Measuring the Acceptability of Self-Balancing Two-Wheeled Personal Mobility Vehicles

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Abstract: Many studies on the development, on-road compatibility, and market potential of personal mobility vehicles have been conducted in recent years. This study focuses on the social acceptability of personal mobility vehicles by the general public, which is a key factor in the future introduction and implementation of these vehicles. Using survey data collected from 124 respondents from the city of Toyota, this study empirically explores the attitudes of the general public toward self-balancing two-wheeled vehicles and differences in the public's acceptance of such vehicles before and after using them. Potential uses of these vehicles include tourism and excursions, short-distance trips in downtown areas, and traversing within buildings. Causal relationships between the acceptability of self-balancing two-wheeled vehicles and attitudes toward various characteristics of these vehicles are also analyzed in this study. The empirical results indicate that attitudes toward self-balancing two-wheeled vehicles increase after using the vehicles. The causal relationships between the acceptability of and attitudes toward self-balancing two-wheeled vehicles are identified using structural equation modeling.

Keywords: Personal Mobility, Self-Balancing Two-Wheeled Vehicle, Acceptability

1. INTRODUCTION

It has been found that the lifestyle in the most developed countries of the world is not sustainable. With an aging population caused by low birth rate and urban sprawl resulting from dispersed urban settlement patterns, developed countries are increasing experiencing problems related to the transportation of elderly people and an over-dependence on private motor vehicles. Moreover, in developing countries, the increasing rate of urbanization and prevalence of motor vehicles has resulted in an unprecedented increase in vehicle ownership, which remains the principal cause of energy over-consumption, greenhouse gas emissions, and environmental deterioration. As a new type of transportation device, personal mobility vehicles (PMVs) may offer several potential benefits to solve current transportation-related problems (Ulrich, 2005).

Recent studies on PMVs have focused on the development of PMVs (Nakagawa *et al.*, 2009), the safety of PMVs (Nakagawa *et al.*, 2010; Boniface *et al.*, 2011), alternative mobility devices for people with disabilities (Sawatzky *et al.*, 2007), and the on-road compatibility of PMVs (Miller *et al.*, 2008). Furthermore, PMVs have been used by security guards or for guided tours in shopping malls, airports, and sightseeing spots. Nevertheless, the laws in the most countries do not allow the use of PMVs on public roads. To introduce PMVs to the public, further research is required. For example, research should focus the social

acceptability of PMVs by the general public, which is a key factor in the future introduction and implementation of these vehicles (Nishihori *et al.*, 2010). According to social behavior theory, whether the people will accept and use PMVs as new transportation devices depends on not only external factors, such as time savings or cost, but also psychological factors, such as attitudes and norms. Thus, this study aims to explore the attitudes of the general public toward self-balancing two-wheeled vehicles and differences in the public's acceptance of such vehicles before and after using them.

The remainder of this study is structured as follows: first, studies pertaining to self-balancing two-wheeled vehicles are briefly summarized; second, a trial held in the city of Toyota is described, and the socio-demographic characteristics of the respondents are analyzed; third, using data from a unique survey conducted in Toyota, the attitudes of the general public toward self-balancing two-wheeled vehicles are analyzed; fourth, causal relationships between the acceptability of self-balancing two-wheeled vehicles and attitudes toward various characteristics of these vehicles are examined; lastly, conclusions are drawn, and suggestions for further work are provided.

2. REVIEW OF RELATED STUDIES

PMVs can be classified into two categories: two-wheeled, self-balancing, standing PMVs, such as Segway and Winglet, and three-wheeled, seated PMVs, such as Marcus and i-REAL. Many studies have focused on two-wheeled, self-balancing, standing PMVs. For example, Nakagawa *et al.* (2009) proposed a PMV that could change between a popular bicycle and a self-balancing two-wheeled vehicle. Sawatzky *et al.* (2007) implemented an operability experiment using a Segway personal transporter. In total, 23 handicapped people who were 19-65 years old took part in the experiment. The study concluded that PMVs are effective transportation devices that promote the independence of people with disabilities and their participation in social activities. Furthermore, Miller *et al.* (2008) studied the use of a Segway rider on a sidewalk with pedestrians and objects. They collected data on the travel speed and the clearance distance to avoid collision. Moreover, Boniface *et al.* (2011) studied bodily injuries from traffic accidents with Segway riders in examining issues concerning the introduction of PMVs to the public.

