Segway Running Behavior focusing on Riders' Experience based on Image Processing Data

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Abstract: This paper analyzes the fundamental characteristics of the Segway's running behavior by means of experiments conducted on a test course, with a focus on the difference in the time the participants had been riding the Segway. Trajectory data for the Segway were collected from 14 male subjects, with five running situations being assumed: acceleration, deceleration, slalom running, overtaking and passing pedestrian, and emergency braking. The experimental results show that there is a difference between beginners and experienced users in deceleration and rotational behavior, as experienced users could smoothly decelerate and had only a small variance in rotational movement during the slalom test, while beginners tended to make jerky movements. The emergency braking experiments showed there is not much difference according to experience, and furthermore, they indicated there was similarity with the stopping behavior of a bicycle. These results are expected to be useful in designing a Segway training scheme, and evaluating the use of the Segway on public roads as well as appropriate rules and regulations such as using a microscopic traffic simulation.

Keywords: Segway, Personal Mobility, Driving Behavior, Image Processing, Field Experiment

1. INTRODUCTION

In the past few years, an electronic two-wheel personal transporter (PT), which is known as the Segway, is being used as a new transport mode, especially for short trips, in Europe, the United States and other countries. This is expected to contribute to an improvement in mobility for not only young people, but also for elderly people as the Segway can be ridden with simple handling. The PT is already in use on public roads for traveling around cities, patrolling, and sightseeing tours and so on. Therefore, rules for using a PT on public roads are being considered and discussed in order to maintain safety and an efficient traffic flow. In Japan, on the other hand, discussions on allowing the use of PTs on public roads have only just started, such as in the case of the Tsukuba Robot Special District area, which is the only city in Japan where one can ride a PT on the road. Currently, the use of a PT on public roads, like in Europe, the United States and other countries, is illegal under Japanese law.

The reason there is difficulty in riding a PT (Segway in this paper) in Japan is due to the difficulty in complying with Japanese law on road traffic and operation. The Segway has a 3-kW (Segway Japan, accessed 2012) motor and two wheels, and it is therefore classified as a small motorized car by definition of the law. Under Japanese law, a small motorized car is required to have brakes and lights, which would mean fitting these to a Segway to satisfy the legalities for use on the road. However, it is not an easy task to mount such safety equipment on a Segway, due to the Segway's operation characteristics. In countries where it is legal to ride a Segway on public roads, it is frequently used to patrol city centers, shopping malls and airports, as well as being utilized on sightseeing tours over large areas of a city in harmony with other transport modes such as bicycles, pedestrians and other road traffic (Darmochwal and Topp, 2006). There are also some cases where a PT is defined by law as a mobility aid for the handicapped. That means there is gap between the definition of Segway under the law in Japan and its envisioned usage. The main reason for the gap is that the Segway's running characteristics and safety on public roads is not sufficiently understood. As for understanding the Segway's running characteristics, several studies have been conducted. Miller et al. (2008) analyzed the running behavior in the avoidance of a box on an experimental road. Emori et al. (2009) analyzed the Segway's running behavior with respect to its ability to avoid objects in consideration of sharing the road with pedestrians. Nishiuchi et al. (2010) analyzed the private space required to maintain the safety of Segway riders in comparison with that of cyclists and also analyzed the characteristics of the perception Segway riders had under different levels of pedestrian occupancy of a space. Nakagawa et al. (2010) conducted studies to evaluate the safety of the Segway and the degree of security with respect to a pedestrian walking space with a simulated pedestrian flow modeling a shopping mall area, and they showed that Segway riders can have a sense of awareness of pedestrians comparable with that of cyclists. However these studies did not clarify the fundamental behavioral characteristics of a Segway such as acceleration, deceleration, meandering, circling and stopping, even if they did mentioned the reaction of pedestrians and the Segway's running characteristics under specific situations, which may not necessarily occur on an actual public road. Therefore, there remains difficulty in evaluating the safety in situations involving a mix of Segways, pedestrians and bicycles.

If the fundamental behavior such as acceleration, deceleration, meandering, circling and stopping of a Segway can be quantitatively shown, it will be possible to establish the parameters to develop PT behavior models for installation in a microscopic traffic simulation. This means that the safety and efficiency of a space shared with a Segway can be evaluated from the traffic engineering point of view. To this end, Goodridge (accessed 2012) has reported the results of an empirical Segway experiment to collect fundamental Segway behavior data. The data showed the stopping distance to be 25 feet to 41 feet running at 15 mph. However, this experiment was conducted using just one subject. In actuality, one can easily imagine that the rider may not be familiar with operating a Segway. These experiments and data need to take into consideration the difference in Segway running behavior caused by the difference in the riding experience of the riders.

This research aims to understand and report on the Segway's running behavior from a traffic engineering point of view under the assumed situation of a Segway on a real public road. A total of 14 subjects with different levels of experience in riding a Segway took part in the experiments and their fundamental behavior in acceleration, deceleration and slalom were analyzed. In addition, overtaking and passing as well as emergency braking were analyzed in comparison to bicycle behavior, which can be assumed to have a similar behavior and role as a Segway as a bicycle is defined as having a speed range from 8 to 20 km/h (JSTE, 2005). These analyses and comparison results could be used as basic values of running characteristics and clarify the Segway's position as a mode of transport. In addition, this paper includes insights gained from the experimental results focusing on the differences in Segway riding experience and also what should be noted if Segways were allowed to be used on public roads.

2. SEGWAY RIDING EXPERIMENTS

2.1 Overview of the Segway

The Segway is a personalized electronic two-wheel vehicle that was developed in the United States in 2001. The rider operates it by standing on a weight sensor plate located between the two wheels. The Segway used in the experiments is the i2 model that was commercially available as of 2006, as shown in Figure 1. Table 1 shows its basic specifications such as maximum speed and motor power.

Figure 1. Segway i2 Model

Table 1. Basic specifications of Segway used in the experiments

Model	Segway i2 (base model)
Max Speed	20 km/h （High Speed Mode） 10 km/h （Beginner Mode） (Max speed is controlled according to the mode by limiter control)
Cruise Distance	14km-19km (Full Battery)
Weight	54.4kg
Length wide	67cm×84cm
Carrying Capacity	45～118kg include rider
Battery	Li-ion Battery Pack (2 set)
Motor Power	1 wheel: 1.5kW, Total 3.0kW

2.2 Outline of Segway Experiment

The experiment was conducted at the experiment site of the College of Science and Technology at Nihon University on February 21, 2011. The course was laid out as shown in Figure 2. The Segway run the course in sections as divided by color cones according to the contents of the experiment. The experiment was recorded by a video camera positioned on the sixth floor of a building neighboring the experiment site. Image-processing data prepared from the video record were used to the create Segway's running trajectory.

As the purpose of this experiment is to provide information for a discussion on the difference in running characteristics according to a rider's experience in operating a Segway, the participants were selected to have attributes and physical abilities that were as similar as possible to each other, so we did not recruit participants of markedly different ages and physical ability. Therefore, this research focuses on males aged 20 to 30 years. The experience of the participants was two beginners and 12 people with varying degrees of experience. The length of time the 12 participants have been riding a Segway and the frequency of riding are show in Table 2.

