公益財団法人 国際交通安全学会
International Association of Traffic and Safety Sciences

April 11, 2025
Research Findings Presentation

2412B

「International Comparative Study on the Acceptance and Environmental Improvements for Enhancing the Safety of Small Electric Mobility」

PL： Koji Suzuki
(Nagoya Institute of Technology)

1. Project Background and Objectives

- **The deployment of diverse small electric mobility devices, including electric kick scooters and seated ultra-compact vehicles, is anticipated to foster safe and accessible transportation. Building upon prior research (Projects 2008A, 2108B, and 2208C), which examined challenges related to electric kick scooters on sidewalks and roadways from user, regulatory, and municipal perspectives.**

- **This project investigates environmental development strategies to promote social acceptance and enhance safety for 1-2 passenger small electric mobility vehicles.**

    - <u>Through international comparative analysis and field studies, we seek to identify issues pertaining to road infrastructure and traffic management considering small electric mobility and to develop policy recommendations for coexistence with existing transport modes.</u>

    - <u>Furthermore, we aim to produce educational materials to facilitate the safe operation of small electric mobility, particularly electric kick scooters (specified small).</u>

2. Project Team and Research Framework

PL

- Koji Suzuki (Nagoya Institute of Technology)

Members

- Miho Iryo (Nagoya University), Kazuhisa Ogawa (Tohoku Institute of Technology), Naoya Kanda (Tohoku University of Public Welfare), Motoki Shino (Tokyo University of Science), Takeru Shibayama (TU Wien), Taro Sekine (Nihon University), Kenji Doi (Osaka University)

Special Researchers

- Hiroto Inoi (University of Toyama), Kazufumi Suzuki (Shizuoka Institute of Science and Technology), Tatsuto Suzuki (University College London), Masamune Takada (Komazawa University), Hideki Tatsumatsu (Oriental Consultants Co., Ltd.), Takahiro Tsuruga (IATSS Advisor), Yoshimi Furukawa (IATSS Advisor), Keisuke Yoshioka (Nihon University), Wael Alhajyaseen (Qatar University), Nick Tyler (University College London)

Collaborative Researchers

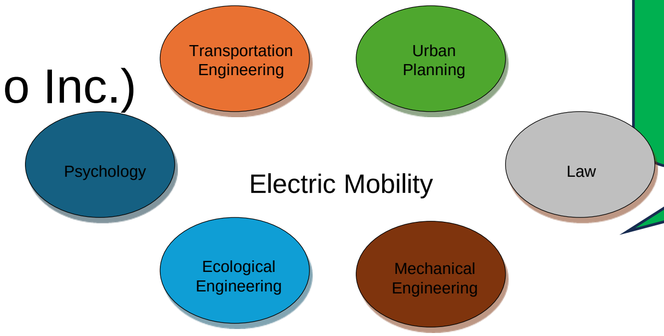
- Yotaro Mori, Keisuke Kishikawa, Erika Hashimoto (Streemo Inc.)

Research Collaborators

- Hiroki Ito (Chodai Co., Ltd.), Weiyi Li (Nagoya University)

Observers

- Ryoichi Nishiguchi, Sakura Ito (Traffic Planning Division, National Police Agency)

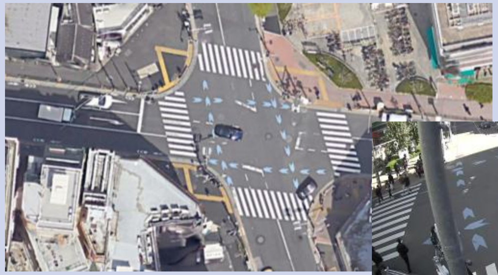


User Psychology/Safety Education/Rules (WG1)
Behavioral Analysis (WG2)
International Research (WG3)

As of April 2024

3. Research Introduction WG2「

- Aim to clarify challenges arising from the interacti and automobiles.
  - Conducted through public road surveys and contro

	① Public Road Driving Experiment/Observation Survey	② Public Ro	
Location	Major roads in Nagoya City	Signalize	
Date	May 29, 2024	November 18 and 20, 2023	October 6 to November 10, 2024 (5 days)
Content	・10 participants navigate selected routes in Nagoya City. ・Conflict analysis via video observation and safety/comfort assessment through post-ride surveys are performed. ・Differences based on traffic conditions and bicycle lane availability are evaluated.  Municipal roads  National highways	・Analysis of electric kick scooter behavior at intersections, focusing on positional data and conflict occurrences. ・Comparisons between electric kick scooter and bicycle behavior within intersections are conducted.  Target Intersection (Shinjuku 1-chome intersection  Video Recording	・Participants: 20 subjects (12 males, 9 females). Controlled experiments involving overtaking, being overtaken, and passing scenarios. ・Variables include separation distance, speed, and vehicle type (2-wheeled or 3-wheeled electric kick scooter, bicycle, pedestrian). ・Avoidance behaviors and subjective user experiences are assessed through video analysis and questionnaires. 

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3. Research Introduction WG2「Behavioral Analysis」
Summary of Survey Results (Part 1/2)

Consideration Item			Findings	Implications
Roadway Section	Straight Road Section	Influence of Pavement and Road Markings [1]	• Potential impact of pavement condition on comfort [1]	• Need for **pavement maintenance**
			• Arrows and text generally pose no issues, but avoidance of the right side of designated bicycle lanes is observed [1]	• **Avoidance of continuous longitudinal road markings** is recommended
		Interaction with Automobiles [2]	• Proximity to automobiles negatively affects perceived safety [2]	• Provision of **sufficient separation from automobiles**, **public awareness campaigns for drivers regarding safe overtaking distances** of electric scooters
			• Presence of side ditches may influence distance from curb for electric scooters [2]	• Need for **urban side ditches**
			• Avoidance maneuvers around parked vehicles negatively affect perceived safety [2]	• **Strategies for on-street parking management** within traffic lanes • Public awareness campaigns on **safe overtaking maneuvers around parked vehicles**
		Interaction with Bicycles [3, 4]	• Differences in riding characteristics between bicycles and electric scooters induce following and overtaking [3]	• **Public awareness campaigns on safe overtaking maneuvers** (targeting bicycles and electric scooters)
			• Electric scooter separation distance tends to be slightly greater than the bicycle separation distance • In cases where electric scooters are overtaken by bicycles, perceived discomfort is noted at a 1.0m center-to-center separation (approximately 0.5m between handlebars) [4]	• Potential need for **wider bicycle lanes** • Education to discourage reckless overtaking (emphasizing speed control and consideration for others)
	Intersection	Signal Clearance[5]	• Over 40% of electric scooters overshot the stop line at some intersections	• Need for **clear stop line markings**
			• Potential for congestion due to limited acceleration [5]	• Need for **light vehicle signals** or **extended signal clearance times**

3. Research Introduction WG2「Behavioral Analysis」

Summary of Survey Results (Part 2/2)

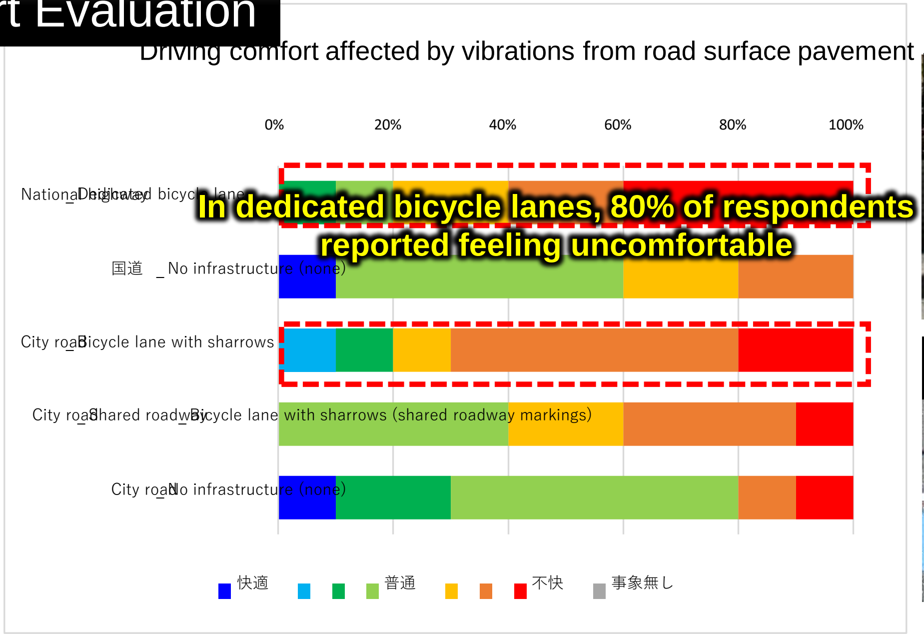
Consideration Item			Findings	Implications
Roadway	Intersection	Interaction with Automobiles [6, 7]	• Electric scooters tend to use roadways more than bicycles, often waiting at corner areas during two-stage right turns [6]	• Ensure **sufficient space** for two-stage right turns at **corner areas**
			• Roadway travel increases the potential for conflicts between straight-moving electric scooters and left-turning vehicles [7]	• **Issue warnings** regarding left-turn conflicts
		Interaction with Bicycles [8]	• Following signal starts, electric scooters and bicycles, accelerating from different starting positions, experience parallel running and overtaking due to differing acceleration characteristics. This proximity is particularly acute at outflow corners with narrowed lanes [8]	• Standardize **starting positions** for electric scooters and bicycles
Sidewalk／Shared space		Coexistence with Pedestrians [9~11]	• Overtaking pedestrians at 6 km/h on electric scooters can lead to prolonged parallel travel and perceived anxiety due to the extended passing time [9] • Regarding pedestrians being overtaken by electric scooters, there is no significant difference in perceived anxiety between 6-10 km/h; however, 20 km/h is poorly rated [10] • For electric scooter passing pedestrians, a 1.2-1.3 m center-to-center clearance (0.7-0.8 m between handlebars and shoulders) is acceptable up to 10 km/h [11]	・Overtaking close to others and the 6 km/h speed limit for designated small electric scooters may cause user anxiety ・Speeds up to 10 km/h generally do not elicit significant anxiety when being overtaken ・Users may tolerate slightly higher speeds during passing if adequate clearance is maintained
Proper use		Road Infrastructure and Regulations [12]	• Road structures exist that may induce legal violations [12]	・**Road space design should consider differences in traffic rules between bicycles** and specified small motorized bicycles
			• Accidents potentially arise from electric scooter use after alcohol consumption	・**Legal regulations**, such as **time-of-use restrictions**, may be necessary
		Legal Violation[12]	• The rate of traffic rule violations is higher for electric scooters compared to bicycles Implications [12]	・Promote **adherence to traffic rules**

