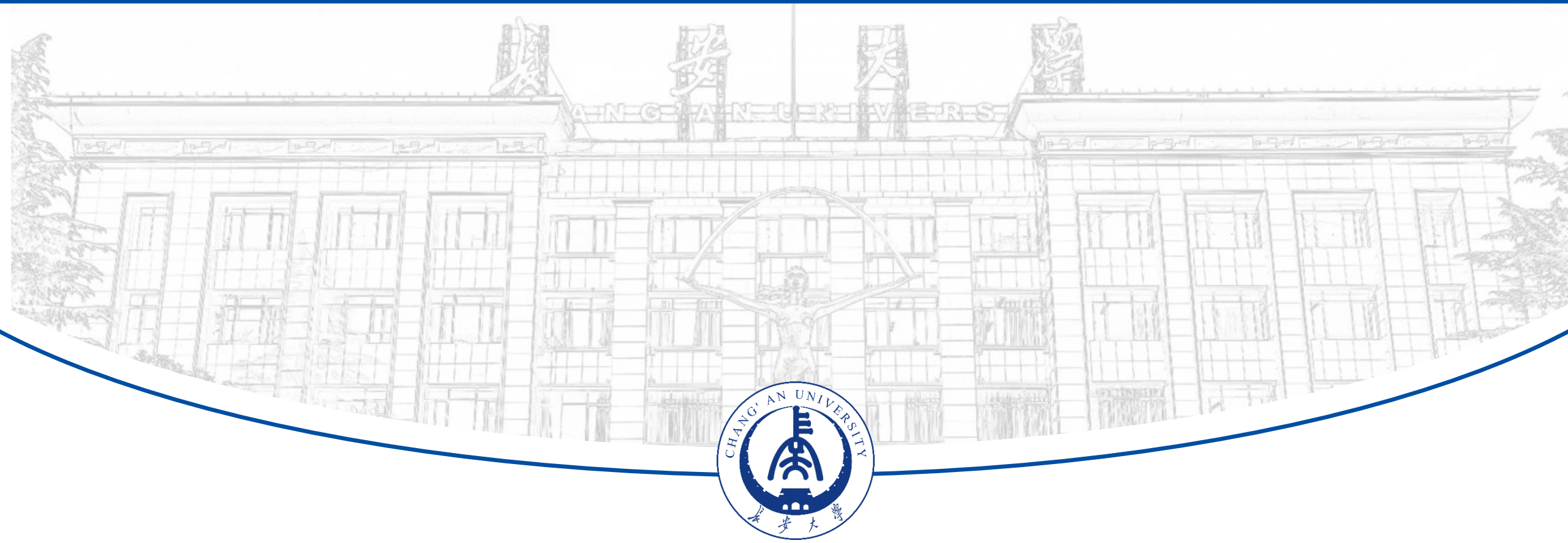

Psychological stress of cycling: trip segment, attitudes and road environment

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Introduction

- Cycling, as a green and healthy mode of transportation, has a positive impact on people’s physical and mental health.
- Increasing cycling usage has become a key objective for many cities aiming to optimize transportation structures, improve public health, and enhance the ecological environment.
- The Measurement of cycling stress helps objectively identify key issues affecting the cycling experience, such as insufficient road safety, recurrent traffic conflicts, and insufficient cycling infrastructure.

