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Verification of the Operability of Short-Distance Mobility Vehicles (Electric Wheelchair) WHILL Through Test Drive Experiments*

Koji Sakai, Mizuho Yasuda
Kyoto Koka Women's University, Ukyo-ku Kyoto, Japan

In this study, we used the short-distance mobility vehicles (electric wheelchair) WHILL, which is sold as a mobility support device rather than a welfare care device, and conducted test rides on campus and on public roads. The participants in the experiment were 10 healthy men and women in their 20s to 60s who did not use electric wheelchairs in their daily lives. The results showed that about half of the experiment participants did not feel anxious about operating WHILL. On the other hand, many participants felt uneasy about the operation of moving backward diagonally. The WHILL's steering wheel was easy to operate, and it was also very comfortable during the test drive. Before and after the test drive, the impression evaluation of WHILL changed significantly from negative to positive. An improved model of WHILL was proposed based on the results of the questionnaire survey and interview survey after the test drive.

Keywords: short-distance mobility vehicles (electric wheelchair), WHILL, test drive experiment, operability, mobility

Introduction

In old age, both physical function and mobility decline, and social participation also tends to decline. It is necessary to secure a means of transportation, and it has become a major social problem as a mobility issue. Mobility issues refer to people who age and lose their means of transportation due to reasons such as voluntarily surrendering their driver's licenses, and whose families are unable to provide transportation support. The issues make it inconvenient for them to go shopping, go to the hospital, participate in society, etc. Being able to go where you want to go is an individual's right in life, and society needs to guarantee this right. In addition, mobility issues can also accelerate the progression to frailty and the need for nursing care due to lack of exercise and lack of vigor in elderly people's lives.

Electric wheelchairs are one of the means of transportation that allow elderly people to go out freely on their own. Electric wheelchairs are treated as pedestrians under the Road Traffic Act and can be driven on sidewalks. No driver's license is required, and the maximum speed is 6 km/h. According to the Electric Wheelchair Safety

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Koji Sakai, Professor, Faculty of Career Development, Kyoto Koka Women's University, Ukyo-ku Kyoto, Japan.
Mizuho Yasuda, Undergraduate student, Faculty of Career Development, Kyoto Koka Women's University, Ukyo-ku Kyoto, Japan.

Promotion Association, there are two main types of electric wheelchairs: those for self-operation and those for assistance. For self-operation, there are both standard and handle types. The standard type is mainly used by people with physical disabilities, and most of them are operated using a joystick lever. Handle-type vehicles are mainly used by elderly people with weak legs, who operate the vehicle by operating the handle. According to the Electric Wheelchair Safety Promotion Association, there were 3,400 electric wheelchairs in 1985, peaked at 35,717 in 2000, and 18,438 were shipped in 2022. As we become a super-aging society, there will be an increase in the number of people who find it difficult to walk or walk long distances, and the number of elderly people who are forced to restrict going out as they surrender their driver's licenses. Electric wheelchairs are expected to be one solution.

In a previous study on electric wheelchairs, Takeshima et al. (2023) evaluated operating skills when driving a handle-type electric wheelchair while driving on an indoor test course both by observing drivers and collecting data from a drive recorder. As a result, observations can be used to comprehensively evaluate the difficulty of tasks and the number of failures, while operation logs can be used to quantitatively evaluate the operational characteristics of steering wheels and speed adjustments, potentially detecting dangerous driving that could lead to a collision. Sadamitsu, Uda, Kiyonaga, and Yada (2021) conducted an interview survey to clarify the circumstances leading up to the purchase and use of electric wheelchairs by elderly people, as well as the living conditions in which they use electric wheelchairs. As a result, in daily life using an electric wheelchair, (1) "safe use" includes (a) easy operation and safety equipment, (b) response when predicting danger, (c) current state of no danger, and (d) continued use of the electric wheelchair. (2) "Activities and Participation" includes (a) maintaining and expanding the range of activities, (b) interacting with others, and (c) enjoying shopping on your own.