3. WG2「Behavioral Analysis」（Roadway/Straight Section①)

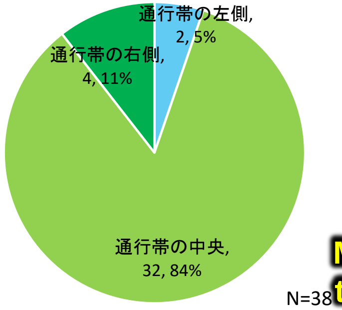
Impact of Pavement/Markings on Comfort and Position

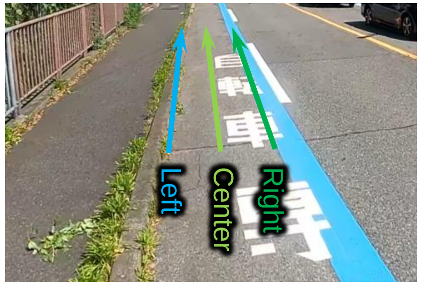
- Road vibrations reduce comfort (80% report discomfort in dedicated bicycle lanes)
- Users frequently travel in the lane center or over arrow markings, avoiding the right-side lane line

Comfort Evaluation

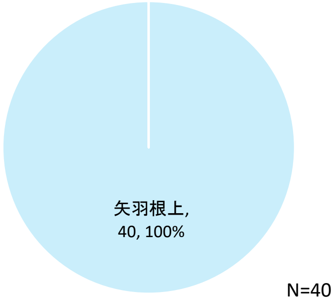


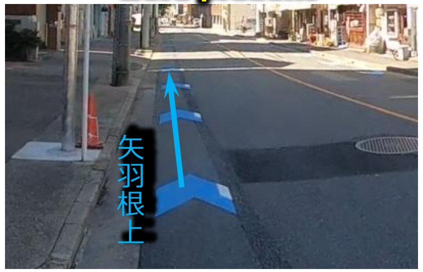
Roadway Travel Position





Many felt discomfort in the center of the lane or where chevron markings were present





- Pavement condition, colored pavement quality, and road marking orientation may affect user comfort and travel position

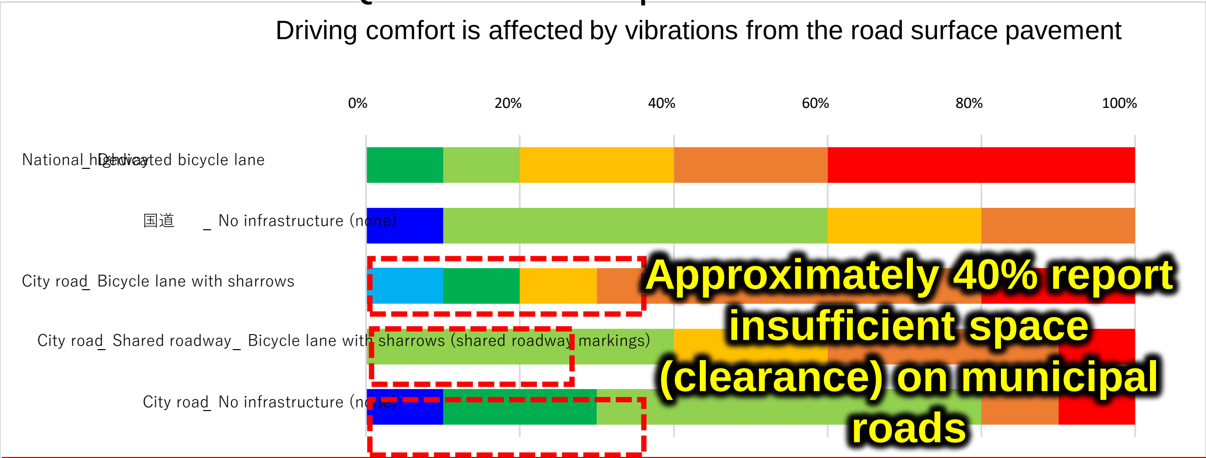
➔ **Pavement maintenance is necessary; attention should be paid to road marking orientation**

3. WG2「Behavioral Analysis」（Roadway/Straight Section②) Evaluation of Electric Scooter-Automobile Interaction (Clearance/Parked Vehicle Avoidance)

- The distance between motorized wheelchairs and automobiles is consistently rated poorly on city roads, regardless of road configuration"
- More than half of the respondents across all routes considered it dangerous to avoid obstacles such as parked vehicles

