A Study on the Balance Sense and Function According to the Sitting-Position Driving of Segway

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Abstract: This study aims to examine the possibilities of interior chairing vehicles applying the self-balance driving of Segway. For the wheelchairs currently being used, the use of both hands is necessary to operate the driving wheels, which often leads to users' inconvenience. Thereupon, this author expects that if self-balance driving just like in Segway is applied to the wheelchairs, users will be able to drive or move just by sitting and shifting the center of gravity with no need to use both hands.

In order to conduct an experiment to verify the abovementioned claim, this research designed an experimental model with a chair to sit on the Segway. The model was set with a variety of movements which are frequently used in our daily lives; for example, some such movements for experiencing and acquiring a sense of balance are driving forward and backward while sitting, picking up an object from a table, lifting a cup from a tray, or opening the door and passing through it.

By analyzing the results of the experiment described above, this article considers how the chairing vehicle applying Segway can change or affect its user's life to be different from the existing one.

Key words: Inclusive Design, Universal Design, Wheelchair, Segway

1. Introduction

The self-drive wheelchair being presently used is structured to move by operating its driving wheels with both hands. According to the result of interviews with wheelchair users and analysis on the videos recording their movements in daily life, it has been again found that the self-drive wheelchair exhibits various problems. For instance, when users have to move from their wheelchair to bed, some of them even feel they might fall off from it since its driving wheels are higher than the seat (Figure.1). And when they try to move an object, they have to use their both hands for the operation with no place to put it on but their own thighs. Because of this, they often spill liquid or even end up being burned while driving one (Figure.2).

In order to settle these problems, this author came up with an idea to apply two-wheel self-balance driving to wheelchairs.

Figure. 1 Moving to a bed

Figure.2 Moving with a dish on thighs

2. Study Purpose

This research aims to design a device operated in a sitting position to which two-wheel self-balance driving is applied in order to examine the functional possibilities of wheelchairs according to the users' sense of balance and everyday movements.

The research is focused on indoor use, so it attempts to figure out up to what degree they can cope with user's indoor life with full of movements.

3. Study Methods

This article used Segway which can be easily applied to understand the function of two-wheel self-balance driving. The research started by this author getting in the Segway in person and experiencing the basic structure of it and sense of balance. After that, a stool was set on the Segway to drive forward and backward in the sitting position so as to examine the possibilities of driving functions according to the sense of balance and movements in the sitting position.

After the above experiment, this study designed a chair unit to do an experiment to study the range of possible movements in the sitting position. Since it is dangerous for actual wheelchair users with paraplegia or quadriplegia to get in the experimental model in person, the researcher used the model and discussed it with the users afterwards. The research procedures are as written below.

(1) Basic examination on the sense of movement in the standing or sitting position in the Segway

(2) Installation of the chair unit to experiment on everyday activities on it

(3) Discussion with the users based on the videos recorded in (2)

(4) Improvement of the chair unit based on (3)

(5) Movement experiments after (4) in the presence of the users

(6) Discussion with the users

4. Study Contents

4.1 The Segway used in the experiment

Segway is originally designed for a standing ride. It has a simple structure with a T-shaped handle installed on the foot plate and two wheels (Figure.3).

As soon as the user turns it on and gets on its foot plate, a gyro sensor installed on the foot plate recognizes the center of the user's weight to keep a balance and induces the user to maintain a stable posture readily. It is operated by the shifts of the center of the user's weight. If the users move their center of gravity forward, it goes forward whereas if they move back to their original position, it stops. When the center of gravity moves backward, it goes back, too. To change the direction, they can turn the lever near the handle (Figure 4).

Figure.3 The Segway used on the experiment

Figure.4 The lever to change the direction

4.2 Movements in the standing/sitting position

According to the result of driving in the standing position, its self-balance function makes it operate in a natural balance as if it were a part of the user without causing any

instability resulted from the two wheels (Figure.5).

Figure 6 shows the stool on the foot plate. The gyro sensor recognizes the center of the user's weight in the sitting position and keeps the balance. Since the sitting lowers the center of gravity, it can not only maintain a more stable condition but also respond to subtle movements more sensitively than the standing ride.

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Figure.5 Standing-position drive

Figure.6 Sitting-position drive

4.3 Designing a chair unit

Chair unit (1) made of reinforced corrugated cardboard (Figure.7) was set on the foot plate of the Segway (Figure.8).