However, the social issue with electric wheelchairs is that there are few users of electric wheelchairs in Japan and overseas. There is little recognition that daily use of electric wheelchairs is natural, and the challenge to popularizing electric wheelchairs is to improve understanding and acceptance in society. Maruoka, Miyano, and Kamoji (2022) analyzed negative attitudes toward the use of electric wheelchairs through a questionnaire survey and found that electric wheelchair users were more likely than non-users to be refused use at restaurants and to be rejected by taxis, trains, and buses. Sahoo and Choudhury (2023) raise the barriers and challenges faced by wheelchair users, such as physical disabilities, social stigma, and inadequate infrastructure, and work to address these barriers through policy changes, awareness campaigns, and inclusive design practices.

The electric wheelchair "WHILL" was developed with the aim of creating a smart vehicle that anyone would want to ride. The company was founded in 2012 with the aim of fundamentally rethinking the design, functionality, and convenience of wheelchairs and developing more user-friendly and stylish electric wheelchairs. WHILL Co., Ltd. has a mission of "making mobility fun and smart for everyone", and uses advanced technology and design to develop innovative mobility that removes barriers to daily life and social participation. As of May 2024, two standard types (WHILL Model F, WHILL Model C2) and one handle type (WHILL Model S) are on sale.

In the WHILL social experiment conducted by Niigata City in 2020, we verified the effectiveness of WHILL's sharing service by incorporating transfers and drop-offs between multiple locations. The results showed that the ability to move around while seated improved the ease of walking around shopping districts and towns, and that the increase in the number of users of facilities and stores stimulated consumer activity and created a lively atmosphere. Additionally, 30% of users were men and 70% were women, and the number of

users aged 60 and over remained at around 6%. When asked about the safety of the aircraft, the most common response, 70%, was that it was easy to operate. On the other hand, the opposing opinion, “There were some scary moments”, cited concerns about operational errors and specific situations such as vibrations when climbing over braille blocks. Additionally, there are many issues with the opinion that “you have to be careful about the low line of sight unique to wheelchairs, the size of the aircraft, and how others see you”, and even within the driving area there are slopes and narrow passages that make driving inconvenient. For mobility aids to be used as a means of going out, it is considered necessary to establish an evaluation system for safe operation.

WHILL is an electric wheelchair that can be comfortably moved by anyone, including physically disabled people and people with weak legs, as well as healthy adults and children. The Niigata City social experiment was a social experiment in which the public could ride. On the other hand, most of the previous studies on electric wheelchair test rides have targeted elderly people (Takeshima et al. (2023), Sadamitsu et al. (2021), et al.). In this study, we will conduct a test drive experiment on the operability of the WHILL Model S, which has a four-wheel drive system with a steering wheel, for healthy persons.

Method

Experiment Period

Experiments were conducted from August to December 2023.

Experiment Participants

A total of 10 people, seven students and three faculty members from Kyoto Koka Women’s University, ranged in age from their 20s to their 60s. The 10 participants in the experiment were healthy, did not drive a WHILL in their daily lives, and eight of the 10 had a driver’s license.