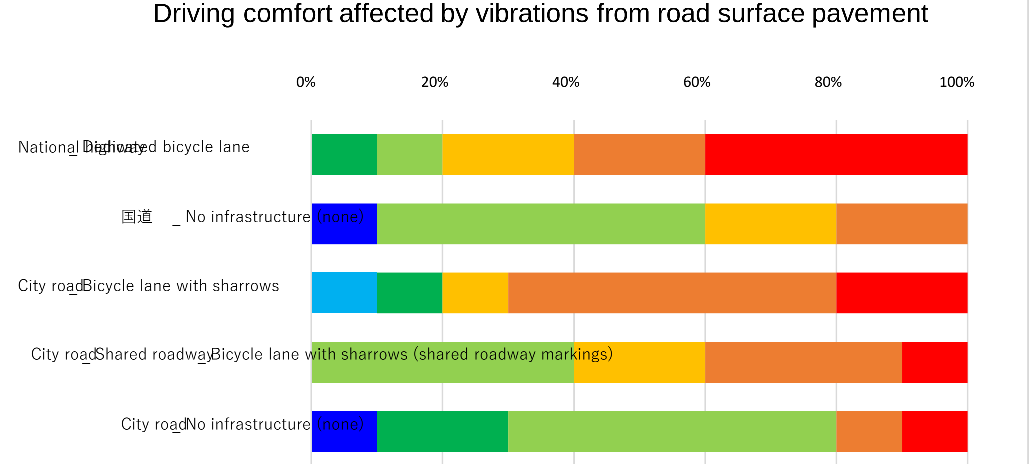
Distance from Vehicles

Q. Insufficient space between vehicles



Parked Vehicle Avoidance

Q. Risk when avoiding obstacles such as parked vehicles



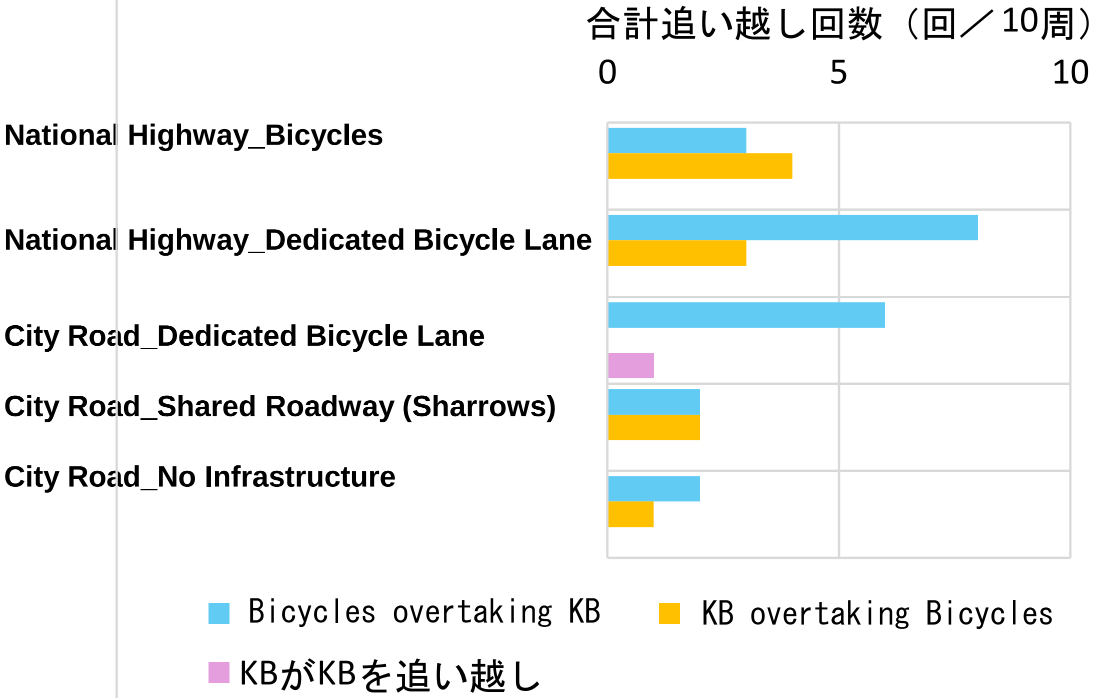
- Proximity to automobiles and avoidance maneuvers around parked vehicles negatively affect perceived safety

➔ **Provide traffic space with adequate automobile clearance, implement on-street parking measures, and conduct public awareness campaigns**

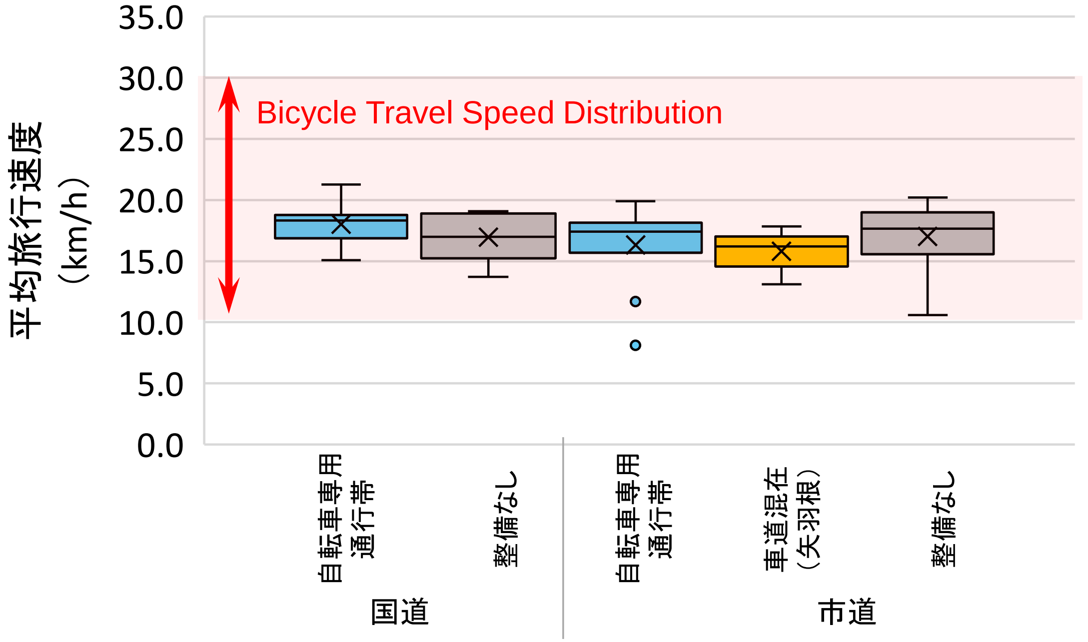
3. WG2「Behavioral Analysis」（Roadway/Straight Section③)
Overtaking Occurrence During Bicycle Interaction

- Overtaking by bicycles is frequent in dedicated bicycle lanes on national highways
- Unlike the broad speed range of bicycles, electric scooter speeds concentrate in a narrow range

Number of overtaking maneuvers



Travel speed of electric scooters



※ 山本彰・大脇鉄也・上坂克巳：自転車の走行空間等の違いによる旅行速度の差異に関する分析，土木計画学研究・講演集Vol.43，2011.

- Differences in travel characteristics between bicycles and electric scooters induce following and overtaking

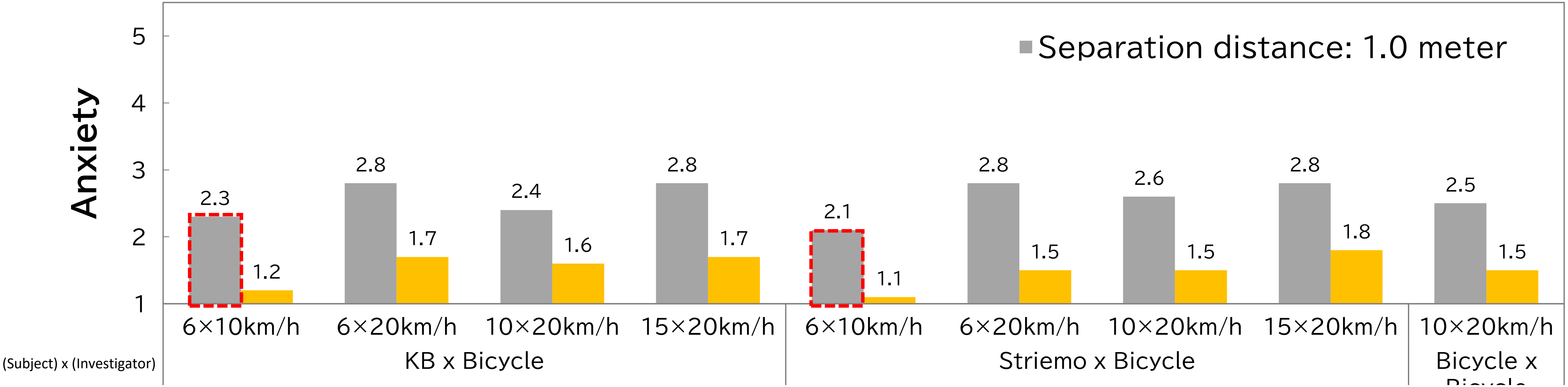
➔ **Conduct public awareness campaigns on safe overtaking practices**

3. WG2「Behavioral Analysis」(Roadway/Straight Section④)
Anxiety During Bicycle Overtaking

- At 10 m clearance, 15-40% report anxiety; anxiety is low at 15 m clearance
- Three-wheeled electric scooters elicit lower anxiety than two-wheeled models at low speeds and 1 m clearance
  ➔ **10 m clearance increases anxiety when electric scooters are overtaken by bicycles**

Feeling of anxiety when being overtaken

Separation distance: Distance between the center of each person's body at the point of being side-by-side (lateral direction)

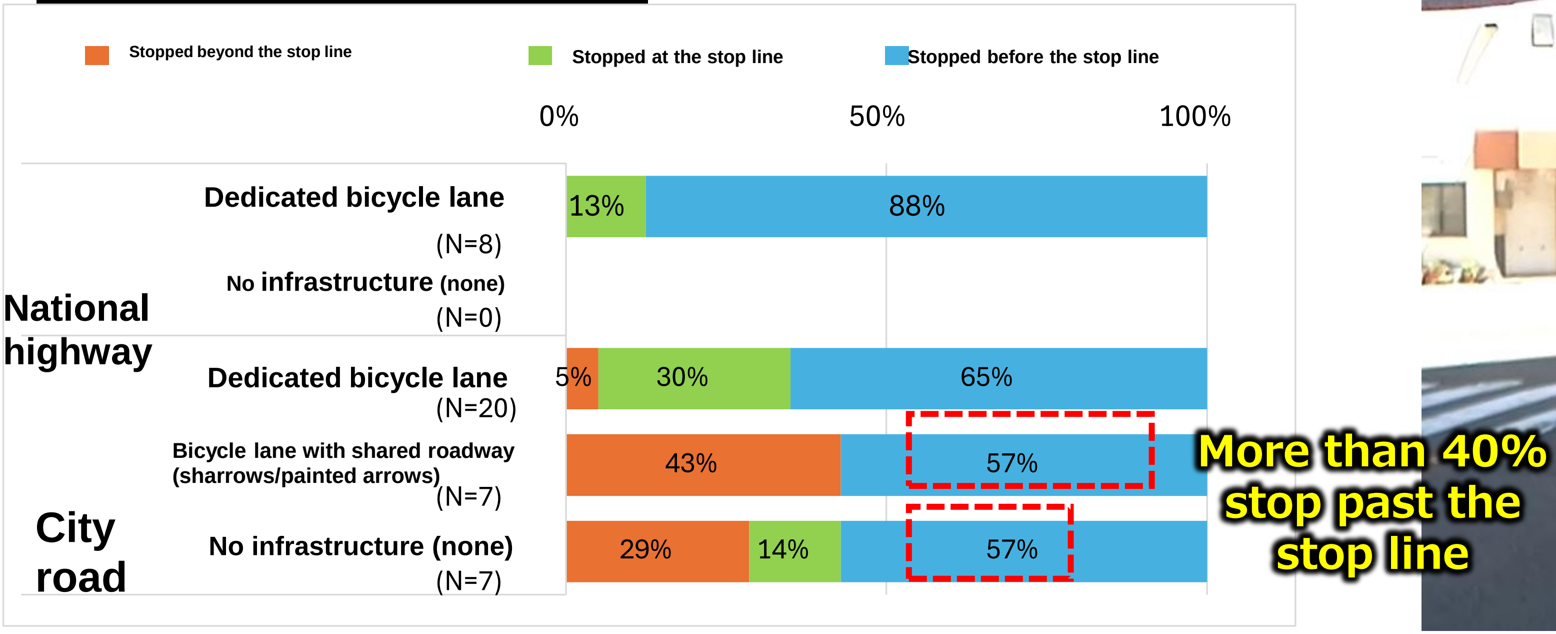


- In cases where motorized wheelchairs are overtaken by bicycles, feelings of anxiety increase at a separation distance of 1.0 meter
  ➔**Ensure wider traffic space than for bicycles and conduct public awareness campaigns for users**