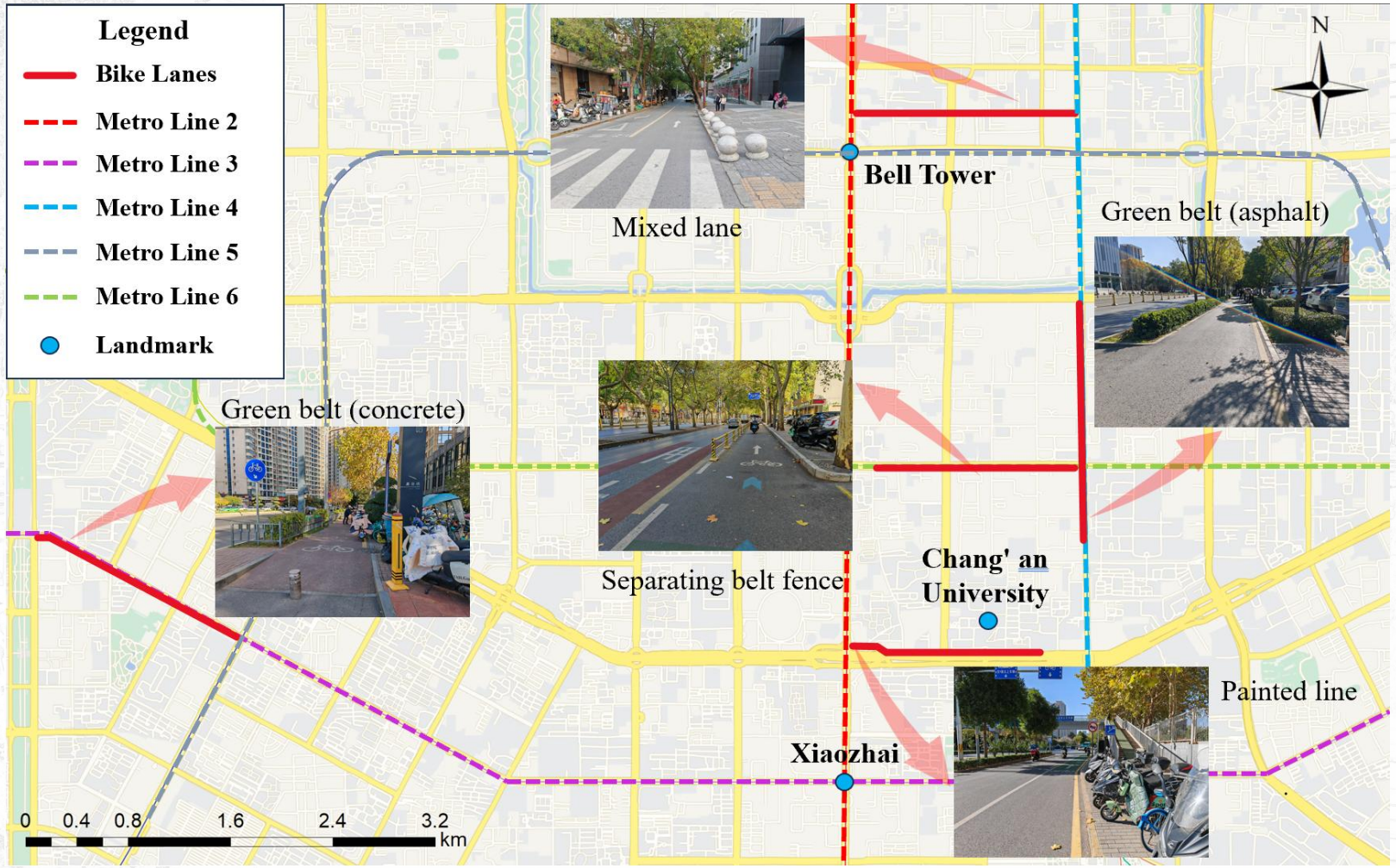
Introduction

- However, infrastructure in reality induces changes in cycling behavior, and such behavioral changes ultimately stem from differences in psychological perception.
- Most studies overlook the psycho-physiological dimensions of bicycle use.
- Understanding how bicycles influences users in road segment level is essential for addressing the current planning and safety challenges.

Introduction

- We employed a time-based slicing approach to capture the dynamic changes of cycling behavior in road-segment level.
- Most studies overlook the psycho-physiological dimensions of bicycle use.
- Understanding the stress-induced effects of personal characteristics and road environments on conservative and aggress cyclists carries significant implications for bicycle infrastructure design and network planning.
- This study aims to examine the impact of changes in bicycle lane infrastructure and environment on cyclists' physiological stress and explored the differences in cyclists' psychological states.