Electric Wheelchair Used in the Experiment

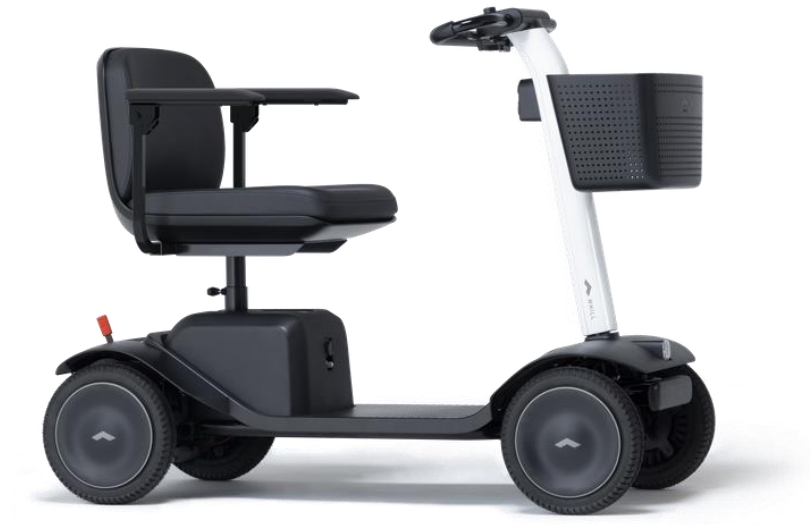


Figure 1. WHILL Model S (image taken from WHILL homepage).

Figure 1 shows the electric wheelchair “WHILL Model S” used in this experiment. The features of WHILL Model S are as follows.

- Maximum speed is 6 km/h forward and 2 km/h reverse.
- Intuitive and easy operation.

- Large capacity battery that can travel 33 km on a full charge.
- Reliable running performance even on 7.5 cm steps.
- Basket that can hold up to 4 kg.

Experimental Procedures

First, the experimenter demonstrated and explained the WHILL operation method to the experiment participants. The WHILL operation method is forward (grasp the D lever located on the right side of the handle), reverse (grasp the R lever located on the left side of the handle), brake (release the D lever or R lever), handle operation (left and right), and adjusting the speed (dial adjustment). Afterwards, the experiment participants drove the WHILL along the designated travel route, first within the university and then on public roads. The movement speed of WHILL was freely controlled by the experiment participants. To ensure the safety of the experiment participants, two authors walked alongside them during the test drive. After the 30-minute test drive, we conducted a 15-minute questionnaire and interview survey about the test drive.

Test Drive Experiment Route

Inside the university. Figure 2 shows the travel route within the university and the travel route out on public roads in this experiment. A test drive experiment was conducted using the following Steps (1) to (3).

(1) Start moving from in front of the laboratory on the 3rd floor of Genpukan.

(2) Use the elevator to go down to the first floor and go outside.

(3) Go around the tennis court and exit the main gate onto the public road.