3. Research Introduction – WG2 Behavioral Analysis – (Roadway/Intersection ①)
Electric Scooter Stop Positions at Signal Changes

- The proportion of scooters stopping beyond the stop line is high on municipal roads
- Stop-line overruns tend to increase at smaller intersections with shortstop line distances

Stop Position at Red Lights

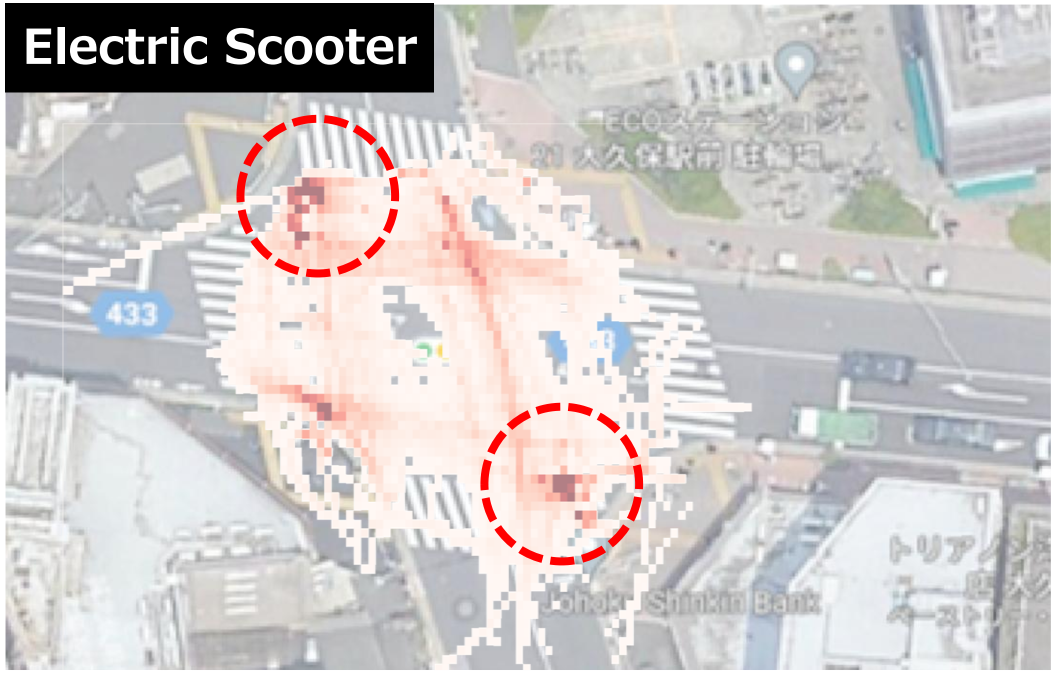


- Electric scooters, due to speed limits and acceleration characteristics, may misjudge stopping or experience delays with automobile signals
  ➔ **Implement light vehicle signals or extend clearance times**

3. Research Introduction – WG2 Behavioral Analysis – (Roadway/Intersection ②)

Electric Scooter Travel Position Within Intersections

- Electric scooters spend more time at intersection corners, waiting for two-stage crossings
- Bicycles primarily travel over arrow markings but are also observed on sidewalks



Note: Heat maps are color-coded based on the duration of target vehicle presence within the intersection.

Motorized wheelchairs: November 18 (Saturday) and 20 (Monday), 2023, 8:00 AM to 5:00 PM
Bicycles: November 18 (Saturday) and 20 (Monday), 2023, 8:00 AM, 12:00 PM, and 4:00 PM time slots

- Electric scooters use roadways more than bicycles, often waiting at corner areas during two-stage right turns

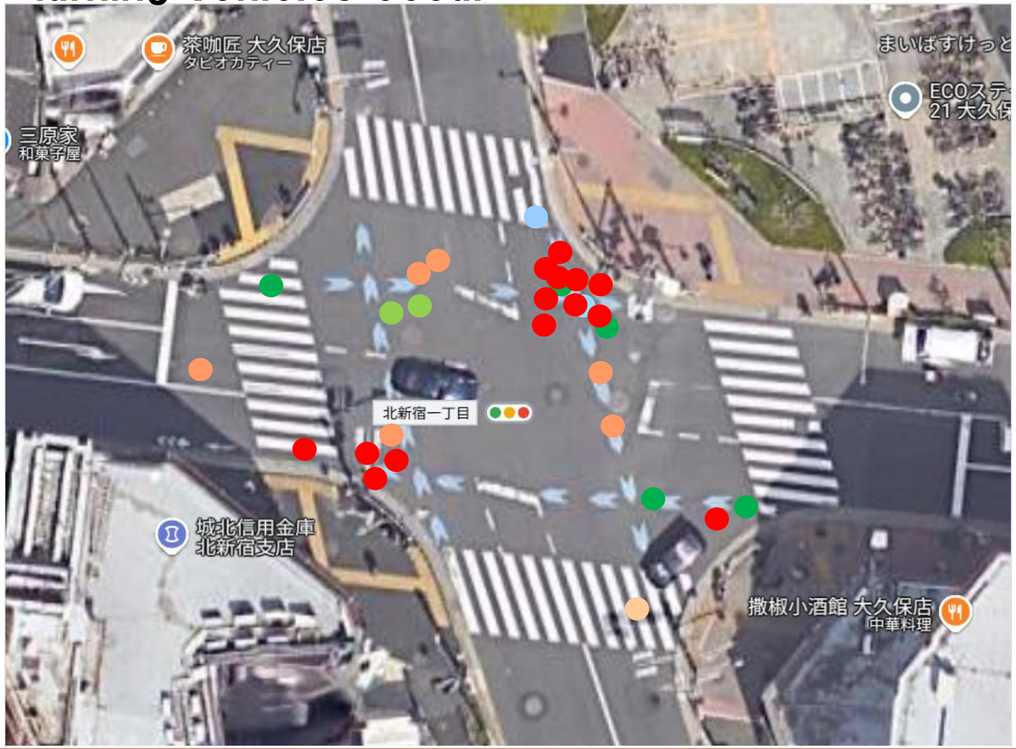
➔ **Ensure holding space for two-stage right turns at corner areas**

3. Research Introduction – WG2 Behavioral Analysis – (Roadway/Intersection ③)

Analysis of Electric Scooter-Automobile Conflict Events

- Using trajectory data, time differences (PET) below 3 seconds are extracted between electric scooters and other vehicles
- Left-turn conflicts and conflicts with oncoming right-turning vehicles occur

Legend	Total	Color
Proximity between bicycles near arrow markings	15	
Proximity between electric scooters (traveling inside arrow markings) and automobiles	6	
Proximity during sidewalk-to-roadway entry	1	
Proximity to oncoming right-turning vehicles	4	
Proximity to left-turning vehicles	1	
Automobiles in close proximity to the electric scooter traveling over the lane markings	1	