Study area



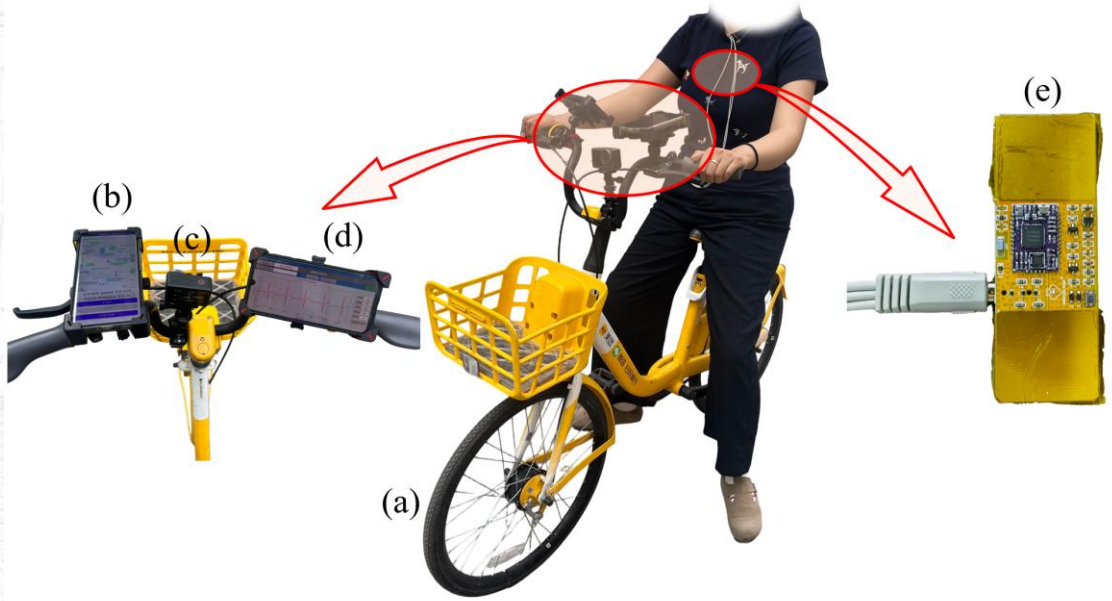
Study area and bike lanes

Lanes	Characteristics
(a) Painted lane	Separated from the motorway by delineated lines
(b) Green belt (asphalt)	Separated from the motorway by a green belt (asphalt pavement)
(c) Separating belt fence	Separated from the motorway by a road fence
(d) Green belt (concrete)	Separated from the motorway by a green belt (coarse-grained concrete pavement)
(e) Mixed lane	Mixed traffic (no bike lanes)

Data and methodology

- The data collected from the experiment

Data	Sources
HRV	ECG acquisition device
Street view images (SVIs)	DJI Action3
Width of the bike lane	Field measurement
RMSVA (root mean square of vertical acceleration)	APP (self-developed)
Questionnaire	APP (self-developed)



Bike and devices. (a) shared bike; (b) smartphone loaded with app "TrackSense"; (c) DJI Action3; (d) smartphone for ECG data reception; (e) ECG monitoring equipment.

Data and methodology

Characteristics of the participants

Variables	Code and Unit	Mean	Std. Dev.	Min.	Max.
N=31					
Gender	0 = Male; 1 = Female	0.48	0.50	0	1
Driver license	0 = No; 1 = Yes	0.87	0.33	0	1
Monthly living expenses (RMB)	0 = 0.6-1k; 1 = 1-1.5k; 2 = 1.5-2k; 3 = 2k+	1.61	0.87	0	3

HRV processing

Heart rate variability (HRV) reflects the activity of the autonomic nervous system and analyzes the tension and balance of cardiac sympathetic and vagal nerve quantitatively. We use an electrocardiogram (ECG) monitor to obtain HRV indicators. The ECG data was collected using a single-chip microcomputer (sampling at 500 Hz).

This device contains a coin cell battery and is capable of transmitting real-time collected data over a Bluetooth connection with a smartphone, making it suitable for use in our experimental scenarios. Participants were required to attach three electrode pads to the upper body to monitor changes in data. The smartphone model that received the data is Huawei Nova5, which is fixed to the right handlebar of the bicycle through a phone holder.

Data and methodology

- We used Pan Tompkins QRS detection algorithm to process the collected ECG data in order to obtain the R-R interval.
- We chose the time-domian metric root mean square of successive differences (RMSSD) as the dependent variable of this study. The method calculating the RMSSD is Eq. (1).

$$RMSSD = \sqrt{\left(\sum_{i=1}^{N-1}((R-R)_{i+1} - (R-R)_i)^2\right)/(N-1)} \qquad (1)$$

where

$RMSSD$ = root mean square of successive differences

N = number of R-R interval terms

Data and methodology

Street view images

The video was collected using the DJI Action 3. The DJI Action 3 was secured to the center of the handlebars by a bracket that recorded video during each experiment and saved it to a memory card. The video data was intercepted at a frequency of once a second to get the SVIs per second and semantic segmentation was performed using DeepLabV3+ model (Liu et al., 2024), as shown in Fig. 4.

The SVI metrics we obtained and used are *sky*, *car flow*, *sidewalk*, *building*, *person*, *width*, *curb parking*, *vegetation*, and *vehicle entrance/exit*.