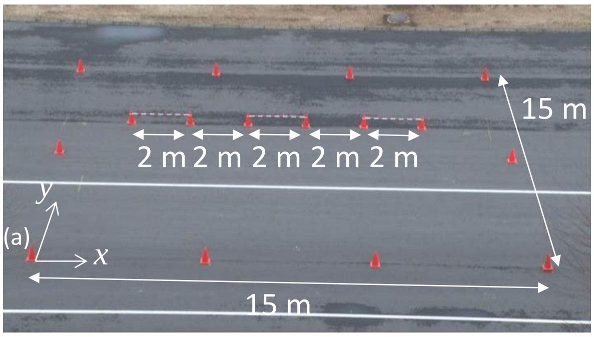

Figure 2. Segway Experimental Course

Table 2. Experience of Segway Riding

Segway Ride Frequency	Timing of first segway ride			
	2007	2009	2010	2011
A few times in a year	0	1	0	2*
Less than 1 time in a month	0	5	3	
More than 1times in a month	1	0	1	
More than 4 times in a month	1	0	0	

* they are first time ride of Segway at this experiment

2.3 Segway Running Situations for Survey Measurement

One of the purposes of the experiments is to provide fundamental information on the Segway's running behavior characteristics to develop a Segway running behavior model. Therefore the contents of the experiments took into consideration fundamental Segway's behavior such as acceleration, deceleration, slalom, overtaking and passing as well as emergency braking. Explanations of each of these factors are provided below.

1) Acceleration and Deceleration

Acceleration and deceleration is one of the most fundamental behaviors of Segway riding. For the acceleration experiment, the rider accelerates until the maximum speed allowed by the limiter function of the Segway is reached for each running mode (beginner or otherwise) in the course area, see Figure 3. For the deceleration experiment, after maximum speed is achieved outside the course area, the riders try to stop around the middle of the course (see figure 4). For both tests, the experiment was implemented twice, once in beginner mode and once in non-beginner mode.

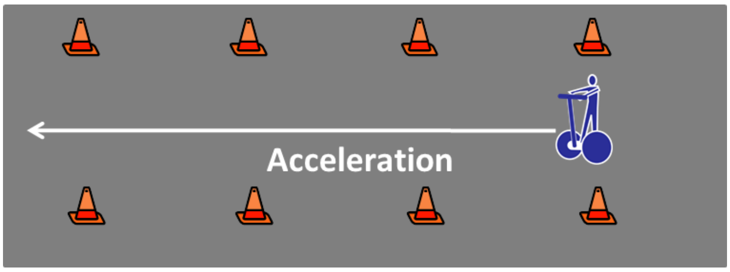

Figure 3. Acceleration Experiment

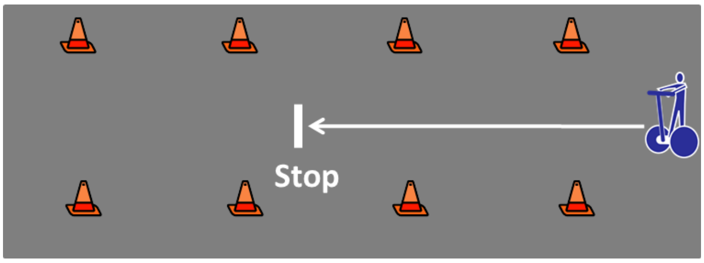

Figure 4. Deceleration Experiment

2) Slalom

Segway running trajectories in a slalom were measured to see how well the Segway can avoid obstacles using a circling angle. The slalom experiment also was implemented twice in two running modes, and the participants run the course in both rounds. However, the authors asked the participants to run the course maintaining a safe posture and speed, even if the experiment had to be repeated due to a difference in running mode (see Figure 5).

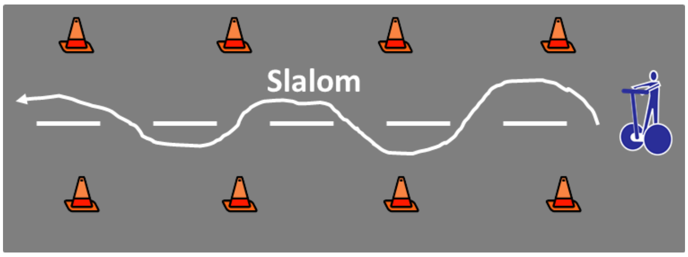

Figure 5. Slalom Experiment

3) Overtaking and Passing

Crossing the path of pedestrians needs to be considered when a Segway running behavior model is developed assuming the Segway's introduction on city streets. This experiment focused on the simplest situation of relative speed with one pedestrian, relative distance when the overtaking and passing experiment starts, and the cross direction distance when overtaking and passing between pedestrians and the Segway. This experiment was also performed twice for overtaking and passing in different running modes (see Figure 6).

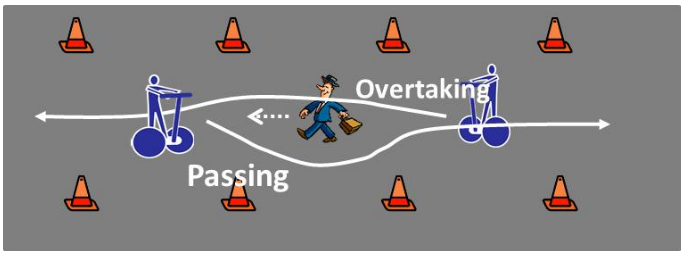

Figure 6. Overtaking and Passing Experiment

4) Emergency braking

A situation in which the Segway has to stop quickly in the event a pedestrian, bicycle or other vehicle suddenly appears from around the corner of an intersection or narrow road can be a point of discussion when introducing the Segway as a new transport mode on public roads. Therefore, this experiment includes sudden stops of the Segway, signaled by a camera strobe. The Segway has to stop quickly when the rider sees the strobe flash. This experiment was also implemented twice, the same as the other tests (see Figure 7).

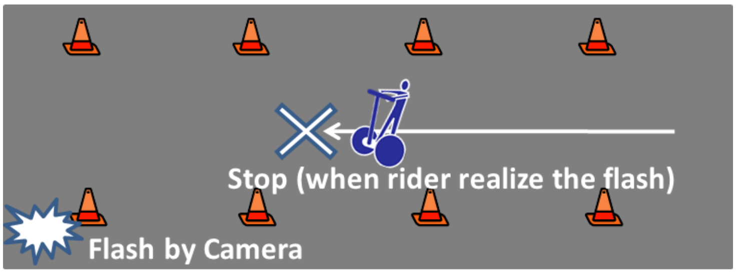

Figure 7. Emergency Braking Experiment

2.4 Collection of Image-Processing Data

This paper analyses the experimental results by using Segway trajectory data based on video image sensing. Video image data is collected every 1/10th of a second, and the coordinates in the image data of the Segway and pedestrians (in the passing and overtaking experiment) are processed as shown in Figure 8. In processing the coordination data, the grounded point of Segway's tire is sampled. The grounded point from the center of gravity point of the pedestrians is assumed the as the coordinate data for pedestrians. The processed coordination data is transformed into a plane coordinate system of the experiment course from the one in the photo plane by using projective transformation. In addition to the above, approximation by equalization spline conversion is conducted to modify errors in coordinate data collection. The positive direction of the x-axis and the y-axis set the right direction and the upper direction, the origin point set as the cone position (a). Then the estimated speed (m/s), acceleration (m/s^2) and angle of direction, from the above video data processing, was used in this analysis.