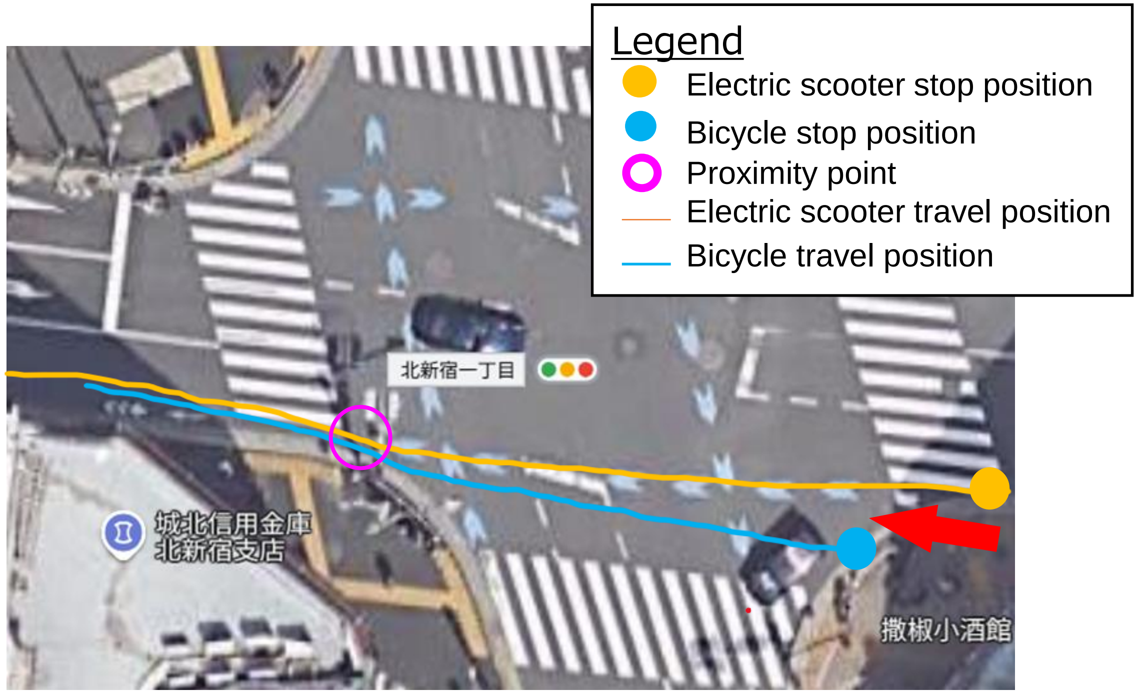


- Roadway travel increases the potential for conflicts between straight-moving electric scooters and left-turning vehicles

➔ **Issue warnings regarding left-turn conflicts**

Electric Scooter and Automobile Conflicts

- ☐ Electric scooters accelerate faster than bicycles, leading to parallel running and overtaking within intersections
- ☐ This is particularly problematic at exit corners where space narrows, causing them to get dangerously close

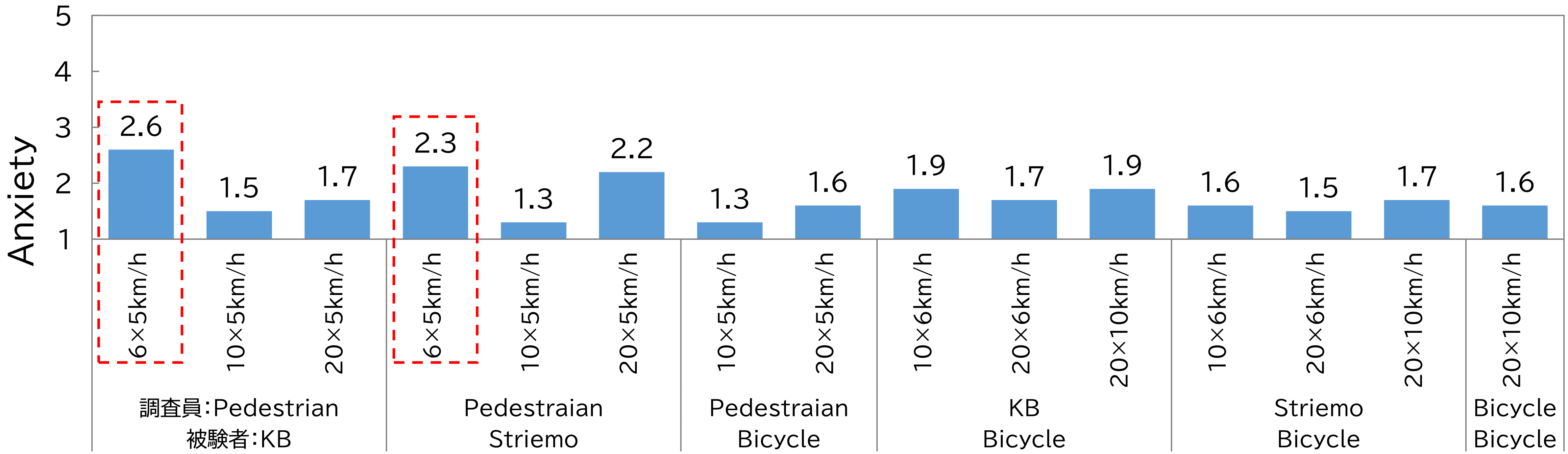


- Differing acceleration characteristics between electric scooters and bicycles after the signal starts result in parallel running and overtaking within intersections Space constraints at exit corners exacerbate proximity
  ➔ **Implication Emphasize consistent stopping positions for both electric scooters and bicycles**

3. Research Introduction – WG2 Behavioral Analysis – (Roadway/Pedestrian Coexistence ①) Anxiety During Overtaking

- Anxiety is lower at 10 km/h and highest at 6 km/h
- There is a possibility that the speed limit of 6 km/h on the sidewalk will not be observed

Anxiety During Overtaking



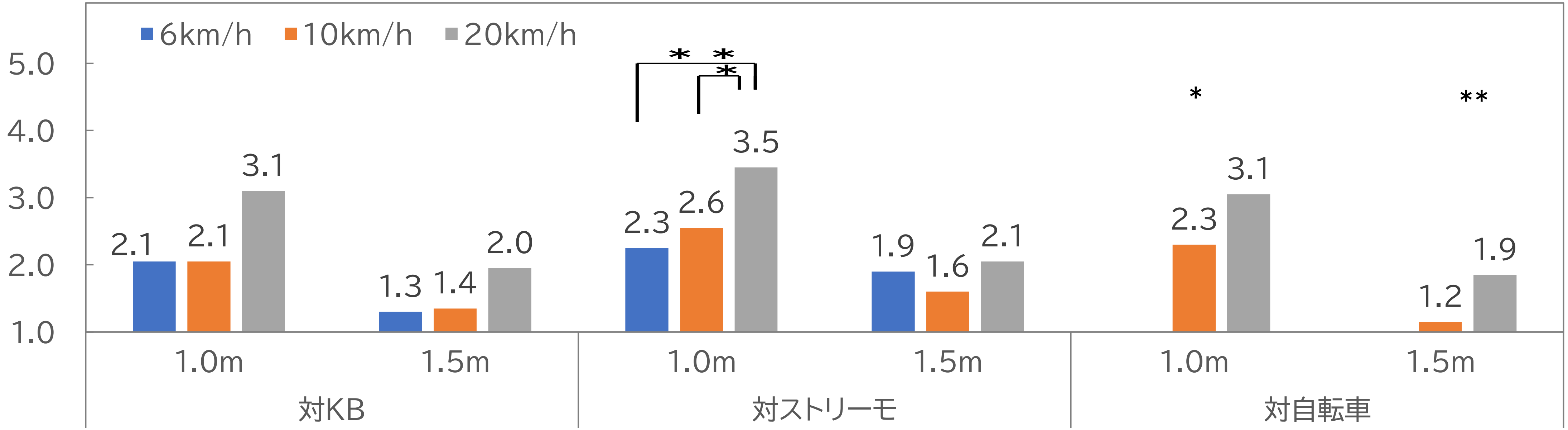
- When electric scooters overtake pedestrians on sidewalks, prolonged parallel travel and extended passing times cause anxiety

➔ **Overtaking close to others and the 6 km/h speed limit for designated small electric scooters may cause user anxiety**

3. Research Introduction – WG2 Behavioral Analysis – (Roadway/Pedestrian Coexistence ②) Anxiety When Overtaken as a Pedestrian

- ◻In the 6-10 km/h speed range, anxiety when overtaken is comparable to or less than that of bicycles
- ◻Anxiety is slightly higher with three-wheeled models (potentially due to unique travel sounds)

