor is one of the main causes of accidents. The relation between neuropsychological features and motor function has been reported in the scientific literature (Di Corrado et al. 2021, Mohammadi and Mohammadi 2023b). Visual perception of the environment plays an important role in bicycle accidents (Schepers et al. 2014). Misinterpretation or misreading of the cycling path can lead to the perception of an unsafe environment for cyclists, with a lack of visual information or inconsistent design exacerbating potential hazards (Sener et al. 2009). An increased visual workload that requires increased concentration may cause a cyclist to perceive the path as uncomfortable, potentially leading to changes in their travel choices (Schepers et al. 2014). Thus, it is important to examine the specific elements that attract the cyclists' attention to identify the factors that truly influence their behaviour.

Exploring the connection between gaze and locomotion is facilitated by measuring head and body movement (Patla and Vickers 2003). The study of gaze angle enhances our understanding of human factors and cyclist psychology, particularly when gaze behaviour during cycling remains poorly documented (Vansteenkiste et al. 2013, Schepers et al. 2014). The effects of speed and path characteristics on bicycle steering have been investigated in a few studies (Vansteenkiste et al. 2013, Vansteenkiste et al. 2014a, Vansteenkiste et al. 2014b). Meanwhile, the results of controlled indoor or simulation studies should be evaluated in the real environment. We included non-professional cyclists and assessed the changes in the cognitive activity using angular movement repeated measures in the short term. The angle data were normally distributed, and we applied various adjustments to ensure accurate statistical results.

Cyclists' Characteristics

Intuition and affect are interrelated concepts that influence both risk perception and decision-making (Böhm and Brun 2008). Maintaining a stable bike ride requires muscular strength, balance, and flexibility (Shaffer et al. 2020). Various stress scenarios, encompassing physiological, psychosocial, cognitive load, or anticipatory stress, trigger physiological responses in the body (Mohammadi and Mohammadi 2023b). We investigated the relationship between the cyclists' characteristics and the angular movement. Those characteristics included sex, age, cycling history, and BAI score. However, none of the participants' characteristics significantly affected the angular movement, suggesting that this metric may be more closely related to movement strategy and environmental factors than to internal traits. This finding is consistent with the outcomes of previous research examining how location-specific factors relate to gaze behaviour (Vansteenkiste et al. 2013, Vansteenkiste et al. 2014a, Vansteenkiste et al. 2014b, Schmidt and von Stülpnagel 2018).

Environmental Features

We assessed the effects of environmental factors on the cyclists' risk perception. The results suggested that the change in the movement angle is related to infrastructure and environmental conditions during urban cycling. Among the examined environmental features, cycling through commercial or residential areas, using one-way streets, having posted speed limits, navigating wide paths of 12 metres or more, having dedicated bike lanes, facing high traffic volumes, and traversing varying elevations, showed significant effects on the cyclists' risk perception. Some of these findings are consistent with previously reported observations in the scientific literature, confirming the consistency of our findings with previous research in this area.

Studies have been conducted to examine the relationship between the cycling infrastructure and the cyclists' perception of risk. Without the physical protection provided by cars, the cyclists face potential risks on the road with motorised vehicles, making them vulnerable to accidents, exposure to air pollution, and increased vulnerability due to their lower mass and slower speed (Reynolds et al. 2009, De Hartog et al. 2010). Infrastructure improvement offers significant advantages in injury prevention because of its population-wide impact, passive nature, and the ability to achieve substantial benefits through a single intervention (Reynolds et al. 2009). Infrastructure plays a central role in preventing injury and reducing crash risk, with a lower risk associated with separated tracks and the presence of bicycle facilities, while major roads were found to pose a higher hazard compared to minor roads (Reynolds et al. 2009). In two-lane roundabouts, the number of crashes and injuries was more than twice the expected number, while in single-lane roundabouts there was no significant difference between the expected and the observed statistics (Brude 2000). Wider medians were found to increase the crash risk for cyclists, and the use of a logistic model to assess the bicycle route safety showed a significant association between wider roads and more severe injuries (Brude 2000, McGraw et al. 2000).

Implications

Briefly, this study provided insight into the factors that influence the cyclists' risk perception in urban areas. The results suggested that environmental factors such as cycling infrastructure and traffic volume have a significant impact on the cyclists' risk perception. The study showed that cycling through residential and commercial areas, one-way routes, routes with speed limits, wide routes, and existing bike lanes were associated with a change in the cyclists' angular movement. The study also implied that cyclist characteristics such as sex, age, cycling history, psychological distress score, and presence of parks were not significant predictors of angular movement. These findings highlight the critical role of cycling infrastructure in shaping the cyclists' risk perception and they provide important implications for urban planners and policymakers. Change in angular movement is an important aspect of cycling and its better understanding can help reduce the incidence of injury.

By investing in the cycling infrastructure, cities can create safer and more attractive environments for cyclists, which can help to promote cycling as a sustainable mode of transportation (Castells-Graells et al. 2020, Cafiso et al. 2021). Our findings could be used as a reference for designing future research on the topic. For instance, a study that analyses the relationship between risk perception and behavioural factors of rural cyclists. This study could also be used to raise awareness among cyclists and policymakers about the importance of cycling infrastructure in promoting safer cycling in urban areas.

Limitations

To the best of our knowledge, there are no previous reports in the literature that have simultaneously assessed the effects of environmental, health, psychological, and demographic variables on the cyclists' risk perception. However, some limitations may have affected the generalizability of our conclusions. Although our sample was representative of the urban cyclist population, its size limited the generalizability of our conclusions. Due to the small sample size, some confounders may not have been adequately controlled for. Moreover, our sample was drawn from urban areas, so caution should be taken when extrapolating our results to cycling in rural areas. Meanwhile, we collected a significant amount of repeated measures data, which reduced the inherent variance, and it increased the power of statistical tests.

Conclusions

We used the angular movement as a measure of cycling risk perception among urban cyclists. Our study implied that environmental factors significantly influence risk perception. Cyclists' age, sex, BAI score, and cycling history did not significantly affect the angular movement. However, there was a statistically significant relationship between the angular movement and the environmental features. The significant environmental factors included cycling through commercial or residential areas, using one-way streets, having posted speed limits, navigating wide paths ≥12 metres, existing dedicated bike lanes, facing high traffic volumes, and varying elevations. One-way streets with high-speed limits and heavy traffic adversely affect the cyclists' perception of risk. In urban design, however, the provision of dedicated bicycle lanes and passageways through residential and commercial areas facilitates the use of bicycles. These findings show the importance of cycling infrastructure in promoting urban cycling as a safe commuting choice. By addressing these elements, urban planners and policymakers can promote urban cycling and support healthier and more sustainable urban environments.

Increasing the perceived safety of cyclists is effective in promoting the use of the bicycle as a mode of transportation. Appropriate urban design and bicycle facilities affect the cyclists' perceptions of safety in motion. Cyclists also respond dynamically to environmental factors. Our study showed that changes in the cyclists' heading angle are primarily related to lane characteristics. Meanwhile, more studies are needed to establish the specific findings of this study. A larger sample size, the inclusion of weather conditions and seasonal variations, and the recruitment of participants with physical disabilities would be helpful in designing further research. Given the benefits of cycling in urban areas, it is imperative to raise the awareness of public authorities of the critical role of cycling infrastructure in the promotion of cycling.

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