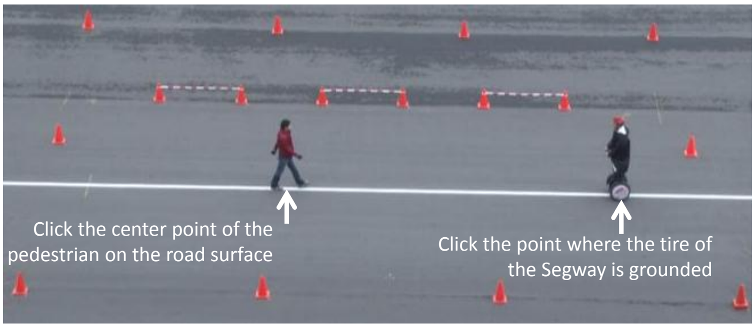

Figure 8. Gravity Point for Image Data Processing

3. FUNDAMENTAL CHARACTERISTICS OF THE SEGWAY'S BEHAVIOR

3.1 Acceleration and Deceleration

The characteristic of acceleration is discussed here. Figure 9 (high-speed mode) and Figure 10 (beginner mode), demonstrate the relationship between the time of the start of measurement and acceleration. Each line represents different participants and the different colors show when a participant first started riding a Segway. Each figure shows a tendency to decrease speed, enforced by the limiter function, at around 6 [m/s] in the high-speed mode and around 4 [m/s] in the beginner mode. There is also a difference in acceleration tendency according to the rider's experience. In particular, the speed of beginners tends to vary according to time-series measurement. To see the statistical difference in the tendency of speed data according to the attributes of participants, a two-way analysis of the variance (ANOVA) of length of riding experience and high-speed mode was conducted (see Table 3), and this shows there is significantly difference by 1% statistical level by running mode. However, no difference was found by length of riding experience and the interaction between this and running mode because the average acceleration for the high-speed mode was 0.799 m/s^2 (standard deviation: 0.214 m/s^2), compared to that for beginner mode (average acceleration: 0.458 m/s^2, standard deviation: 0.165 m/s^2). Furthermore, the start of acceleration of a bicycle is 0.716 m/s^2 (Harada, et al., 2011) and a two-wheel vehicle's acceleration is 2.94 m/s^2 (Hanamori, et al., 2010). Therefore, the acceleration level of the Segway can be considered to be the same as that of a bicycle.

For deceleration, the results of the running experiment shown in Figures 11 and 12 are the same as the results for acceleration. There is a slower pace in deceleration in beginner mode, even if there is almost the same speed change in high-speed mode. The speed of beginners tends to vary according to time-series measurement, the same as the tendency in high-speed mode. To ascertain the difference by rider attributes, a two-way ANOVA was conducted using the same factors as the analysis for acceleration. However, data for the test are collected if the speed is decreased to 1 [m/s] from the measured maximum speed. Table 4 shows the results of the test. The table shows there is a significantly difference by 1% statistical level by the length of riding experience and the running mode. However, no difference was found by length of riding experience and the interaction between this and running mode.

To see more details of the significance of the difference in length of riding experience, multiple Bonferroni comparisons are conducted. Table 5 shows that there is a significant difference between participants who started riding in 2007 and other years, and there is a tendency toward a higher level of deceleration for these 2007 riders. Therefore it can be said that Segway riders who have longer experience can decelerate smoothly even if there is a limited number of samples.

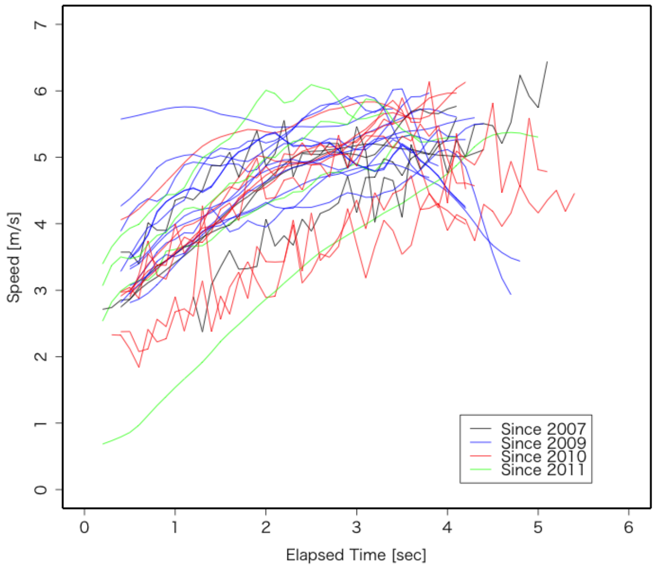

Figure 9 Elapsed time and speed in acceleration (high-speed mode) by riding experience

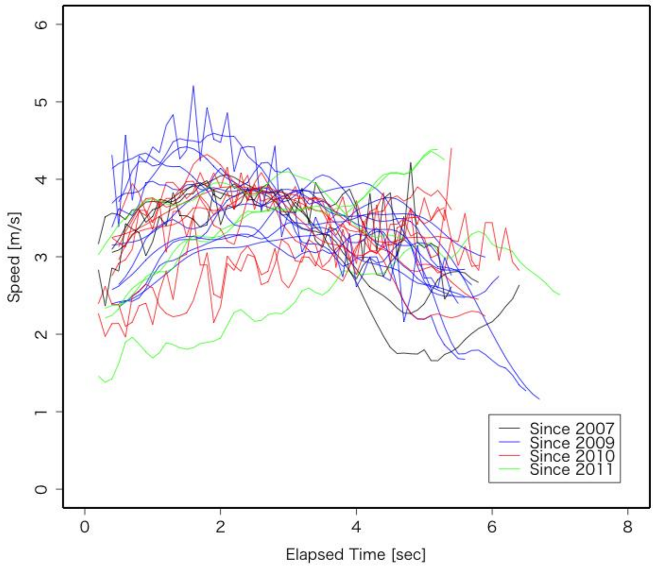

Figure 10 Elapsed time and speed in acceleration (beginner mode) by riding experience

Table 3 ANOVA of acceleration experiment

Factors	Square Sum	Degree of Freedom	Average Square	F-Value
(a) First Ride Timing	0.057	3	0.019	0.53
(b) Running Mode	1.587	1	1.587	44.19*
Interaction (a) * (b)	0.200	3	0.067	1.852
Error	1.687	47	0.036	
Total	25.47	55		
Modified Error	3.546	54		