Anxiety During Overtaking



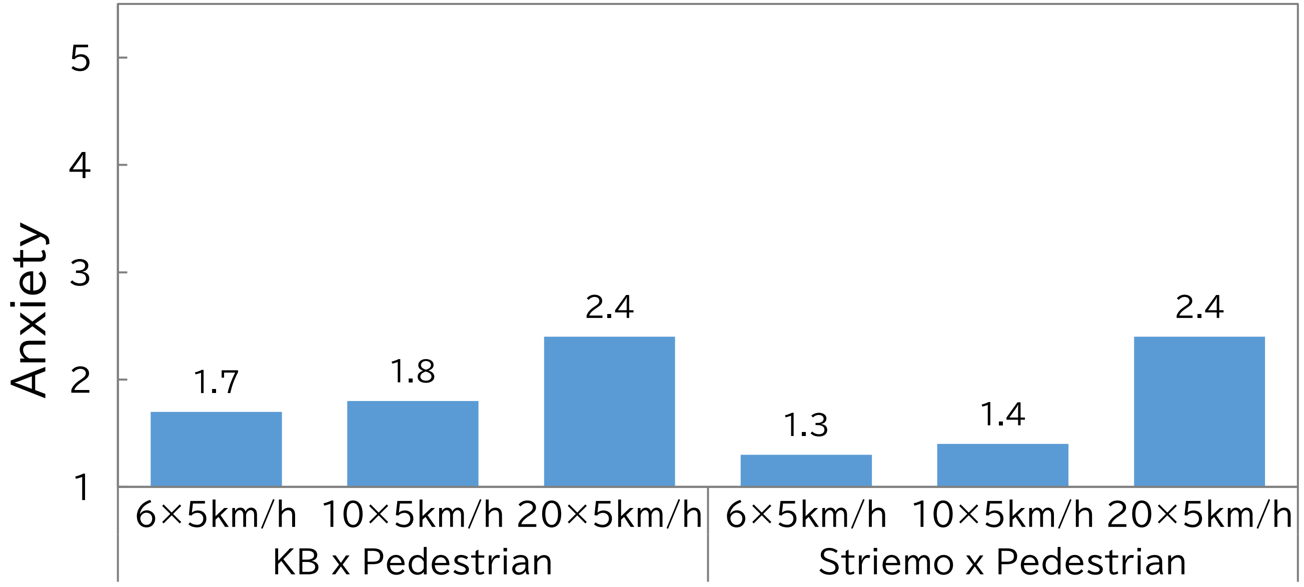
- When overtaken by electric scooters, no difference in anxiety is observed between 6-10 km/h; however, 20 km/h is poorly rated

➔ **Speeds up to 10 km/h generally result in low anxiety when being overtaken**

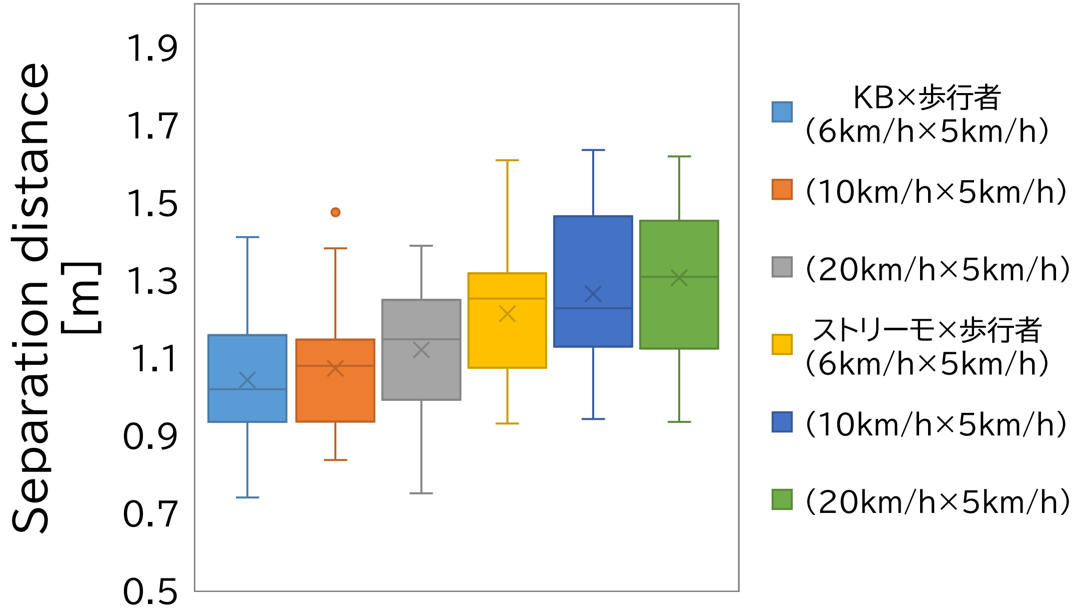
3. Research Introduction – WG2 Behavioral Analysis – (Roadway/Pedestrian Coexistence ③)
Anxiety When Passing Pedestrians

- Anxiety is lower with three-wheeled models than two-wheeled models at 6 and 10 km/h, but the difference is small at 20 km/h
- Three-wheeled models tend to maintain greater separation distances regardless of speed

Anxiety and Acceptability During Passing



Passing Separation Distance

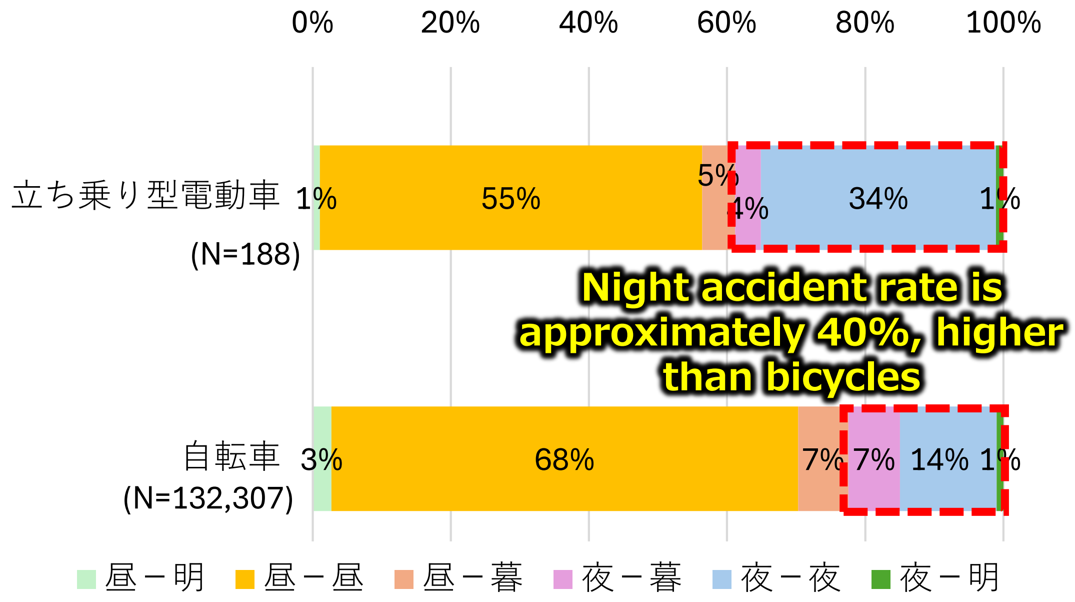


- Electric scooters traveling at up to 10 km/h are acceptable with a 12-13 m center-to-center separation distance
  ➔ **Users may tolerate slightly higher speeds if adequate clearance is maintained**

3. WG2「Behavioral Analysis」（Proper Use / Accidents and Violations）
Traffic Accidents and Legal Violations

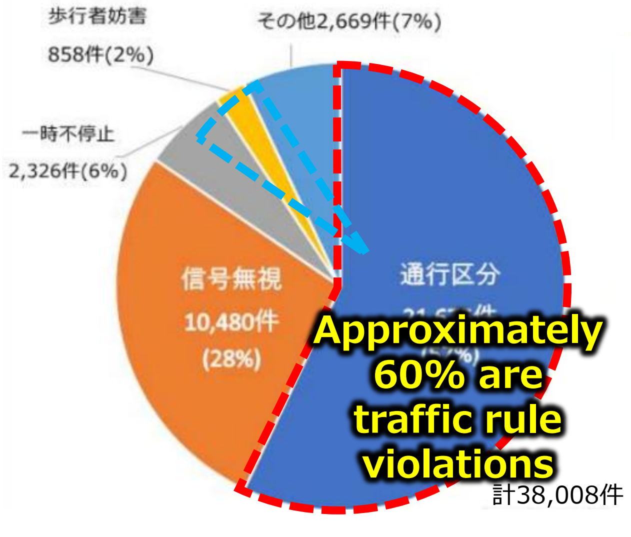
- Fatal and injury accidents involving standing electric vehicles occur more frequently at night compared to bicycles
- Electric scooters have a higher rate of traffic rule violations than bicycles but a lower rate of stop sign violations

Accident Frequency by period

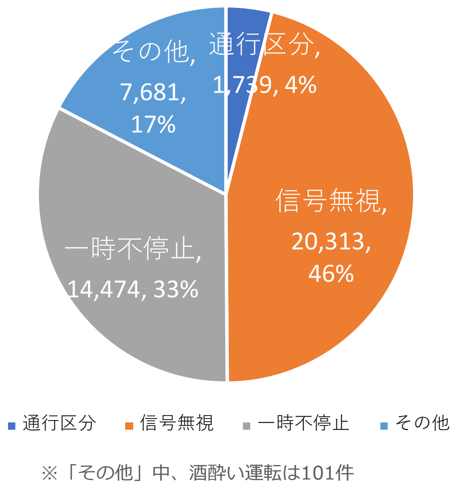


※ Source National Police Agency Traffic Accident Statistics Open Data (2022-2023)

Legal Violation Occurrence



Designated Small Motorized Bicycles
(July 2023 - September 2024)



Bicycles
(2023)

- Potential for accidents due to electric scooter use after alcohol consumption and the existence of road structures that may induce legal violations

➔ Time-of-use restrictions, public awareness campaigns on traffic rule differences between bicycles and designated small motorized bicycles, and road space development accommodating both