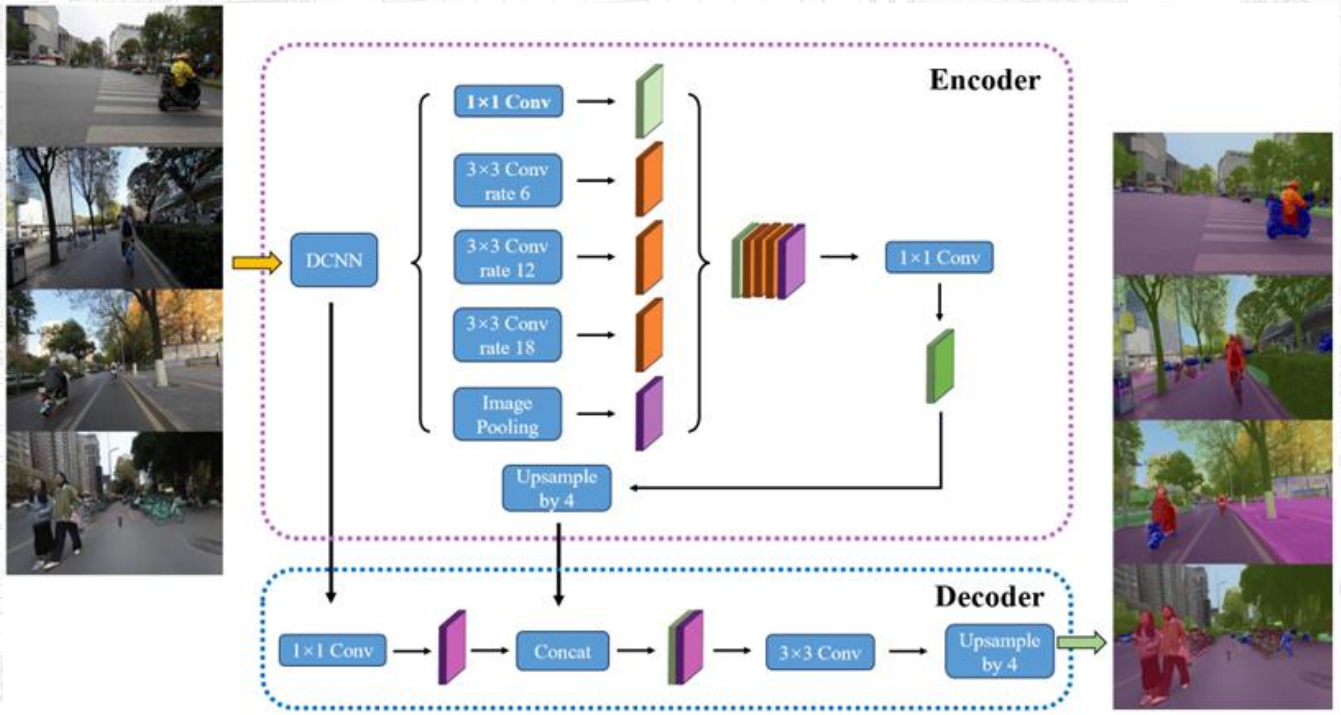


Fig. 4 Semantic segmentation of street view images

Data and methodology

Self-developed mobile application

We use the RMSVA (Root Mean Square of Vertical Acceleration) to represent the bumpiness of the road surface while riding (Bíl et al., 2015; Bisconsini et al., 2018).
The linear acceleration of the Z-axis was captured by the acceleration sensor of the phone, and the RMSVA was calculated once a second with this acceleration data. The method of calculating the RMSVA is Eq. (2).

$$RMSVA = \sqrt{\sum_{i=1}^{N} a_{zi}^2 \Big/ N} \qquad (2)$$

where

$RMSVA$ = Root Mean Square of Vertical Acceleration (m/s^2)