* P < 0.01

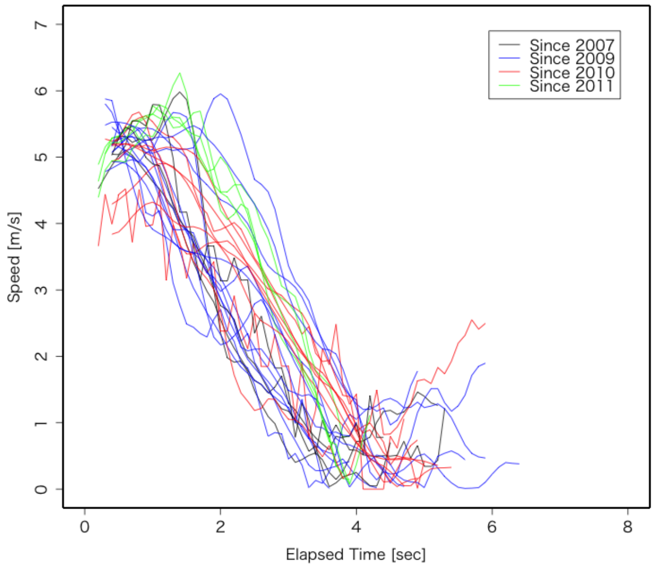

Figure 11 Elapsed time and speed in deceleration (high-speed mode) by riding experience

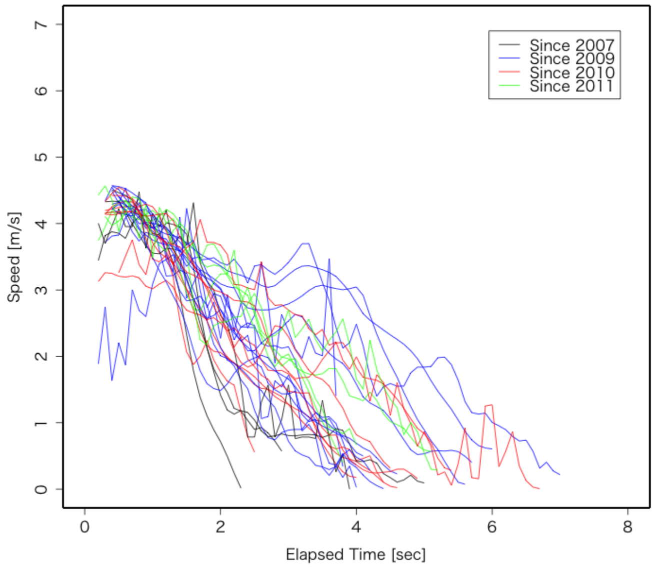

Figure 12 Elapsed time and speed in deceleration (beginner mode) by riding experience

Table 4. ANOVA of deceleration experiment

Factors	Square Sum	Degree of Freedom	Average Square	F-Value
(a) First Ride Timing	3.226	1	3.226	19.81*
(b) Running Mode	4.826	3	1.609	9.878*
Interaction (a) * (b)	1.014	3	0.338	2.975
Error	7.491	46	0.163	
Total	141.22	54		
Modified Error	17.046	53		

* P < 0.01

Table 5. Multiple comparison of length of riding Segway

		(J) 2007	2009	2010	2011
(I)	2007		0.744(0.167)*	0.921(0.175)*	0.656(0.202)**
	2009			0.147(0.133)	-0.117(0.167)
	2010				-0.265(0.175)
	2011				

Values in table shows error (I - J). Values in brackets is standard error.

* P < 0.01, ** P < 0.05

3.2 Slalom

This paper ascertains the relationship between running speed and rotating angle during a slalom course experiment. Figures 13 and 14 show the slalom experiment results for high-speed mode and beginner mode, respectively. In the figures, the relationship between running speed and rotating angle for each time step (1/10 s) is described. However, note that the rotating angle is defined as the angle by speed vector between time *t*[s] and *t*+0.1[s].

Both figures show that riders can avoid objectives with almost the same variation of rotating angle regardless of experience in both high-speed mode and beginner mode. Tables 6 and 7 show the results of a statistic test to confirm the difference of distribution of rotating angle by groups sorted by Segway ride experience. The results show a statistical difference could not be confirmed among the groups as the P-value is greater than 0.8. Therefore, Segway riding behavior during slalom running does not seem to be affected by Segway riding experience.

On the other hand, running speed tends to be higher among experienced Segway riders from the running speed distribution during the slalom ride as shown in Figures 15 and 16. Moreover, Tables 8 and 9 show there is statistical difference by Segway riding experience as the P-value is less than 0.01. Therefore, the distribution of slalom running speed for different Segway riding experience has a statistical significant difference by 1% of probability.

Figures 17 and 18 show the running trajectory of all participants for the first of four slalom experiments for each speed mode. Even if the statistical test results could not show a difference according to Segway riding experience, some riders, who are really beginners, possibly felt unsteady doing the course. Therefore, it should be noted that suitable training is important for the beginners when they are required to ride a Segway smoothly and at high speed and they need to be able to avoid obstacles.