3. Research Introduction
WG1 User Psychology/Safety Education/Rules

Revised Road Traffic Law ⇒
Educational materials on traffic rules and electric mobility operation are widely distributed

Traffic rule explanation examples
(Tokyo Metropolitan Government Bureau of Lifestyle and Cultural Sports)

Electric kick scooter operation explanation (Luup)

Current materials primarily focus on basic explanations and do not provide detailed commentary or awareness of actual usage-based hazards

WG Objective Develop safety education content based on small electric mobility usage insights from this project, <u>moving beyond basic rule and operation understanding</u>

3. Research Introduction – WG1 User Psychology/Safety Education/Rules – Implementation Details

1）Web Survey

Targeting automobile drivers and pedestrians **who see electric kick scooters at least once a week** (valid responses 586 automobile drivers, 614 pedestrians)

【Perception of Dangerous Electric Kick Scooter Behavior by Surrounding People】

- **Automobile drives：** Recognize electric kick scooters as having a higher collision risk than bicycles for dangerous behaviors such as **speeding, stop sign violations, and zigzagging**
- **Pedestrians：** Recognize electric kick scooters as having a higher collision risk than bicycles when traveling on **crosswalks and sidewalks**
- Those without electric kick scooter usage experience perceive a higher possibility of collisions from dangerous behaviors than **those with experience**

2）Hearing Survey

Targeting 20 participants from the Nagoya Institute of Technology on-campus driving experiment (WG2)

Questions： Surrounding electric kick scooter usage, personal near-miss experiences, desired travel methods, and traffic rule understanding

【Key Responses】

- **Traffic rules (sidewalk travel conditions, one-way street handling, intersection travel methods)** are unclear and not well understood. Opportunities to gain knowledge are needed
- Requests for **dedicated lane development and road surface improvements**
- **6 km/h** is too slow, making the device unappealing

3）Integrate project insights to develop educational materials (draft) to enhance awareness of dangerous behaviors

3. Research Introduction – WG1 User Psychology/Safety Education/Rules
Target Audience

- Target： Individuals who are becoming somewhat accustomed to electric kick scooter operation
- Objective： Increase awareness of personal safety and promote understanding of the importance of cooperative and safe travel

Points to Note ：

- Focus on disseminating information regarding dangerous behaviors, refrain from recommending specific traveling methods (information is not sufficient)
- Effective information delivery methods （expression and media） will be addressed in the future

3. Research Introduction – WG1 User Psychology/Safety Education/Rules
Material Structure

１． Electric kick scooter accident occurrence statistics

２． Physical characteristics of electric kick scooter behavior（differences from bicycles）

Small wheels ⇒ Handlebars are easily taken（low-speed instability, fall risk）
Low travel sound ⇒ Approach is easily unnoticed

Highlighting behaviors from interviews and web surveys that are poorly understood or deemed dangerous

３． Electric kick scooter travel rules

Special requirements for 'sidewalk travel allowed', differences between bicycle lanes/ dedicated bicycle lanes/bicycle-pedestrian paths

４． Common User Actions and Underlying Dangers

Presenting behaviors frequently exhibited by electric kick scooter users that disrupt harmony with surroundings, based on insights from this project

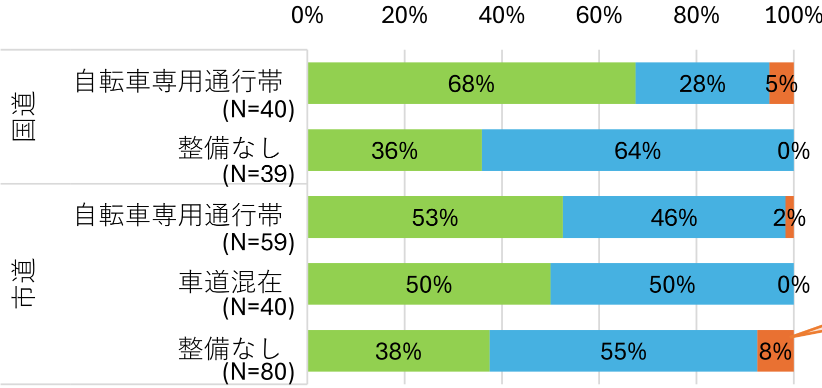
3. Research Introduction – WG1 User Psychology/Safety Education/Rules
Example of Common User Actions ① Avoiding Bumps

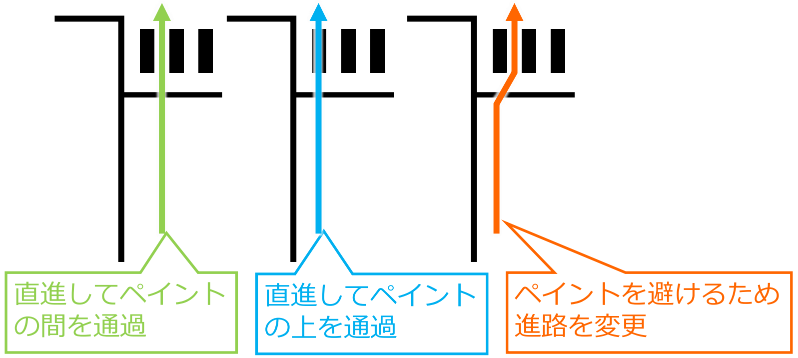
■ **Insights from Interviews and Riding Experiments**

- Vulnerable to bumps

Tend to avoid asphalt joints, white lines on crosswalks, etc

■ **Behavior at Crosswalks**

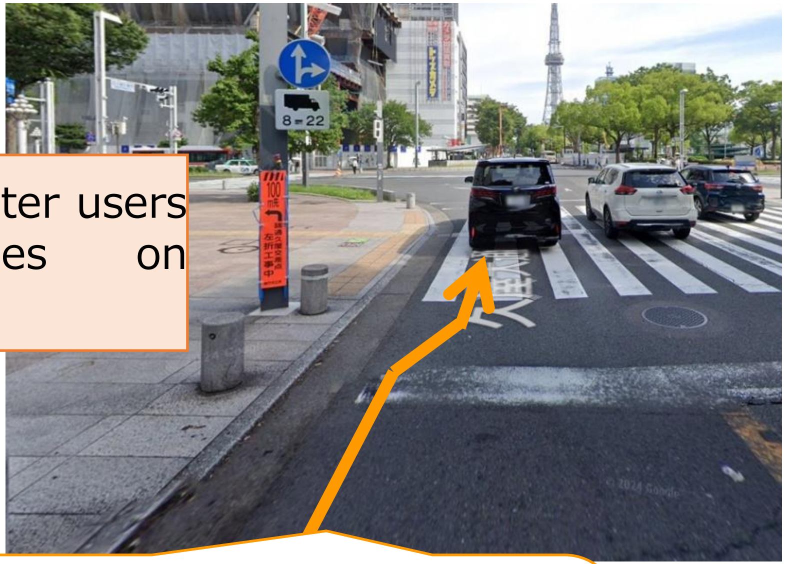




■ **Dangerous Behavior**

Sudden changes in travel position

Some electric kick scooter users avoid painted lines on crosswalks



From Automobile Driver Interviews

・Concerned about erratic behavior or sudden cut-ins

・Concerned about limited visibility due to small size, potentially leading to collisions

3. Research Introduction – WG1 User Psychology/Safety Education/Rules
Example of Common User Actions ② Avoiding Pedestrians

■ **Insights from Interviews and Riding Experiments**

- 6 km/h mode is too slow
- Assumed sidewalk riding was permissible
- Electric kick scooters have high maneuverability

■ **Dangerous Behavior**

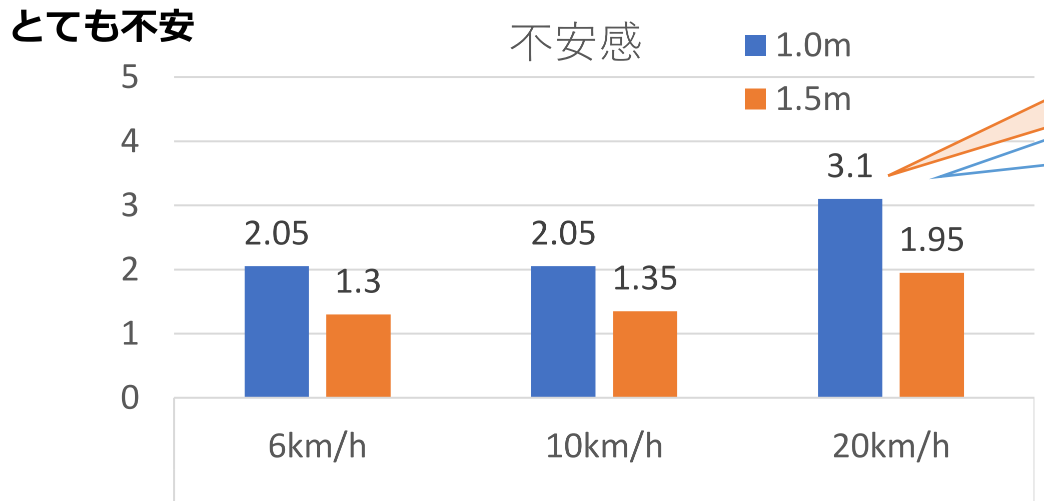
High-speed sidewalk riding
Attempts to quickly maneuver through narrow spaces