a_{zi} = Z-axis linear acceleration value at the i th time

N = number of samples

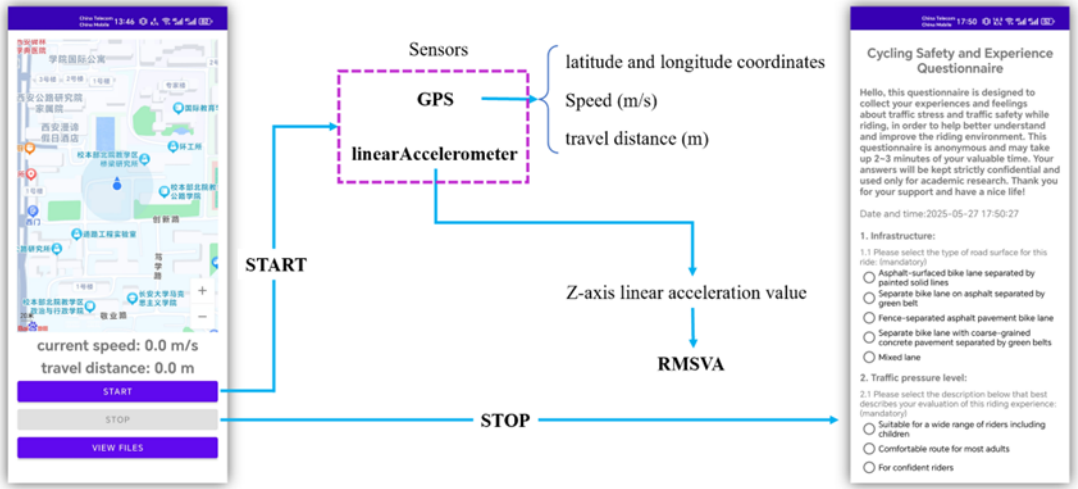


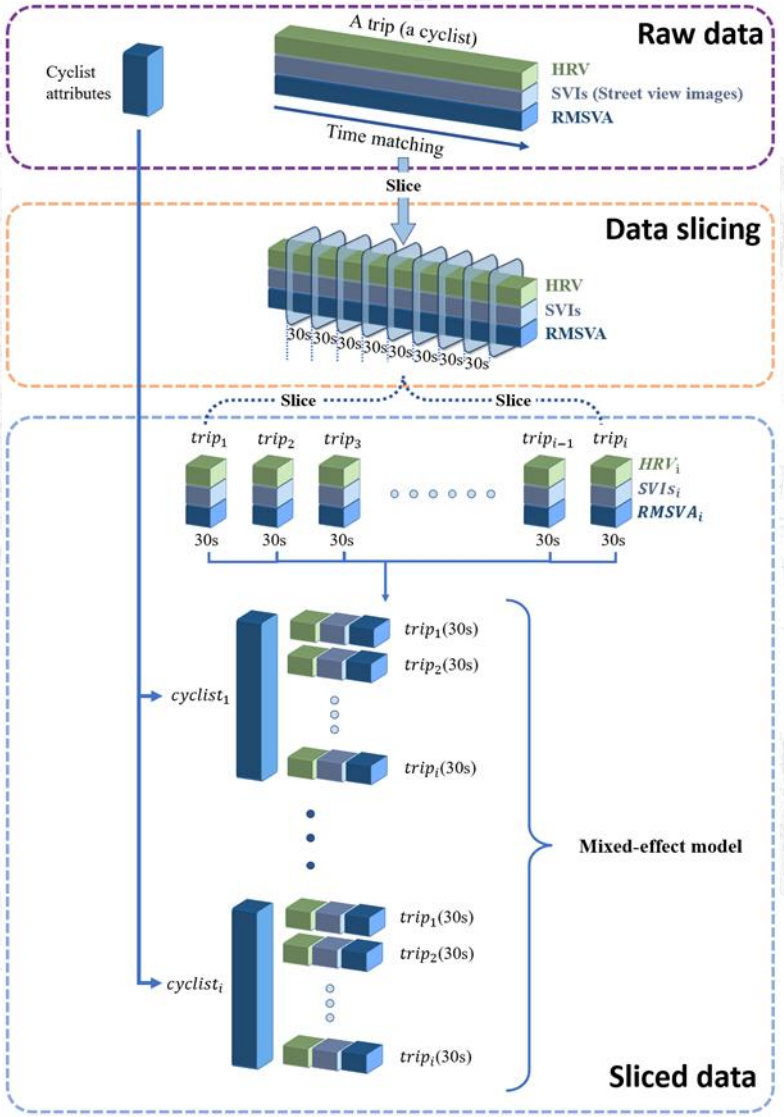
Fig. 5. Software operation logic and interface

Data and methodology

In order to study the participants' perception of their surroundings while riding in more detail, we sliced the data for each individual in 30s increments. Fig. 6 shows this processing. The R-R intervals were calculated every 30s to obtain RMSSD.

We used K-Means to categorize all the participants into 2 classes based on the speed and speed standard deviation collected by TrackSense, one class is aggressive cyclists, there are 17 people in total, and this group of people ride faster. The other category was the conservative cyclists with 14 people who rode at a slower speed.

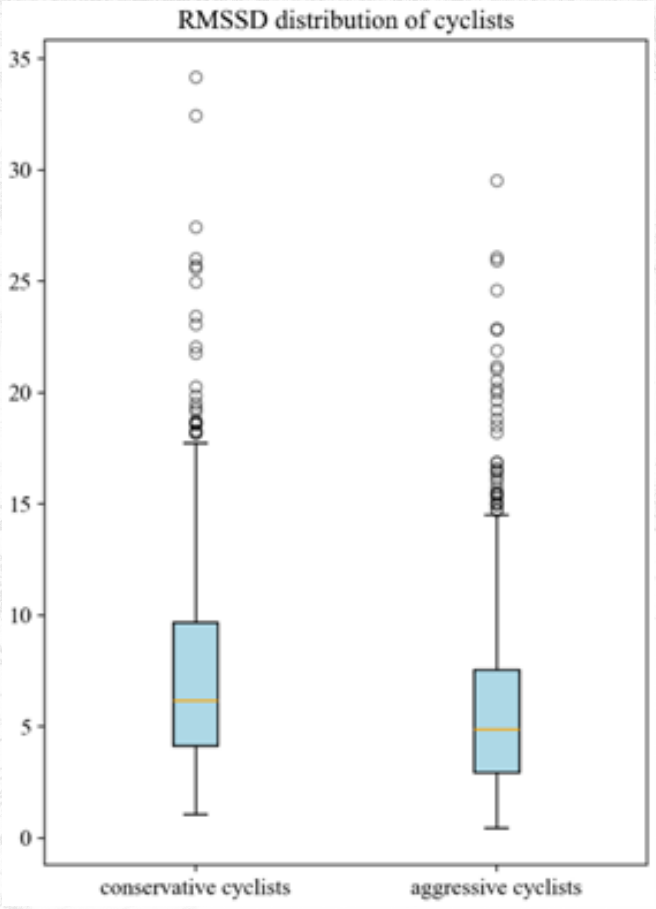
Two-level mixed-effect model was used to capture the heterogeneity of cyclists.