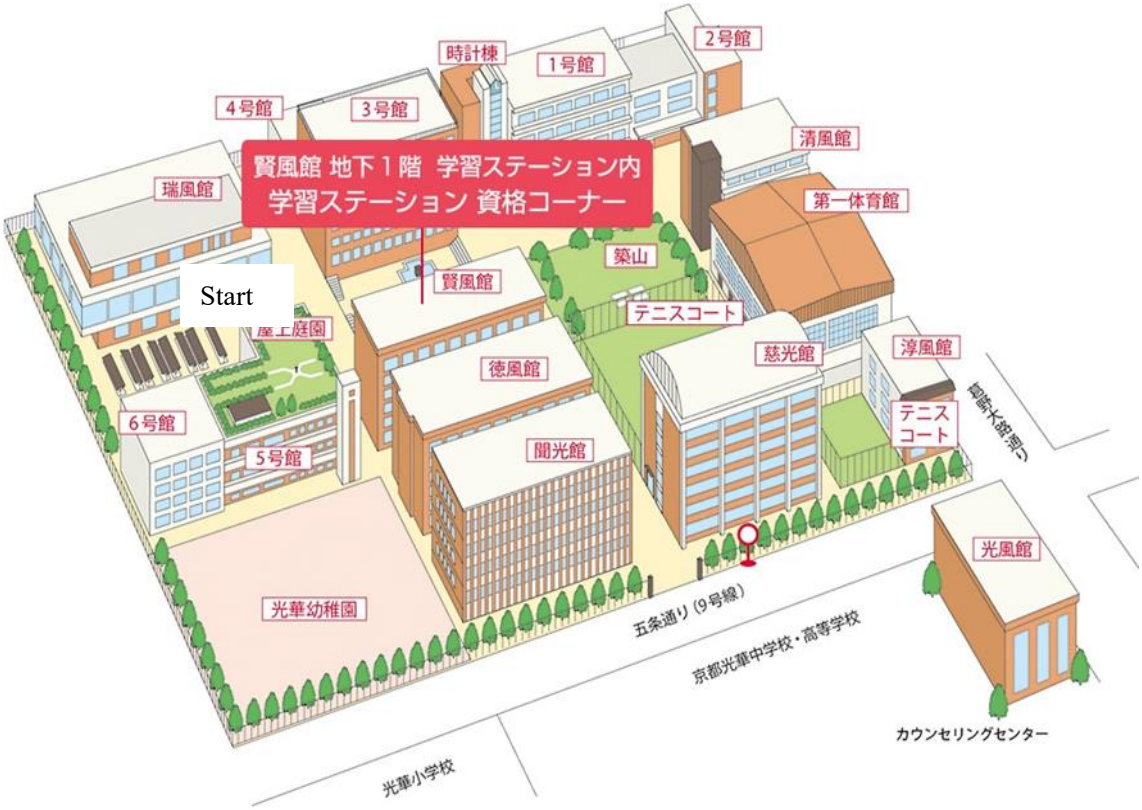


Figure 2. Routes for moving around the school and going outdoors (image taken from Kyoto Koka Women's University website).

General roads outside the university. Figure 3 shows the general road route map, and the test drive experiment was conducted using the following Steps (1) to (4).

(1) Leave the university and head to the Kadono-ouji Gojo intersection.

(2) Cross the crosswalk and go straight south.

(3) Parking at 7-Eleven Nishikyogoku Nishiohmaru-cho store.

(4) Go back the way you came and park in front of the laboratory on the 3rd floor of Genpukan, which is the starting point for moving around the university.

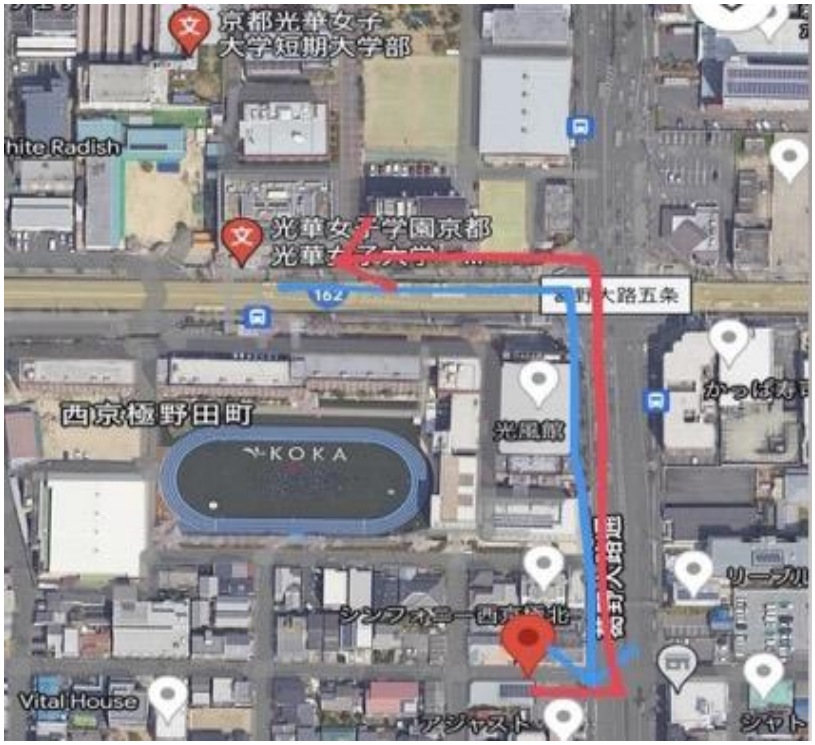
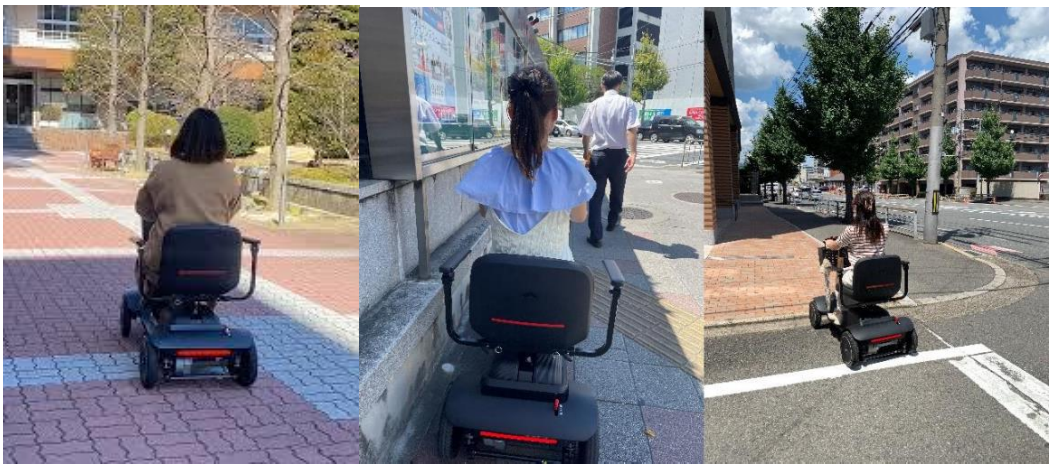