■ **Anxiety when <u>Electric Kick Scooters</u> Overtake Pedestrians**

Anxiety when overtaking pedestrians at 6 km/h (slow overtaking time)

- Anxiety at high electric kick scooter speeds (20 km/h)
- Anxiety at 1 m center-to-center separation distance

■ Anxiety when <u>Pedestrians</u> are Overtaken by Electric Kick Scooters



From Interviews ：
- Young people often speed
- Scary to be overtaken while walking on a narrow street at night

Low speeds and adequate separation reduce anxiety for surrounding pedestrians

3. Research Introduction – WG1 User Psychology/Safety Education/Rules
Example of Common User Actions ③ Underestimating Safety

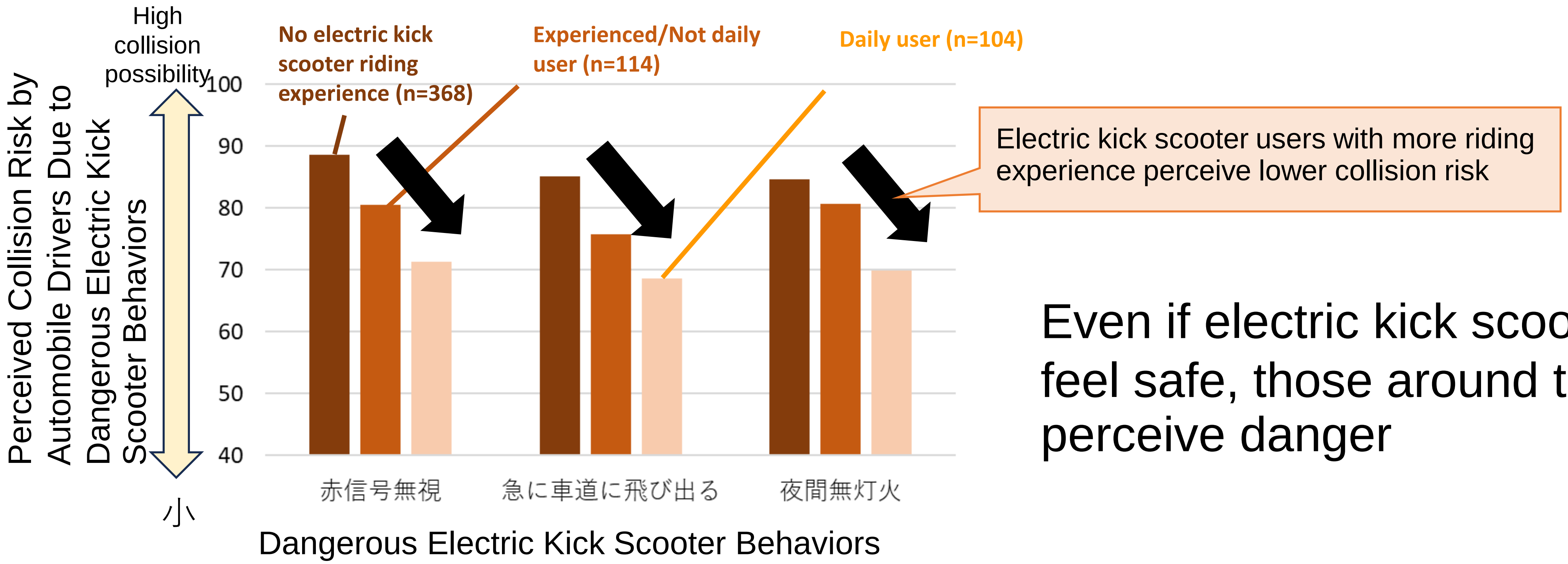
■ **Web Survey Results**

・Electric kick scooter users have low sensitivity to danger
・Believe they can avoid collisions even with dangerous behaviors

■ **Dangerous Behavior**

・**Disregard for minor traffic rule violations**
・**Non-users perceive significant danger**

■ **Differences in Danger Perception by Automobile Drivers Based on Electric Kick Scooter Riding Experience**



Even if electric kick scooter users feel safe, those around them may perceive danger

3. Research Introduction
WG3 International Workshops

目的

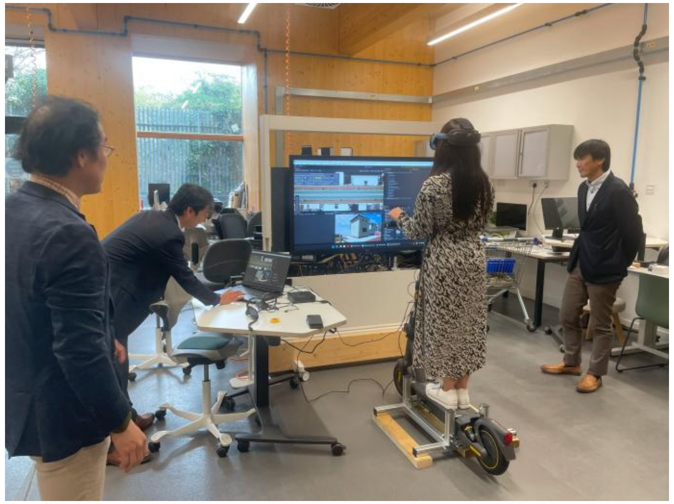
- Share research findings from this project
- Gather insights and challenges related to small electric mobility in various countries
- Understand unique and common challenges across countries through discussions
- Build a network of researchers and practitioners related to micromobility

Workshops Held

- Vienna Workshop (February 2023) - Prior Research
- WCTR 2023 Special Session (July 2023, Montreal)
- Workshop at UCL PEARL (March 2024, London)
- Workshop at Qatar University (September 2024, Doha)

3. Research Introduction – WG3 International Workshops UCL Workshop

- March 8, 2024, 900-1430 @ UCL, PEARL（Person-Environment-Activity Research Laboratory)
- Theme：The Role of Small Electric Mobility in Modern Transportation Systems Challenges and Expectations
- Hybrid Format
- Main Program
  - Presentation of research from this project
  - Micromobility policy of the UK（Stephanie Apostolou, DfT)
  - TfL Micromobility Strategy（Saskia Van-Emden, TfL)
  - Panel discussion
  - Tour of UCL Pearl facilities
- Participants：6 project members, 5 external members, 4 online participants



3. Research Introduction – WG3 International Workshops Qatar Workshop

- September 29, 2024, 830-1440 @ Qatar University
- Theme：Micromobility in Modern Transport – Overcoming Challenges and Seizing Opportunities
- Main Program
  - Presentation of research from this project（PI, Iryo, Suzuki（T））
  - The Role of Micromobility in Sustainable Cities（Susanna Zammataro, IRF)
  - STACS Micromobility control at signalized intersections（Daniel Jaros, Traffic Tech, Qatar)
  - Qatar Government Bicycle Master Plan（Chris Lucas, Conor Semler, Rula Khashman)
  - Potential of micromobility in low-density and depopulated areas in Austria（Shibayama)
- Participants：5 project members, 129 external members, 260 online participants

3. Research Introduction – WG3 International Workshops Key Discussion Points

- **Should driver-side issues be addressed through vehicle design or street infrastructure**
- **How to control privately owned electric kick scooters?**
  - Easy for individuals to modify (so-called 'jailbreaking')
  - Difficult to control through regulations like sharing systems
- **Risk perception and acceptance by other road users**
  - Are attitudes and acceptance of automobile and motorcycle drivers worsening over time (London)?
  - Is sidewalk riding permission perceived as 'punishment' for pedestrians?
- **Consistency with sustainability goals**
  - How to prevent shifts from walking and cycling?
  - Positioning and implementation within the mode shift from automobiles?
- **Geographical characteristics of usage locations**
  - **Primarily development in urban, high-density areas (focus on sharing)**
  - **Usage in rural areas and policy guidance (including private ownership)?**
  - **Climate Issues (usage in climates where cycling is not always comfortable)**

4. Summary

Achievements

- Through on-site surveys after the revision of the Road Traffic Act and case studies both domestically and internationally, we were able to deepen our understanding of small electric mobility (mainly electric kick scooters) using roadways and sidewalks, and to organize issues and countermeasures at straight road sections, intersections, and other locations
- Based on on-campus experiments, we were able to suggest safe and acceptable road cross-sectional configurations for pedestrians, cyclists, and small electric mobility users
- We were able to advance the development of content for safety education for non-driver's license holders regarding the safe use of small electric mobility (electric kick scooters (specified small))

4. Summary

□Future Challenges

- By exchanging opinions with road administrators and businesses regarding research results, we will gather on-site needs and disseminate the results of IATSS research to the general public
- Conduct safety education for non-driver's license holders using the deliverables
- Quantify the safety improvement effects of clarifying and separating hierarchical road networks where mobility vehicles with different speed levels coexist