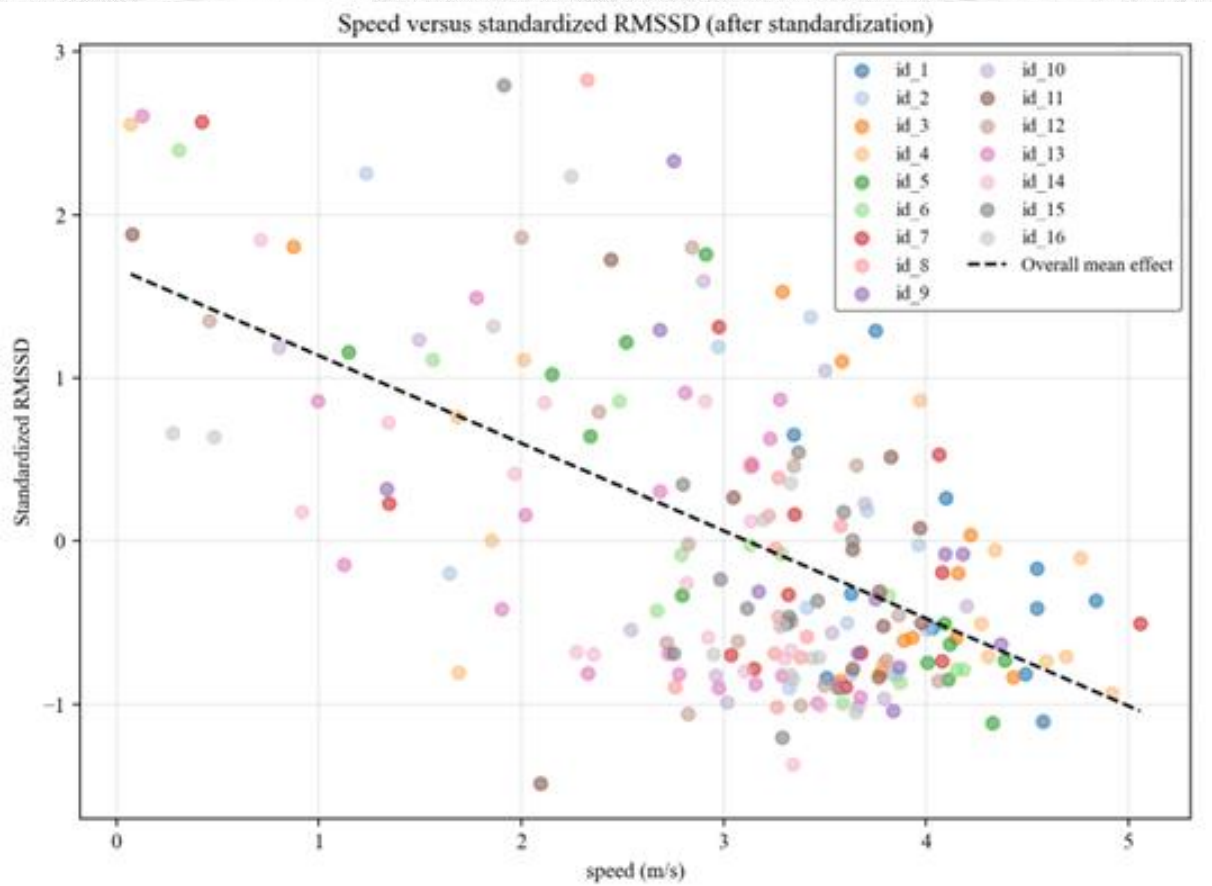


Results

Distribution of RMSSD

Fig. 7(a) shows the distribution of RMSSD for the two types of cyclists, with aggressive cyclists typically having smaller RMSSD values compared to conservative cyclists. The faster the cycling speed, the lower the RMSSD value, as shown in Fig. 7(b), where we randomly selected a portion of the data from the full cycling data to demonstrate this relationship.