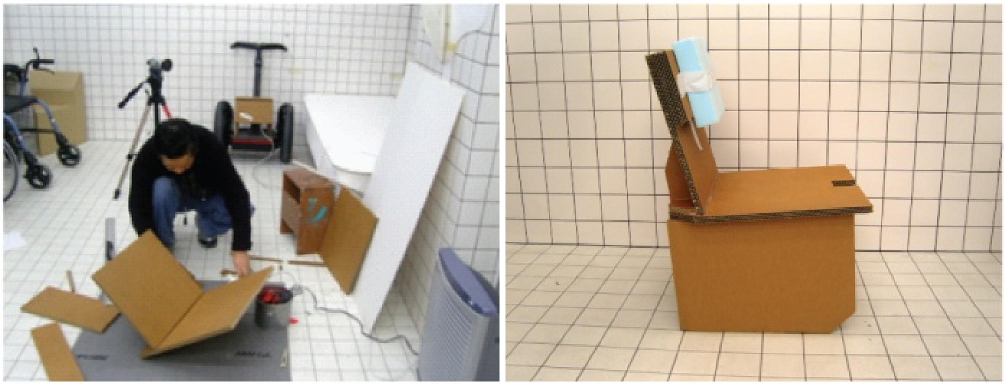

Figure.7 The chair unit (1)

Although the model with chair unit (1) has the Segway's handle, this experiment supposed a model without the handle as in Figure.9. So the user did not touch anywhere near the handle to move. However, the lever placed near the handle was used to change the direction.

Figure.8 The model with chair unit (1)

Figure.9 The image from which the handle part is deleted

The size of chair unit (1) is L470 ×W460 × H680 mm, and the height of its seat is 350mm, the length is 390mm, the angle is 3°, and the angle of the backboard is 115° (Figure.10).

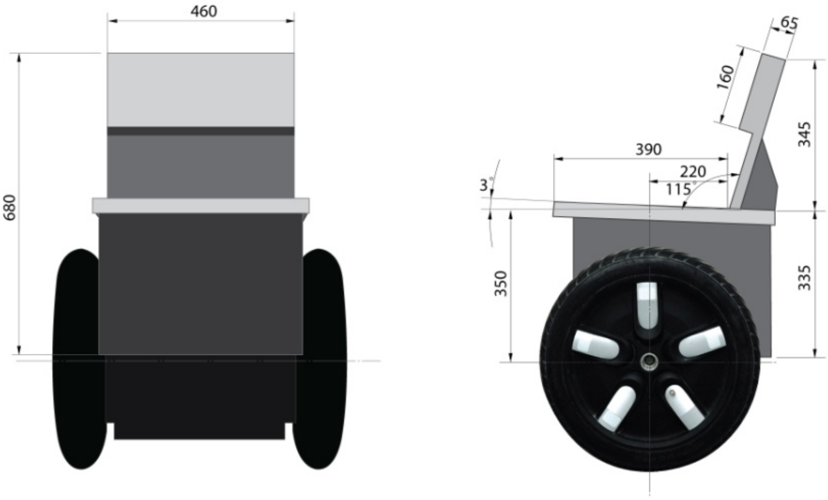

Figure.10 The size of chair unit (1)

4.4 Experiments on the movements conducted in the sitting position

Movement experiments described below were conducted with the model equipped with chair unit (1) in the Segway.

(1) Pick up books and move (Table 1).

Pick up two books on the wagon and move while holding them. After putting the books on the table, try to move away from it.

(2) Move while holding a tray (Table 2).

Pick up the pot from the wagon and pour water from it to three cups on the tray. Move to the table while holding the tray, and then put the tray on the table. Again, hold the tray lying on the table and move to the wagon to place the tray on it again.

(3) Open the door with a door closer and go out (Table 3).

Approach to the door with the door closer. Open the door and push it to go out.

(4) Use the elevator (Table 4).

Push the button at the entrance of the elevator and go into it. Press the button to reach the destination and change the direction up to 180°. Get off the elevator.

Regarding the movement experiments,

In (1), it made a slight movement due to the change of the central axis of gravity resulted from the

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addition of two books. However, if the user is familiar with the sense of balance in the Segway, he may be able to keep the balance changing the center of gravity naturally.