Figure 3. Test drive route on general roads (image taken from Google Maps).

Figure 4 shows the WHILL test drive (a) inside the university and (b) on a public road.



(a) (b)

Figure 4. Test drive experiments (a) within the university and (b) on public roads.

Post-test Drive Questionnaire Survey and Interview Survey

After the WHILL test drive, participants were asked to fill in the following information regarding the ease of driving, seating comfort, warning buzzer, luggage basket, impression of the electric wheelchair, and points for improvement. After the questionnaire survey, we conducted an interview survey.

[Ease of driving operation]: 1. Going straight, 2. Turning left and right, 3. Moving forward diagonally, 4. Moving backward diagonally, 5. Moving backward, 6. Ease of driving in general, 7. Getting used to the controls, 8. Parking, 9. Turning around, 10. Appropriate movement speed, 11. Ease of gripping the steering wheel, 12. Comfort while driving.

[Sitting comfort]: 1. Chair (tired back and buttocks), 2. Steering wheel (tired arms and shoulders), 3. Road surface condition and vibration when riding, 4. Leg fatigue.

[Warning buzzer]: 1. Loudness, 2. Length of sound.

[Luggage basket]: 1. Luggage content.

[Impressions of electric wheelchairs]: 1. Did it change before and after riding it? 2. Do you want yourself (parents, grandparents) to ride it in the future?

[Improvement points]: 1. Ideal parts to have, 2. Ideal locations to have.

Result

Table 1 shows the results of the questionnaire survey after the WHILL test drive. We analyze the results in Table 1 in Sections 3.1 to 3.4.

Table 1

Results of the Questionnaire Survey After the WHILL Test Drive

Ease of driving operation				n: number of experiment participants		
		No anxious	A little anxious	Anxious		
1	Going straight	5	5	0		
2	Turning left and right	5	5	0		
3	Moving forward diagonally	5	4	1		
4	Moving backward diagonally	1	6	2		
5	Moving backward	5	5	0		
6	Ease of driving in general	4	6	0		
7	Getting used to the controls	4	6	0		
8	Parking	5	4	1		
9	Turning around	6	2	2		
		Fast	Appropriate	Slow		
10	Appropriate movement speed	0	10	0		
		Easy	Normal	Not easy		
11	Ease of gripping the steering wheel	10	0	0		
		Good	A little good	Normal	A little bad	Bad
12	Comfort while driving	6	3	0	1	0
Seating comfort						
		Not at all	A little	Quite		
1	Chair (tired back and buttocks)	8	2	0		
2	Steering wheel (tired arms and shoulders)	8	2	0		
3	Road surface conditions and vibrations	1	5	4		
4	Leg fatigue	8	2	0		