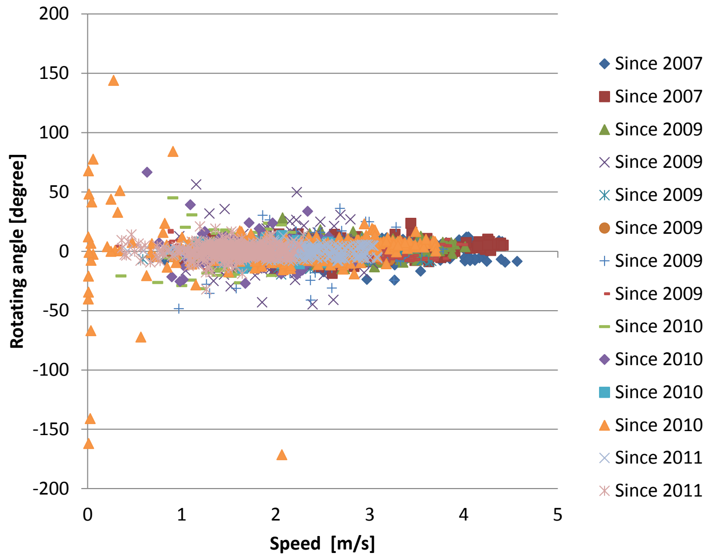

Figure 13 Speed and rotating angle on slalom course in high-speed mode

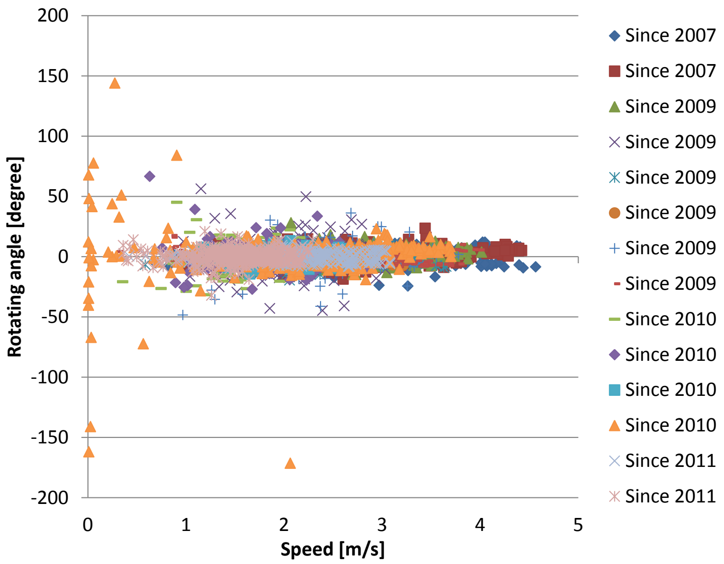

Figure 14 Speed and rotating angle on slalom course in beginner mode

Table 6 ANOVA of rotating angle on slalom course in high-speed mode

Source of Variation	Sum of Squares	df	Mean Square	F0	P-Value
Between groups	55.647	3	18.549	0.230	0.875
Error (within groups)	329857.840	4092	80.610		
Total	329913.487	4095			

Gropus: since 2007, since 2009, since 2010, and since 2011

Table 7 ANOVA of rotating angle on slalom course in beginner mode

Source of Variation	Sum of Squares	df	Mean Square	F0	P-Value
Between groups	45.910	3	15.303	0.263	0.852
Error (within groups)	270692.909	4651	58.201		
Total	270738.818	4654			

Gropus: since 2007, since 2009, since 2010, and since 2011

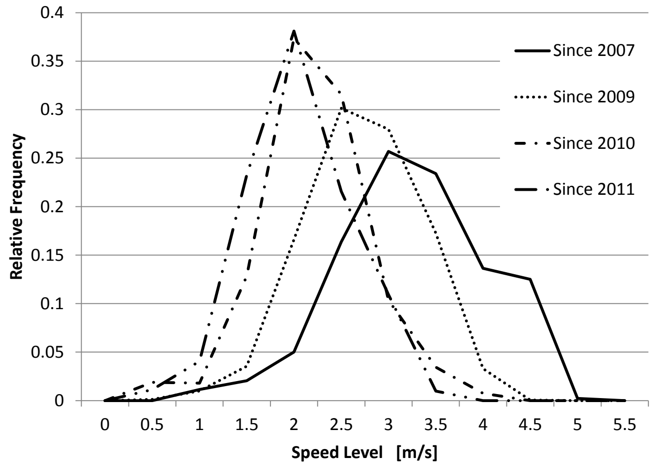

Figure 15 Speed distributions on slalom course in high-speed mode

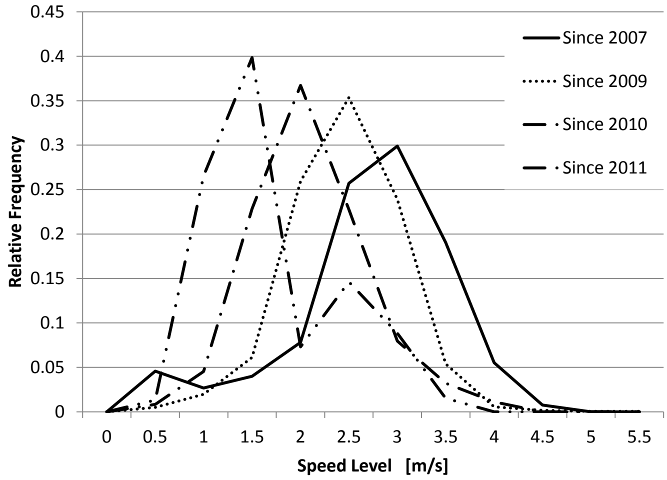

Figure 16 Speed distributions on slalom course in beginner mode

Table 8 ANOVA of speed on slalom course in high-speed mode

Source of Variation	Sum of Squares	df	Mean Square	F0	P-Value
Between groups	585.288	3	195.096	554.646	0.000
Error (within groups)	1439.355	4092	0.352		
Total	2024.643	4095			

Gropus: since 2007, since 2009, since 2010, and since 2011

Table 9 ANOVA of speed on slalom course in beginner mode

Source of Variation	Sum of Squares	df	Mean Square	F0	P-Value
Between groups	520.411	3	173.470	448.392	0.000
Error (within groups)	1799.344	4651	0.387		
Total	2319.755	4654			