In (2), there was no noticeable problem while the user moved holding the tray after pouring water from the pot to the cups in the static state.

In (3), the user was able to go forward pushing through the door with his hand using the Segway's force to move forward against that from the door going back to the original position for the door closer.

In (4), the user changed the direction up to 180° in the elevator with rather a small radius of rotation and then got off it to the forward direction. And it was easily done.

Table 1 Pick up the books and move in the sitting position.

	Pick up the books lying on the wagon in the static state.
	There was a slight movement for the weight of the books, but he could recover the balance again naturally.
	(After changing the direction with the lever of the handle), he advanced forward holding the books with his both hands.
	Approach to the table and stop it to put the books on the table. *It slightly moved forward since the center of gravity went forward.
	Move backward.

Table 2 Hold the tray and move in the sitting position.

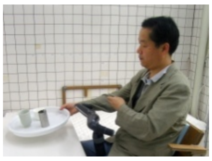
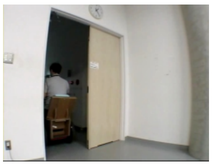
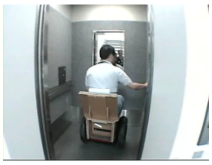
	Pour water from the pot into the three cups on the tray in the static state.
	Pick up the tray lying on the wagon in the static state. Hold the tray with both hands and move to the table.
	After approaching to the table and stopping it, hold the tray with one hand and put it down on the table. * It slightly moved forward since the center of gravity went forward.
	(After changing the direction with the lever of the handle,) Hold the tray with both hands and move to the wagon.
	Come back to the wagon and stop it to place the tray on the wagon.

Table 3 Open the door and go out in the sitting position.

Table 4 Use the elevator in the sitting position

	Approach to the door.
	Open the door with the operation of the lever on the door and advance forward.
	Push the door further and move forward.
	Pass through the door while pushing it.
	Go out while pushing the door.

	Push the button at the entrance of the elevator.
	Go into the elevator.
	Press the button to reach the destination in the elevator.
	(With the lever of the handle), change the direction up to 180°.
	Get off the elevator.

4.5 Discussion with the users about the videos recording the movement experiments on chair unit (1)

Discussion with the users was conducted in a way to exchange opinions with two actual wheelchair users (Table 5) while watching the videos recoding movement experiments, (1) through (4) (Figure.11).

Table 5 The wheelchair users participating in the discussion

Users	Characteristics
A A male in his fifties	1> The name of disorder: Cervical cord injury, C6-7 2> Dysfunction: Tetraplegia 3> Means to move: Self-drive wheelchair (for indoor/outdoor use)
B A male in his forties	1> The name of disorder: Cervical cord injury, C6-7 2> Dysfunction: Tetraplegia 3> Means to move: Self-drive wheelchair (for indoor/outdoor use)

It was promising as a device of transport operated in the sitting position to which two-wheel self-balance driving was applied. On the other hand, there also were some problems pointed out.

Wheelchair users with cervical cord damage need not just a seat but also a backboard to withstand the weight (support their upper body) in order to maintain a stable sitting position. However, the load was mostly applied to the seat in the case of chair unit (1).

Figure.11 Discussion with the wheelchair users

4.6 Designing chair unit (2)

Chair unit (2) was designed by improving chair unit (1) (Figure.12).

Although the model with chair unit (2) has the Segway's handle, this experiment supposed a model without the handle as in Figure.13. And the user did not touch anywhere near the handle to move. However, the lever placed near the handle was used to change the direction.

Figure.12 The improved model with chair unit (2)

Figure.13 The image from which the handle part is deleted

The location of chair unit (2) installed in the Segway is 30mm ahead of chair unit (1).

The user's sitting position also changed from (1) to (2) as shown in Figure.14.

In the case of chair unit (2), the backboard withstands the weight of user's upper body in both the static and driving state.