Table 1 to be continued

Warning buzzer						
		Too loud	A little loud	Normal	A little small	Too small
1	Loudness	0	0	3	5	2
		Too long	A little long	Normal	A little short	Too short
2	Length of sound			9		1
Luggage basket						
		Too big	A little big	Normal	A little small	Too small
1	Size of luggage basket			4	6	

Ease of Operation When Driving

Around 50% of respondents said they felt “not anxious” regarding the following items: 1. Going straight, 2. Turning left and right, 3. Moving forward diagonally, 5. Moving backward, 6. Ease of driving in general, 7. Getting used to the controls, and 8. Parking. The percentage of anxiety ratings was high regarding 4. Moving backward diagonally. The results were that one person said “not anxious”, six people said “somewhat anxious”, and two people said “anxiety”. All 10 participants rated it as “appropriate” regarding 10. Appropriate movement speed, probably because the participants were allowed to freely set the movement speed. All 10 people rated the ease of grip of the handle as “easy to grip”. Additionally, 12. Comfort while driving was also highly rated: Six people said it was “good”, three people said it was “somewhat good”, one person said it was “somewhat bad”.

The results of an interview survey regarding the reasons for anxiety are shown below.

1. Going straight: Some participants said that if they go straight on a slope, they are afraid of falling and are worried that their body will be carried away.

2. Turning left and right: Some people said that they were worried because they were not aware that the people around them were turning because there was no indicator.

3. Moving forward diagonally: Some people expressed concerns that the width of the electric wheelchair may be a hindrance when moving forward diagonally on public roads.

4. Moving backward diagonally: Students who do not have a driver’s license have expressed concerns that if they turn the steering wheel while moving backward, they will not be able to tell which direction the vehicle is moving. Many comments also pointed out concerns about the lack of rearview mirrors.

5. Moving backward: Some said they were worried about not having a rearview mirror, and others were worried about passers not being aware that they were going backwards.

6. Ease of driving in general: Opinions were raised that it was their first time to ride in the electric wheelchair so I could not get used to it, and that the vibrations from the braille blocks and bumpy roads were scary. Some said they were worried about the road, and others were concerned about how others would look at them during a test drive.

7. Getting used to the controls: Participants in this experiment did not use electric wheelchairs in their daily lives, so there was an opinion that they could not get used to them after a 30-minute test drive.

8. Parking: In this experiment, we did not park in bicycle parking lots or areas with lines drawn. There were opinions that if we had the opportunity to park in the future, we would not be able to park well, and that we would not be able to park in reverse.

9. Turning around: Many people commented that the Model S used in this experiment was difficult to turn around.

12. Comfort while driving: Overall it was good, but there were opinions that they were worried about sudden rainy weather, and that they had to consider the time if they were going to test drive in the summer.

Seating Comfort

In the questionnaire survey, the results were the same for 1. Chair (tired back and buttocks), 2. Steering wheel (tired arms and shoulders), and 4. Leg fatigue, with eight people saying "not at all" and two saying "a little bit". Perhaps because it was a short test drive of about 30 minutes, the participants felt less fatigued. Many people felt strong vibrations during test rides, regarding 3. Road surface conditions and vibrations while riding. In the interview survey, there were opinions that the chair and steering wheel could get hot quickly, based on the results of a test drive in the summer.

Warning Buzzer

In the questionnaire survey, the answers were that the volume of the sound was a little low and the length of the sound was just right. Below are the results of the interview survey.