Gropus: since 2007, since 2009, since 2010, and since 2011

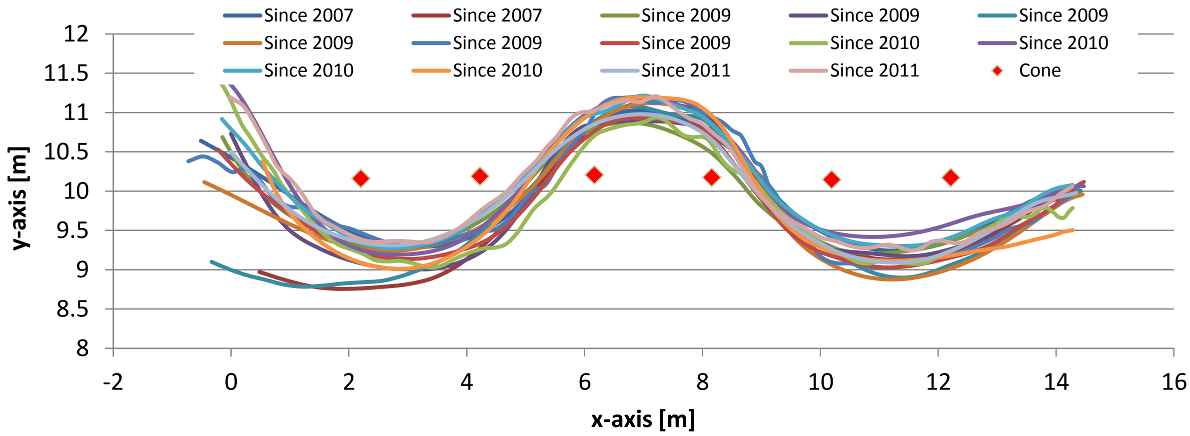

Figure 17 Trajectories of the Segway on slalom course in high-speed mode

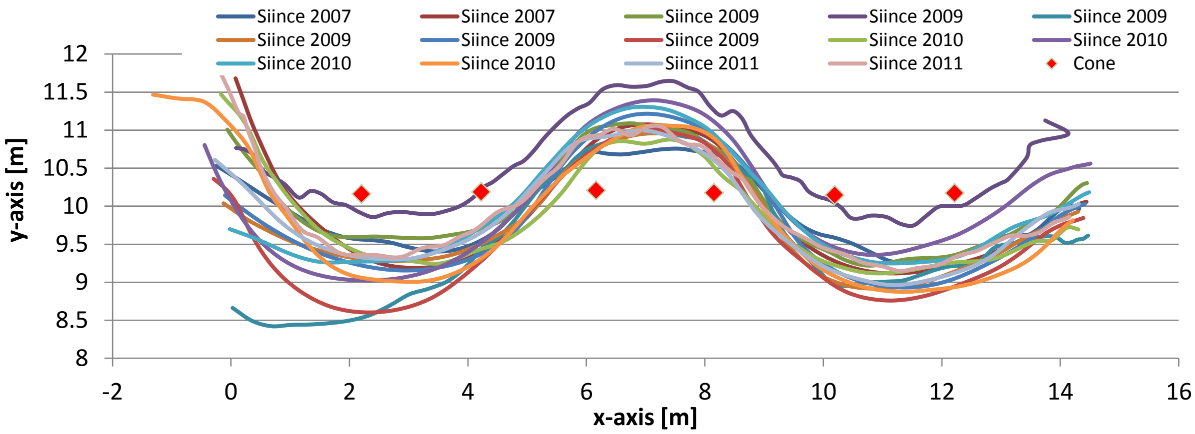

Figure 18 Trajectories of the Segway on slalom course in beginner mode

4. COMPARATIVE ANALYSIS WITH A BICYCLE'S BEHAVIOR

It is expected that the Segway has a similarity with bicycles in terms of running behavior, because the cruising speed of both vehicles is almost same. In this section, the Segway's running behavior in passing and overtaking a pedestrian and in a situation where emergency braking is required is compared with that of bicycles. The running characteristics of bicycles were taken from the Handbook of Traffic Engineering (JSTE, 2005).

4.1 Passing and Overtaking

Understanding the behavioral characteristics of the Segway in responding to nearby pedestrians is essential in order to be able to evaluate the safety and the efficiency of a shared traffic space with pedestrians and the Segway. Among the various interactive behaviors, the behavior of passing and overtaking is focused on in this section.

Figure 19 shows an example of a time-space diagram of the trajectories both of the Segway and a pedestrian when the Segway overtakes a pedestrian. The left and right axes indicate the x and y coordinates, respectively, of the Segway and the pedestrian in the experimental field at a given time. In the figure, the line indicated by (a) refers to the distance between the Segway and the pedestrian at the time when the Segway changes direction to overtake or pass the pedestrian, while the line indicated by (b) refers to the lateral distance between the Segway and the pedestrian when the Segway passes the pedestrian. These two distances are considered as indices characterizing the behavior of the Segway and then analyzed by taking into account each rider's experience.

Figure 20 shows the relationship between the relative speed between the rider and the pedestrian and the distance when changing direction. Figure 21 shows the relationship between the relative speed and the lateral distance when passing by or overtaking a pedestrian. In both figures, the cases of passing and overtaking are mixed and depicted in one figure. Because the relative speed is defined as the differences between the speed of the Segway and the pedestrian (namely, $r = v_s - v_p$, where r is the relative speed, v_s is the speed of the Segway, and v_p is the speed of the pedestrian. As for the speed, the moving direction of the Segway is defined as positive), the lower relative speed refers to a case of overtaking and the higher refers to a case of passing.

It is clear in Figure 20 that, as a whole, the distance linearly increases as the relative speed increases. Figure 20 also shows the results of linear regressions estimated depending on riding experience. The constant value of the linear equation implies the minimum distance that the Segway can get to a pedestrian, so it can be interpreted as the sum of the personal spaces of the Segway and the pedestrian. The coefficient variable in the relative speed is the time to reach the minimum distance from the pedestrian if the Segway and a pedestrian maintain their speed, which can be interpreted as the safety margin to avoid a collision with the pedestrian. Focusing on the differences of the coefficient according to riding experience, it can be seen that the longer the riding experience, the smaller the coefficient, while the minimum distances are almost the same level regardless of experience. This implies that users with less riding experience tend to be more careful about avoiding a collision with a pedestrian. In other words, the more experienced users can move quicker and more agilely, which is better suited to riding the Segway in a crowded situation.

Figure 21 shows that as the relative speed increases, the lateral distance slightly decreases. At the time when the Segway is about to overtake a pedestrian, the relative speed is relatively low and the Segway should aggressively accelerate to overtake the pedestrian. That is why the Segway needs more lateral distance in the case of overtaking than the case of a Segway and a pedestrian. According to the Handbook of Traffic Engineering, this tendency was reported for bicycles overtaking and passing pedestrians. Concretely, the handbook states that the average lateral distance in the case of passing each other is 1.2 [m], while in the case of overtaking it is 1.4 m. Thus, the Segway has the same tendency as bicycles in terms of behavior in passing and overtaking.