Results

Distribution of RMSSD

On the fence-separated bike lane, both types of cyclists had a greater distribution of RMSSD at lower values, which was correlated with higher physiological stress. On the green belt separated bike lane (coarse-grained concrete), the RMSSD of both types of cyclists was more distributed at high values, which was correlated with lower physiological stress.

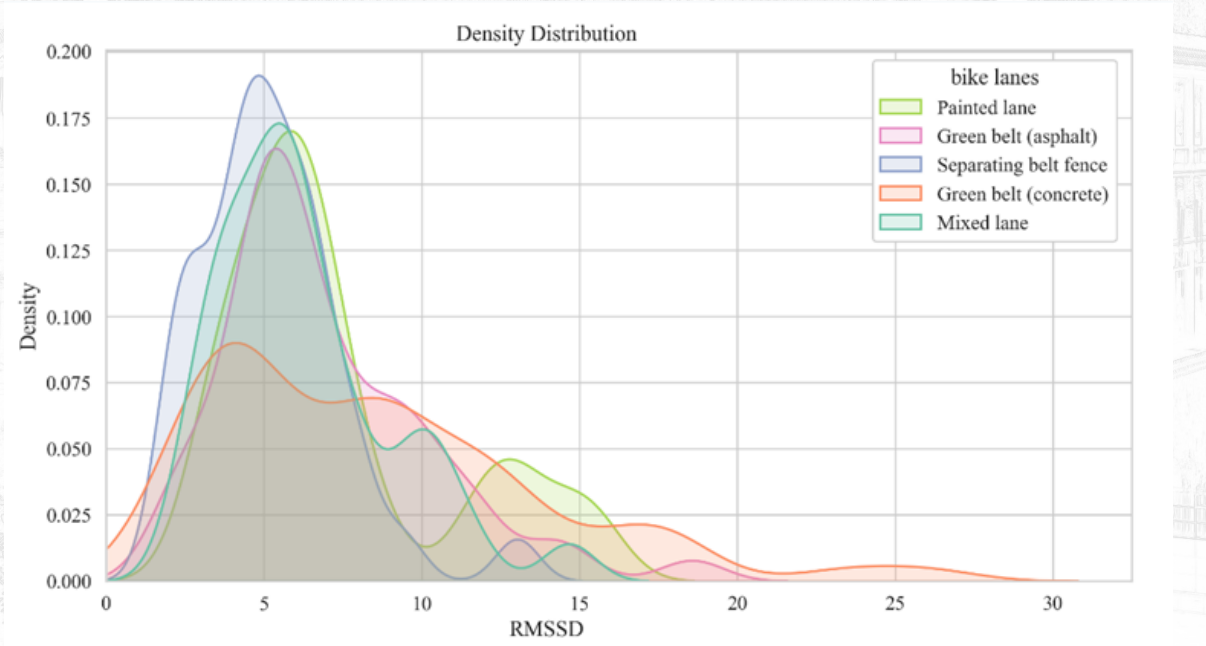


Fig. 8. Distribution of RMSSD on the five bike lanes for conservative fixed cyclists