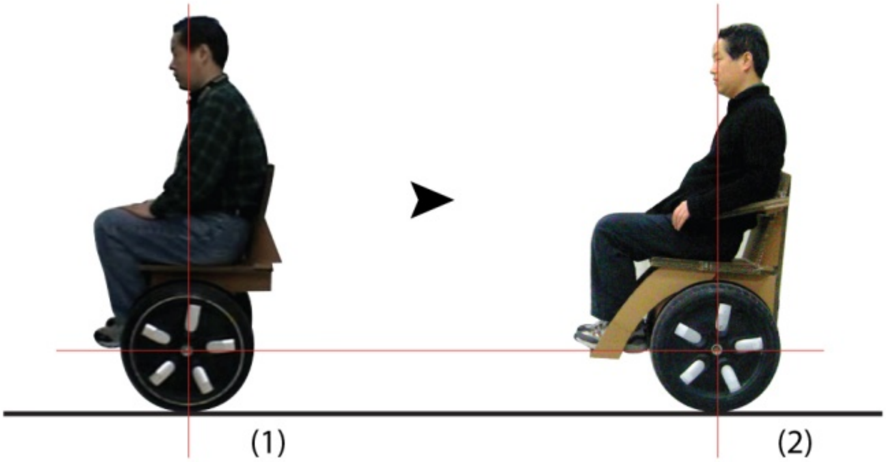


Figure.14 Comparison on the changes of the sitting position
(the image from which the handle part is deleted)

The angle of the seat of chair unit (2) changed from 3° to 6°. And the foot plate and armrests were attached on it. The basic dimension of it is as shown in Figure.15.

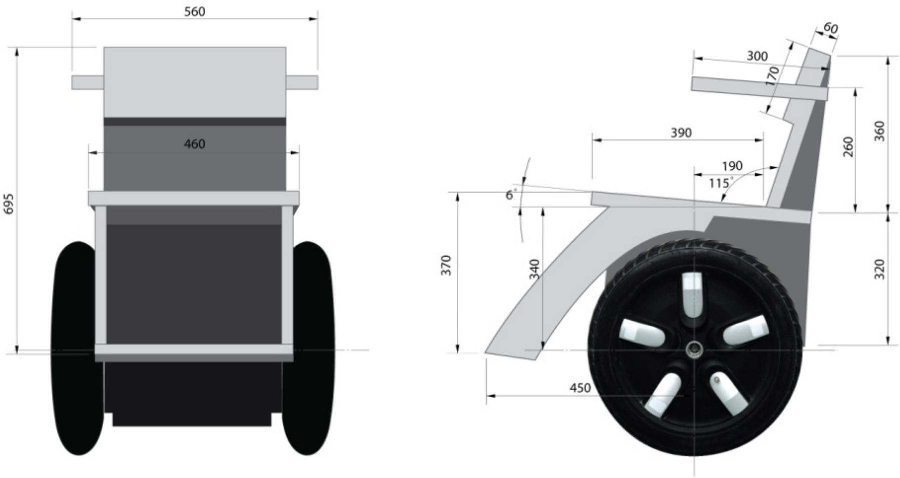


Figure.15 The size of chair unit (2)

4.7 Movement experiments on chair unit (2) while the users were present

The three wheelchair users (Table 6) were present at the place of the experiments. While everyday movements from (1) to (3) were being conducted, we exchanged our opinions for comparative analysis.

Table 6 The wheelchair users participating in the discussion

Users	Characteristics

A A male in his fifties	1> The name of disorder: Cervical cord injury, C6-7 2> Dysfunction: Tetraplegia 3> Means to move: Self-drive wheelchair (for indoor/outdoor use)
B A male in his forties	1> The name of disorder: Cervical cord injury, C6-7 2> Dysfunction: Tetraplegia 3> Means to move: Self-drive wheelchair (for indoor/outdoor use)
C A female in her thirties	1> The name of disorder: Spinal cord injury, Th-7 2> Dysfunction: Paraplegia 3> Means to move: Self-drive wheelchair (for both indoor/outdoor use)

In terms of study methods, the wheelchair user conducted everyday movements in the place supposed as indoors with the experimental model for reproduction. The procedures of the movement experiments are as written below.

Table 7 Moving to the bed

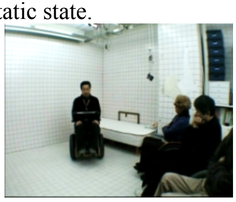
Wheelchair	The experimental model
 Approach to the bed.	 Approach to the bed.
 Approach to the bed across the room. Put on the brake and be ready to move to the bed.	 Approach to the bed in a parallel way. Move to the bed in the static state.
 Move backward from the bed. There was not enough space to move back and change the direction.	 Move backward from the bed. No need for backing.