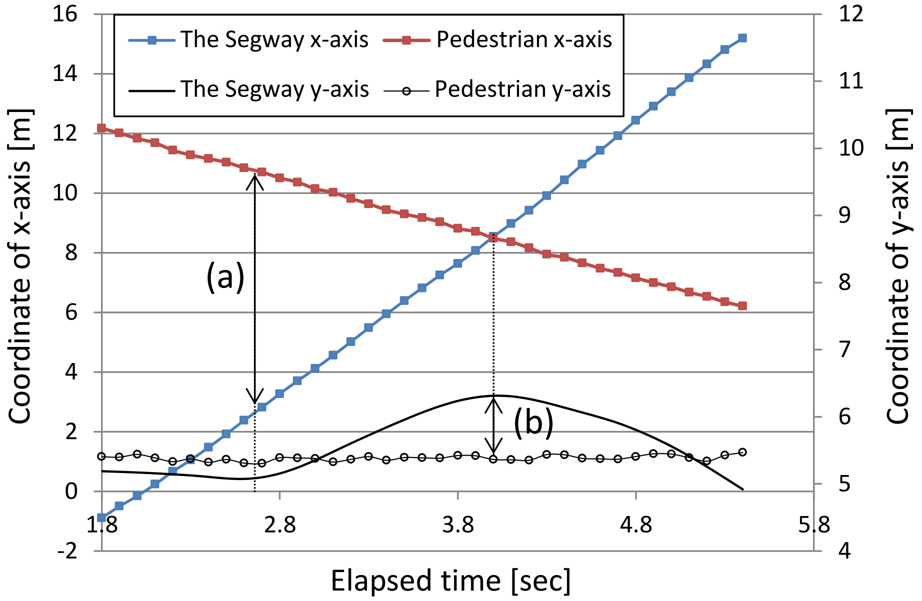

Figure 19 Example of trajectories of the Segway and a pedestrian

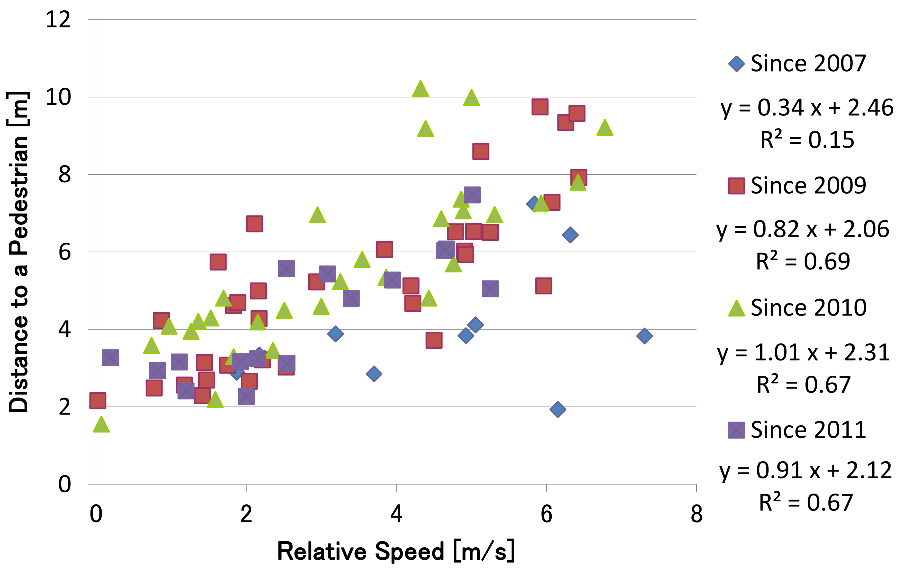

Figure 20 Relationship between relative speed and distance to a pedestrian when the Segway changes direction
(Note: Except for “Since 2007”, all coefficients and intercepts are significant with 1 % level.)

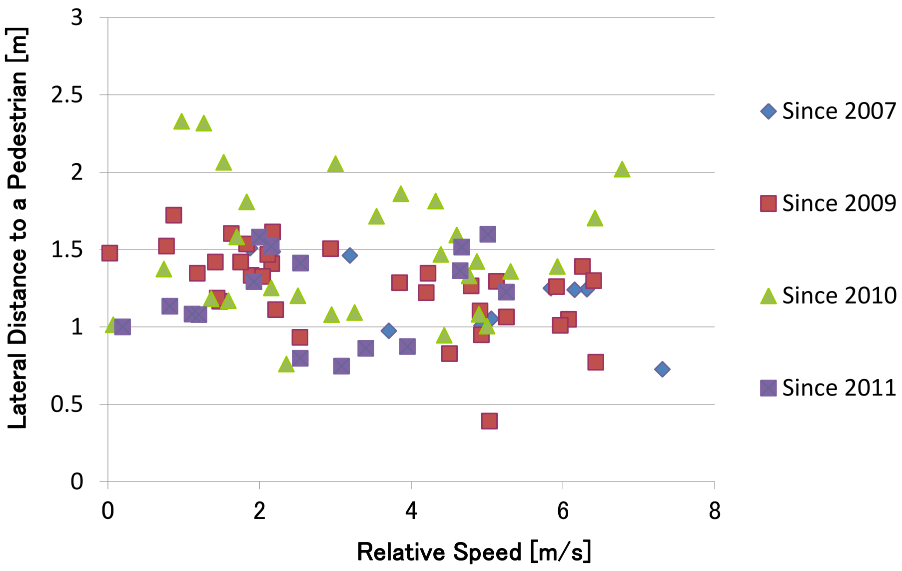

Figure 21 Relationship between relative speed and lateral distance to a pedestrian just when Segway past Pedestrian

4.2 Emergency braking

It is essential to understand the behavioral characteristics of emergency braking in the event of an emergency in order to evaluate the safety of the Segway in the public realm. In this study, experiments in which the Segway rider had to brake quickly upon noticing a flash from a camera strobe were executed to ascertain this. Note that there were some experimental cases in which the flash was not recorded properly by the video camera because the time duration of the flash was too short. In further analyses, the data of such cases were eliminated.

Generally, emergency braking behavior consists of the following four phases: 1) the rider notices an emergency, 2) the rider reacts to it and operates the brake, 3) the brake begins to work, and 4) the rider stops completely. The time duration from phase 1 to phase 3 is defined as idle running time, and the time duration from phase 3 to phase 4 is defined as braking time. Figure 22 shows one example of the time-series change of moving speed of the Segway after a strobe flashes. Line (a) in the figure shows the time when the light flashes, line (b) shows the time when the Segway starts deceleration and line (c) shows the time when it stops completely. It is interesting to note that just before the Segway starts deceleration, its speed slightly increases. This could be observed in almost all participants. This might be due to the Segway's unique operating manner, in which the rider of the Segway leans forward to accelerate and backward to decelerate. In an emergency, the rider might grasp the handle to lean backward quickly, and at that time the gravity center might slightly move forward. Consequently, the driving forth was generated in the Segway without any conscious act of the rider and this might be the reason for the slight acceleration shown in Figure 22. This moving characteristic is unique to the Segway, which generates the driving and deceleration force by shifting the weight of the body. In future work, such unique movement characteristics should be evaluated from the aspect of the impact on the safety of surrounding pedestrians. In this analysis, we focus on the time duration (or distance) from (a) to (b) defined as idle running time (or distance) and the time duration (or distance) from (b) to (c) defined as braking time (or distance).

Figure 23 shows the relationship between driving speed and idle running time according to riding experience. The figure shows that the idle running time is distributed within 0.4 s to 0.8 s, and its correlation with speed is not significant. It is reported that the idle running time of bicycles is approximately 1.0 s (JSTE, 2005), which is higher than that of the Segway in the experiment. The reason for this might be that in an experimental environment the riders pay more attention to the flash than in the field.

Figure 24 shows the relationship between driving speed and stopping distance, which is defined as the summation of idle running distance and brake distance. It can be seen that the speed and the stopping distance has a positive relationship and differences depending on riding experience are not significant. According to the Handbook of Traffic Engineering (JSTE, 2005), the stopping distance of a bicycle is 6.1 m when it is moving at 15 km/h, and 15 m when it is moving at 30 km/h, which is on the almost same line as the results of the Segway as shown in Figure 24. To confirm this similarity of the Segway and bicycles statistically, a t-test is applied to two distributions: one is the distribution of the residual errors between the observed stopping distance and the estimated stopping distance based on the linear equation of the Segway ($y = 1.90x - 0.979$), and the other is the distribution of the residual errors between the observed stopping distance and the estimated stopping distance based on the linear equation of bicycles ($y = 2.15x - 2.60$). In this test, the null hypothesis is H0: the means of two distributions are equal. If the null hypothesis is rejected, it implies that the relationship between the speed and the stopping distance of bicycles does not fit the observed relationship of the Segway. The results of Welch's t-test, where it is assumed that the variances of two distributions are not equal, are shown as follow:

t-statistics = -1.718, df = 50.0, p-value = 0.092.

This result does not support the null hypothesis at a 5% significance level. Thus, we cannot conclude that the linear equation of speed and stopping distance of bicycles is not equal to that of the Segway. It implies that there is no clear difference between the Segway and bicycles in emergency braking behavior.