1. Loudness: Respondents who said it was "low" said that even if they could hear it, they were worried about whether it was reaching passers. In addition, one elderly person who answered that the sound was "just right" said that although the volume was good, it was different from the warning sound of a car, so some questioned whether passers would recognize it as a warning sound.

2. Length of sound: A high percentage of respondents answered that it was just right. However, there were also opinions that it was scary to have to operate the steering wheel with one hand when sounding the warning sound.

Luggage Basket

Regarding the size of the luggage basket, four people said it was "just right" and six people said it was "a little small". As a result of the interview survey, there was an opinion that if they were planning on shopping, they would like a larger basket. There was an opinion that in addition to the front basket, it would be possible to create a rear basket or a luggage storage area under the chair.

Impression of Electric Wheelchair

Regarding participants' impressions before and after riding the WHILL, the following statements were made in the free description responses in the questionnaire.

Before test drive of WHILL.

- Impression that it is used indoors.
- Difficult to operate.
- I'm worried about driving.
- The impression is that it is used by the elderly, disabled, and injured people.

After test drive of WHILL.

- Things that can contribute to many people.
- Convenient for large movements.
- I want to use WHILL when its existence becomes commonplace.
- When I rode it, it felt surprisingly stable and easy to ride.

- When using it on the sidewalk, if an able-bodied person is riding it, it will be considered a nuisance.
- Young people are concerned about how others will look at them when using the service.
- I felt the ride was comfortable and fun.

When students were asked if they would like their parents or grandparents to ride in an electric wheelchair, they answered, “It would be convenient if there was one, and I would like them to ride in it, but I’m worried about an accident”, and “Due to low public awareness, it is difficult to recommend it to parents and grandparents”. When asked if they would like to ride in the future, some of the faculty and staff members gave positive comments such as, “I would like to take care of them someday”, and “I hope that one day I will be able to ride alongside not only myself, but also my children and grandchildren”.

Improvements in WHILL

Among the free description responses in the questionnaire after the test drive, there were opinions that it would be ideal if the WHILL had the following parts as improvements: rearview mirror, side mirror, indicator, warning people when moving backward, seat belt, stronger volume of warning buzzer, speedometer.

Regarding seat belts and arm rests, respondents were divided between those who thought they were necessary and those who thought they were unnecessary. WHILL is treated as a pedestrian, so seatbelts are not required, but there are opinions that it is necessary because the body is carried away when tilting, and others say that there is a sense of freedom without seatbelts. Regarding arm rests, no one drove with their arms resting on the arm rests during the experiment. On the other hand, there were scenes where the arm rest almost collided with the wall or the bicycle. It would be desirable to reconsider whether seat belts and arm rests are necessary or unnecessary.

In addition, the following opinions were expressed as ideal places to have a WHILL: theme parks, shopping malls, long roads to shopping, scenic views while riding the WHILL (Kyoto Skywalk, etc.), and areas with many slopes.

Discussion

The results of this experiment showed that about half of the experiment participants felt no anxious while operating WHILL, and the other half felt a little anxious. This result can be interpreted to mean that few of the experiment participants felt anxious, considering that this was the first time they tried riding the WHILL and the electric wheelchair. Approximately half of the participants in test drives not only on campus but also on public roads were able to test drive the WHILL without any anxiety, indicating that even first-time test drivers can operate the WHILL quickly. However, to ensure safety in this experiment, two experimenters accompanied the experiment participants during the test drive. If the experiment participant were to test drive on a public road alone without an experimenter, there is a possibility that the anxiety tendency would be slightly higher than the results of this experiment.

Among the various operations of the WHILL, many experiment participants felt particularly anxious when moving diagonally backwards, as shown in Table 1. It is thought that this operation was difficult, as it required attention both to check what was behind and to operate the steering wheel. In this experiment, no side mirrors were installed on the WHILL. By installing side mirrors to make it easier to see what’s behind the participants, they can allocate more attention to operating the steering wheel when moving backward diagonally, which is thought to reduce anxiety and increase safety. The improvement of safety and security by installing side mirrors will need to be verified through future demonstration experiments.