Table 8 Deskwork

Table 9 At the kitchen

Wheelchair	The experimental model
 Approach to the kitchen counter while facing it.	 Approach to the kitchen counter while facing it.
 Put on the brake at the spot seemingly easy to work in and begin to cook.	 Stop it at the spot seemingly easy to work in. Make it pause or stop.
 Move to the sink. Release the brake and move while relying on the table with hands.	 Move to the sink. After setting it on, change the direction and move.

Wheelchair	The experimental model
 Approach to the desk. Approach to it while facing it.	 Approach to the desk. Approach to it while facing it.
 Put on the brake to stop it at the spot that seems easy to work in.	 Stop it at the spot seemingly easy to work in. Make it pause or stop.
 Drive back from the desk. Move backward and change the direction.	 Drive back from the desk. It was possible to rotate it at the spot and keep moving.

 Approach to the sink while facing it.	 Approach to the sink while facing it.
 Put on the brake and work.	 Press pause while it is still on and keep working.
 Drive back from the kitchen counter. Release the brake and move backward. Change the direction and keep moving.	 Drive back from the kitchen counter. Set it on operation from pause. Change the direction and move backward.

(1)Moving to the bed (Table 7)

Approach to the bed. Approach to the side of it to choose a spot to move to a bed. Try to move back from the bed.

(2) Deskwork (Table 8)

Approach to the desk while facing it. Choose a spot seemingly easy to work in. Try to move backward from the desk.

(3) At the kitchen (Table 9)

Approach to the kitchen counter while facing it. Move to the sink from the cooking counter. Try to move backward from the kitchen.

4.8 The result of discussion with the users

This study has found the following results based on the movement experiments on chair unit (1) and (2) and discussion with the users.

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(1) It responded to subtle changes of the center of gravity in the stable sitting position. The users could drive it only with forward or backward movements of their one hand.

(2) For changing the direction, the manual wheelchair needed more space around to operate the drive wheels. However, it was not necessary for the experimental model.

(3) It was possible to approach to the bed in a parallel way. Once the armrests were folded, the users could move their body to the side to transfer to the bed.

(4) In terms of its operational functions, it needs three switches for ‘operation’, ‘pause’, and ‘stop’. The ‘pause’ switch is for users to stop temporarily on the way to their destination and do a certain intended act before they keep moving to it. This function can be directly connected to ‘operation’ while the user is sitting on it.

(5) ‘Operation’ and ‘pause’ need a converting switch. And they should be operable even when the user’s both hands are occupied.

(6) It should be able to cope with everyday movements that are either fast or slow. For instance, when it approaches to the bed in a parallel way, the speed should be adjustable. Either fast or slow connectivity such as ‘delicacy’ should be available.

(7) User safety for the sitting drive should be ensured. An unexpected physical stop during a sitting drive may frighten the wheelchair user or even cause a dangerous situation. For such circumstances, it should be equipped with appropriate safety policies as well.

And it needs to be able to move for a while even when the power is off for the failure with systems like emergency power supply.

Figure.16 Discussion with the wheelchair users

5. Conclusion

This researcher designed a Segway-applied experimental model allowing a sitting-position drive and conducted several usual movements while sitting on it with the adjustments of the center of gravity. Thereby, it has been found that the model has a possibility to cope with various indoor activities. It was beyond expectation that the researcher could hold up the pot to pour water from it to the cups on the tray and move on while holding the tray without much difficulty. However, what is still needed to be verified is whether the user can maintain a firm sitting position with the support of its seat and backboard so that it can be applied to the actual wheelchair users. Having no need to operate drive wheels means that not only the user can use his both hands in it but also it takes less space to move around since space for the drive wheels is no longer necessary. Moreover, it allows the user to move to a place like where the bed is more easily. However, it still requires proper switching or better quality for moving so as to let its users feel more pleased while they are doing everyday activities. Moreover, it has to clear up safety issues as well.

This designer conducted the experiments with the hypothetical model and examined the results with the actual wheelchair users. The presence of the users was a great help to figure out crucial conditions for designing it and assure its possibility as well. It must be an effective method in conducting a hypothetical design experiment with potential problems related with safety. Based on this result, this researcher would like to be in pursuit of developing a suitable means into the chairing vehicle for our life space.

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