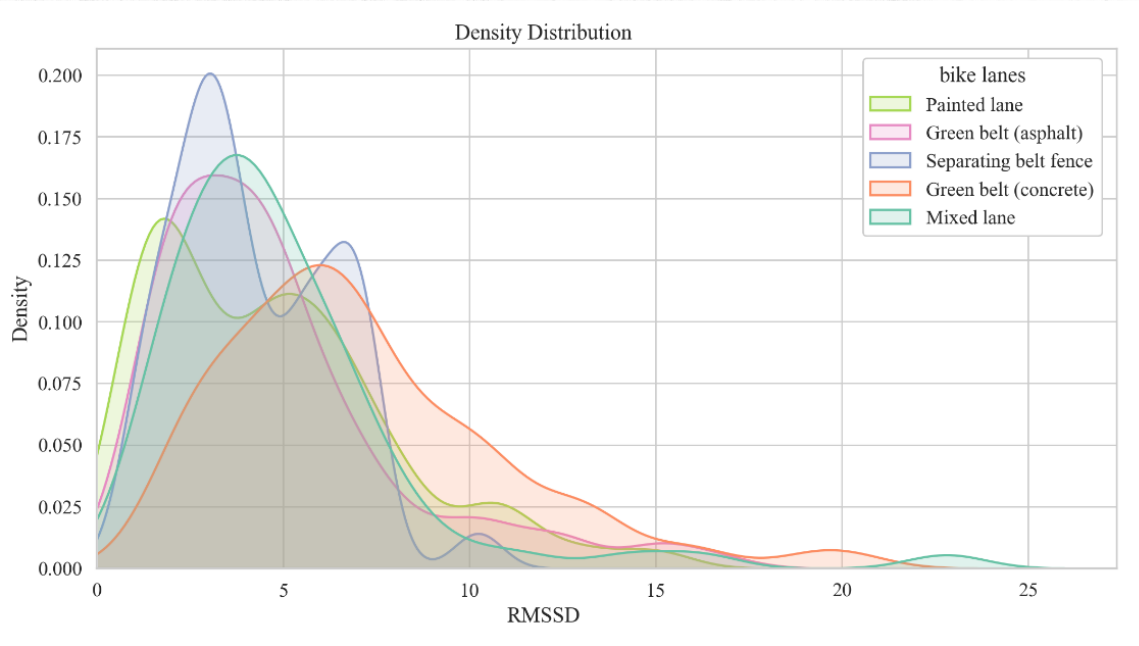


Fig. 9. Distribution of RMSSD on the five bike lanes for aggressive fixed cyclists.

Results

Note. "*" Significant at 0.1; "**" Significant at 0.05; "***" Significant at 0.01. Positive coefficients indicate higher RMSSD, i.e., lower physiological stress; negative coefficients indicate lower RMSSD, i.e., higher physiological stress.

The greenbelt segregated bike lanes (asphalt) also showed a negative correlation on physiological stress for aggressive cyclists, mixed lanes showed a positive correlation, and the greenbelt segregated bike lanes (concrete) did not show a significant correlation.

	Model 1 (Conservative cyclists)		Model 2 (Aggressive cyclists)	
	Coef.	Std.err.	Coef.	Std.err.
Intercept	**1.653*** **	**0.254**	**1.523*** **	**0.193**
Level 1 (cycling)				
(a) Painted lane	0.171	0.125	0.161	0.127
(e) Mixed lane	0.192	0.227	**-0.511***	**0.251**
(b) Green belt (asphalt)	**0.443*** **	**0.147**	**0.438*** **	**0.167**
(d) Green belt (concrete)	**0.404*** **	**0.151**	-0.076	0.177
Sky	0.044	0.037	-0.060	0.052
Car flow	-0.012	0.021	0.018	0.025
Sidewalk	**-0.099*** **	**0.032**	-0.036	0.044
Building	**0.066** **	**0.033**	**0.105***	**0.054**
Person	0.030	0.022	-0.023	0.026
Width	0.027	0.074	**-0.129***	**0.069**
Curb parking	-0.029	0.023	0.028	0.027
Vegetation	0.064	0.047	0.080	0.069
Vehicle entrance/exit	-0.029	0.021	-0.018	0.024
RMSVA	**-0.121*** **	**0.024**	**-0.056** **	**0.029**
Level 2 (individual)				
Gender	-0.215	0.307	-0.198	0.226
Ride fast	**-0.391*** **	**0.068**	-0.005	0.033
Like the bike lanes separated from vehicles	-0.020	0.037	0.024	0.047
Safety-attention to cars	**-0.118** **	**0.048**	0.046	0.062
Safety-attention to others	**-0.106***	**0.060**	**-0.168*** **	**0.042**
Safety-attention of the car to me	-0.022	0.034	**-0.059** **	**0.044**
Comfort-attention of pavement	**-0.108***	**0.058**	0.036	0.054
Goodness of Fit				
Conditional R^2	0.73		0.51	
Marginal R^2	0.37		0.14	
AIC	881.13		797.12	
BIC	986.85		898.70	
Log-Likelihood	-416.56		-372.63	

Policy implications

- To minimize pedestrian-cyclist conflicts, the direct adjacency of sidewalks and bicycle lanes should be avoided.
- Design wider and more physically separated bike lanes in high-demand commuter areas to accommodate aggressive cyclists and ensure safety.
- In recreational zones like parks and near schools, prioritize separation from vehicles and pedestrians to enhance comfort and safety for conservative riders

Conclusions

- The research involved multiple data sources, including wearable devices, street view images, mobile apps, and questionnaires.
- A mixed-effects model was used, with HRV as the dependent variable representing the physiological stress of cyclists, to study the relationship between HRV and road environments and facilities.
- The innovation of this study lies in slicing each cyclist's riding process to more accurately capture the impact of road environment changes on cyclists.
- Our results show that the impact of road environment and facilities on the two types of cyclists is significantly different.
- The types of bike lanes have different effects on the physiological stress of the two types of cyclists.
- Aggressive cyclists will increase their cycling speed due to the widening of the bike lanes, thereby showing higher physiological stress, while no obvious effect was observed on conservative cyclists.
- Conservative cyclists are more inclined to actively perceive cars around them for safety, while aggressive cyclists prefer cars to notice their presence. These findings exemplify the differences between the riding styles of the two types of cyclists.

Thank you!

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