When the participants want to apply the brakes, as mentioned in Section 2.4, they should release the D lever. Otherwise, when they use a bicycle, they hold the left and right brakes with their hands. In other words, the brake operation for WHILL and bicycle is completely different. It is assumed that the students participating in this experiment often ride bicycles in their daily lives. In this test ride experiment, it was a human's spontaneous decision to use the brake function, which stops the WHILL just by letting go of the handlebars; they held it in the opposite direction and moved forward. This reason would be that they were used to operating the bicycle. There were two incorrect operations with two participants. Test-driving experiments have revealed that regardless of age, incorrect operation of the WHILL can lead to an accident.

Additionally, when moving backward, parking, or turning around, whether a driver's license was present made a difference in the level of understanding of the direction of travel, the accuracy of parking, and the speed at which drivers grasped the basics. The steering wheel of the electric wheelchair is the same as that of a car, so it is assumed that the experimenters who drive the car regularly were more accustomed to driving it. The WHILL's steering wheel was easy to operate, and it was also very comfortable during the test drive. WHILL's steering wheel can be relatively operated smoothly left, right, up, and down, and the WHILL's body also moves without delay after operation. It is presumed that this ease of operation of the steering wheel and vehicle body greatly contributed to the increased comfort during test drives. In addition, the seats are relatively wide and comfortable with both seat width and depth of 43 cm, suspension is mounted on the rear wheels to absorb shock, and the stylish design may be factors contributing to the high level of comfort. The factors contributing to WHILL's high comfort level require further verification.

On the other hand, student experiment participants expressed the opinion that they were concerned about how others looked at them while test driving. This result is consistent with the results of Niigata City's WHILL social experiment. Socially, electric wheelchairs are used mainly by the elderly and people with disabilities. Therefore, the students felt uncomfortable when young people, such as students, were riding them, and assumed that people recognized that they had a similar impression. Through this study, we were able to recognize the "psychological distance" that leads to the acceptance of electric wheelchairs in public spaces. As demand for electric wheelchairs increases as a means of transportation in a super-aging society, there is a need to make more people aware of the safety, usefulness, and comfort of electric wheelchairs.

Before and after the test drive in this experiment, the impression evaluation of WHILL changed significantly from negative to positive. This change is based on the results of this experiment, which showed that the anxiety during the test drive was not particularly high, the steering wheel was easy to operate, and the comfort was high. Currently, two types of WHILLs are being introduced in many facilities such as airports, hospitals, theme parks, and city halls: one that is operated by the user himself, and the other that is equipped with an autonomous driving system. Test drive sessions are also being held at educational sites such as elementary schools. Based on the findings of this study, it is expected that by increasing the number of opportunities to test drive the WHILL, positive impressions of electric wheelchairs will increase, positive social recognition will become stronger, and the number of electric wheelchair users will increase.

Electric wheelchairs sold by many manufacturers are targeted at people with physical disabilities, people who have difficulty walking, and elderly people who have surrendered their driver's licenses. In the case of WHILL, there is room for consideration of the improvements shown in this study to expand the needs to healthy people. Through these improvements, WHILL will become more popular, and more people will use it, which will reduce the hesitancy to go out, such as "worried about my legs and stamina", "worried about whether I can

keep up with the walking speed of my family and friends", and "I want to invite someone to go on a trip, but I'm worried that I'll make them tired". As a result, it will be possible for families to go out and travel, making transportation fun and smart for many people. If WHILL becomes commonplace in the world, we can expect it to lead to new urban development and infrastructure and have a positive impact.

This research was conducted using a WHILL Model S electric wheelchair. The WHILL model that is suitable for use will change depending on the user's needs, physical condition, and usage situation. For example, if we conduct an experiment like this experiment with a WHILL of a different model type, such as WHILL Model C2, you may get some different results. Verification through future test rides is required.

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