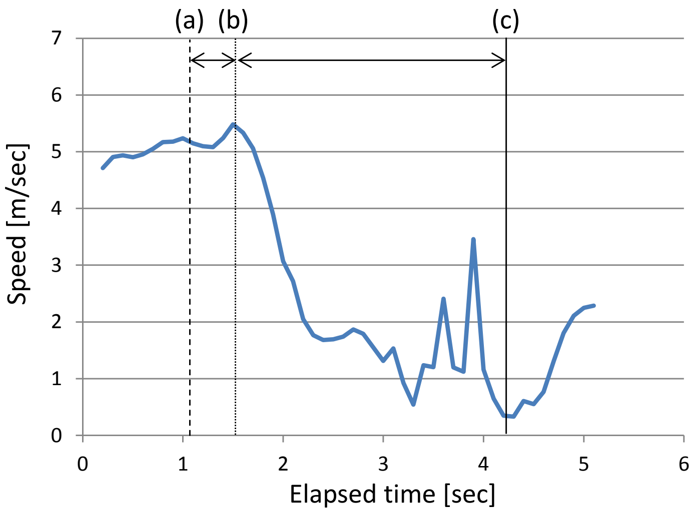

Figure 22 Example of sequential speed change after strobe flashes

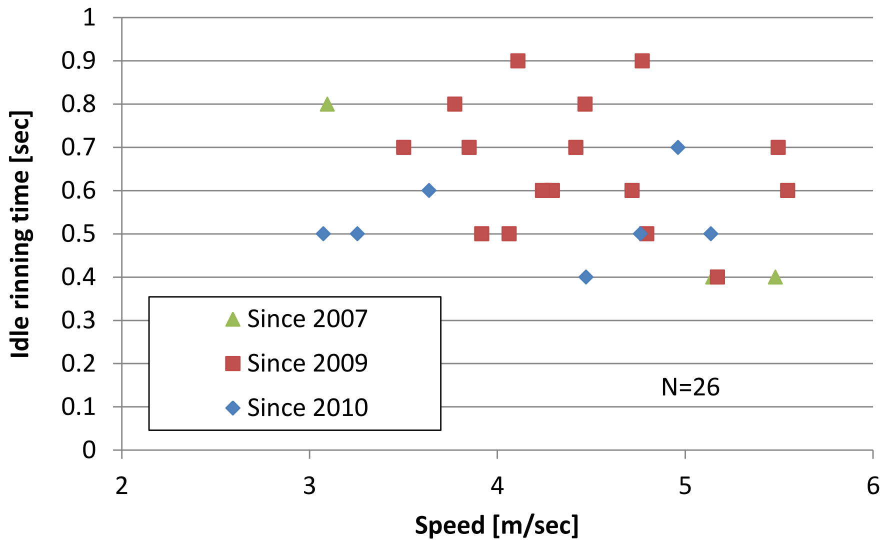

Figure 23 Speed and idle running time by riding experience

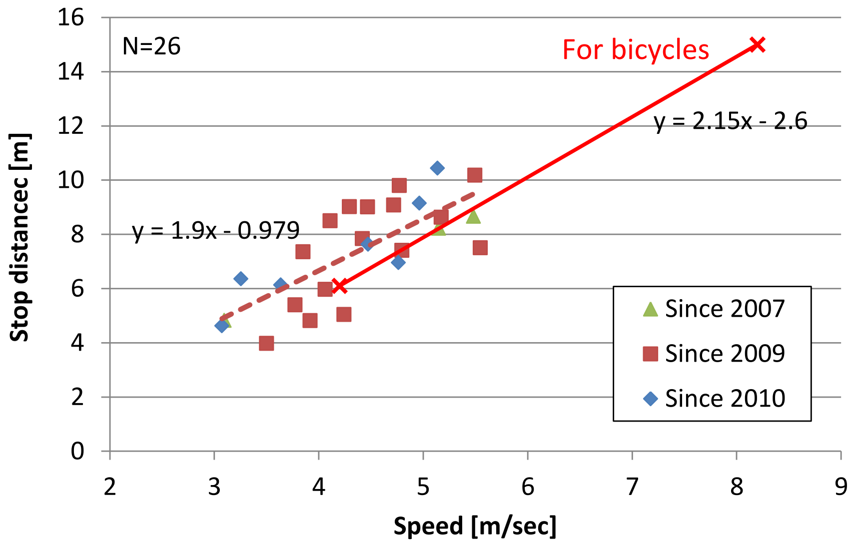

Figure 24 Speed and stop distance by riding experience
(Note: The coefficient of the linear equation of the Segway is significant with 1% level, though the intercept is not significant.)

5. CONCLUSIONS

In this study, the fundamental characteristics of the Segway were analyzed on the basis of trajectory data obtained by experiments conducted on a test course focusing on riding experience, so as to develop a microscopic behavioral model depicting the movement of personal transporters. The main findings are as follows:

1) The maximum acceleration of the Segway is distributed from 0.45 to 0.8 [m/s^2]. This is dependant on driving mode (high-speed mode or beginner mode), but not on riding experience.
2) The characteristics of deceleration were varied according to riding experience. The participants who had more riding experience were able to decelerate more smoothly.
3) The differences according to riding experience with respect to rotating behavior on the

slalom course were pronounced. Participants with more experience were able to move with less variance of rotating angle and at higher speed.

4) The experiments on passing and overtaking a pedestrian showed more experienced riders were able to move more promptly and agilely. The lateral distance to a pedestrian in passing or overtaking was almost the same as for bicycles.
5) Pronounced differences in emergency braking behavior according to experience were not found.
6) The emergency stopping distance of the Segway is almost the same as for bicycles, but a slight acceleration immediately before the start of deceleration was observed, which is specific to the Segway.

On the basis of these findings, it can be said that the Segway has similarity with bicycles in terms of behavioral characteristics, although the Segway is defined as a mini-motor vehicle according to the Road Trucking Vehicle Act in Japan. To investigate the possibility of allowing the Segway on public roads, the following viewpoints must be taken into consideration:

1) The experiments including more varieties of sample should be investigated, and the results should be compared to clarify whether there is significantly difference by difference of riders' attributions.
2) The Segway can be operated in an intuitive manner, that is, leaning the body weight towards the direction in which the rider wishes to move. This enables beginners to ride the Segway without any special training. In this sense, we can say the Segway is one of the most universal motor-assisted vehicles. However, there are significant differences between beginners and skilled riders, particularly in the promptness of response and agility of movement.
3) If the Segway is allowed for use in pedestrian spaces such as sidewalks and train stations, promptness and agility of movement on the part of riders is essential to ensuring safety. Special care for beginners who tend to lack the ability to perform prompt and agile movements is required. Otherwise, an efficient way to conduct a training course for beginners should be developed.
4) The Segway has similarities with bicycles in terms of passing and overtaking as well as emergency braking, while it has specific movement characteristics due to its unique operation manner. Further studies are required to evaluate the safety and the friendliness with other transportation mode such as pedestrians.

In future work, we will develop microscopic simulation models by evaluating the efficiency and the safety of a shared mobility space where the Segway, bicycles, pedestrians and other transportation modes are mixed. Then, by clarify the similarities and differences between the Segway and the other existing transportation modes, total mobility in urban areas should be realized to ensure the universality of mobility and to enhance the livability and attractiveness of urban cities. In this sense, the differences in the behavioral characteristics among people with various attributes such as the elderly and the handicapped are recommended for analysis through test-course experiments.

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