Regarding attitudes toward self-balancing two-wheeled PMVs, Shaheen *et al.* (2005) reviewed the safety of PMVs. In the study, the authors summarized national and state regulations and policies related to PMVs. Then, the authors summarized results from 13 pilot trials conducted in the USA. As a part of the study, they reported comments on and attitudes toward PMVs from interviews with experts and related people. In Japan, Nakagawa *et al.* (2010) conducted an experiment in which PMVs were used in pedestrian flows at a shopping area. A questionnaire was completed by both the riders and the pedestrians. From the questionnaire, based on the difficulties experienced in avoiding collisions and the discomfort experienced, the safety and reliability were evaluated. In our previous studies, we evaluated the operability of self-balancing two-wheeled PMVs using 15 items. Furthermore, we evaluated attitudes with groups divided by age and gender (Ando and Li, 2012). Moreover, we assessed attitudes and usage intentions between self-balancing two-wheeled PMVs and three-wheeled seated PMVs, among 66 survey respondents who did not use the vehicles but rather watched the demonstrations and received the information distributed (Ando *et al.*, 2013).

As reviewed above, most of the previous studies on PMVs have focus on the operability of PMVs concerning traffic engineering, automotive engineering, safety, affinity with

pedestrians, and social effectiveness. Only a few studies have analyzed attitudes toward self-balancing two-wheeled PMVs. Furthermore, the relationship between the acceptability of and attitudes toward self-balancing two-wheeled vehicles, as well as how experience using PMVs influences this acceptability, has not been reported. Thus, this study uniquely focuses on the causal relationships between the acceptability of self-balancing two-wheeled vehicles and attitudes toward various characteristics of these vehicles and differences in people's acceptance of these vehicles before and after using them.

3. OUTLINE OF THE DATA

3.1 Outline of the Questionnaire

The data are from a survey that we conducted in October 2010, when a public trial to drive a self-balancing two-wheeled PMV was organized in the city of Toyota. The self-balancing two-wheeled PMV that was used in the public trial was the Winglet Type L, which was developed by Toyota Motor Corporation. After 10 minutes of driving, all participants were asked complete a questionnaire. The contents of the questionnaire included the participants' demographic data, daily travel/transportation activities, recognition of the self-balancing two-wheeled PMV, and usage intention. Moreover, at the trial, informative posters, promotional videos, and demonstrations for three types of self-balancing two-wheeled Winglet PMVs, Type L, Type M, and Type S, were also presented (Photo 1). The questionnaire was completed and returned by 124 respondents. Of these, 62 respondents rode the self-balancing two-wheeled PMV. The other respondents did not use the vehicles but rather watched the demonstrations and received the information that was distributed.

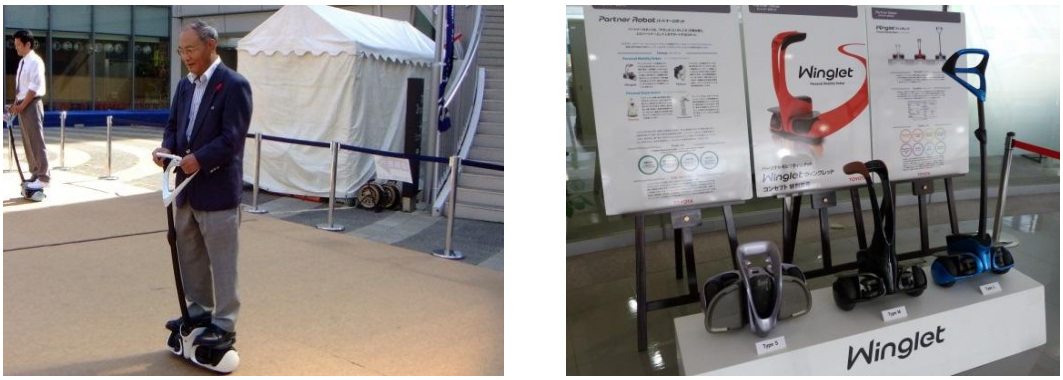

Photo 1. Self-balancing two-wheeled Winglet in the Toyota trial

3.2 Characteristics of the Objectives

In this study, since the main purpose is to analyze differences in acceptability before and after using the PMV, the 124 respondents were divided into two categories: a control group, which included the 62 respondents who did not experience using the Winglet, and an experimental group, which included the 62 respondents who experienced using the Winglet. To test whether the classification was appropriate, we examined whether respondents in the control group differed from the respondents in the experimental group in terms of socio-demographic data. Table 1 presents the comparisons between the two groups by the percentage or mean value of each factor with the t-test result.

With respect to the control group, 61.3% were men, and 38.7% were women. In contrast, 69.4% of the respondents in the experimental group were men, and 27.4% were women. The control group consisted of 13 people (21%) aged less than 29, 36 people (58.1%) aged from 30 to 59, and 12 people (19.4%) aged 60 and over. On the other hand, the experimental group consisted of 20 people (32.3%) aged less than 29, 34 people (54.8%) aged from 30 to 59, and 6 people (9.7%) aged 60 and over. Compared to respondents in the experimental group, a higher percentage of respondents in the control group hold a driver's license and are employed. However, no statistically significant differences at the 5% level in terms of "gender", "year of birth", "employment status", and "driver's license" were found between the groups.

As pointed out by Yamamoto *et al.* (2004), the types of vehicles held by a household significantly affect the modes of transportation that members within that household find acceptable. Therefore, the mean values of different modes of transportation held by the respondents' households were compared using t-tests. Although the statistical analysis shows that a greater number of car and bicycle than other modes were held by the respondents' households, the average scores for each mode of transportation were not significantly different between the respondent groups. Thus, it is appropriate to analyze differences in acceptability before and after using the PMV by using the control group and the experimental group.

Table 1. Socio-demographics for the control group and the experimental group

	Control group N=62 (%)	Experimental group N=62 (%)	
Gender			t (120)=1.21
Man	61.3	69.4	
Woman	38.7	27.4	
Data missing	0.0	3.2	
Year of birth			t (119)=1.88
Before 1950	19.4	9.7	
Between 1950 and 1980	58.1	54.8	
After 1980	21.0	32.3	
Data missing	1.6	3.2	
Employment status			t (119)=0.44
Employed	58.1	53.2	
Not employed	40.3	43.5	
Data missing	1.6	3.2	
Driver's license			t (106)= -1.24
Yes	90.3	75.8	
No	9.7	16.1	
Data missing	0.0	8.1	
Mean values of different modes of transportation held by respondents' households			
	M (SD)	M (SD)	
Car	1.8 (1.2)	1.5 (1.0)	t (122)=1.49
Motorcycle	0.2 (0.5)	0.2 (0.4)	t (122)=0.20
Motor-assisted bicycle/moped	0.1 (0.4)	0.1 (0.2)	t (91)=1.33
Bicycle	1.2 (1.1)	1.3 (1.4)	t (122)= -0.66
Other	0.0 (0.1)	0.0 (0.1)	t (122)=0.00

4. RECOGNITION AND USAGE INTENTIONS

4.1 Evaluation of Recognition

Regarding recognition of the self-balancing two-wheeled PMV, only half of respondents in the control group and 41% in the experimental group knew of the vehicle before the public trial. In addition, 83% of respondents in the control group would like to have an opportunity to drive the self-balancing two-wheeled vehicle in the future. Nearly all of the people (97%) in the experimental group expressed that they would like to have more chances to use the PMV. Thus, although recognition of the PMV was relatively low, a high proportion of respondents wanted to test drive the PMV. Moreover, the driving experience had a positive impact on the respondents' desire to drive the self-balancing two-wheeled PMV.

The answers for the question "how did you find out about the self-balancing two-wheeled PMV, e.g., Winglet or Segway?" show that the most common way that the respondents found out about the PMV was through news/TV/magazine (60% for the control group and 50% for the experimental group). In contrast, less than 10% of respondents in both groups found out about the PMV through the Internet. Thus, in introducing these vehicles in the future, publicity should be increased among various media, especially the Internet.

Table 2. Usage intentions of self-balancing two-wheeled PMV

	Control group N=62		Experimental group N=62		t (df)	Percentages by group
	Sample size	%	Sample size	%		
1.short-distance trips in downtown areas	36	14.1	30	13.8	1.08(122)	
2.medium-distance commutes	9	3.5	7	3.2	0.53(122)	
3.transportation on hiking trails	9	3.5	4	1.8	1.47(122)	
4.business travel in urban areas	18	7.0	4	1.8	3.42(122)**	
5.tourism and excursions	37	14.5	38	17.5	-0.18(122)	
6.access between home and the nearest station	27	10.5	18	8.3	1.69(122)	
7.shopping in neighborhood	18	7.0	17	7.8	0.20(122)	
8.going to the neighborhood hospital	11	4.3	15	6.9	-0.88(122)	
9.access between home and Toyota-shi station	13	5.1	14	6.5	-0.22(122)	
10.traversing within buildings	33	12.9	26	12.0	1.26(122)	
11.transportation for disabled or elderly people	9	3.5	16	7.4	-1.57(122)	
12.extended travel as car for elderly people	7	2.7	12	5.5	-1.24(122)	
13.access between destination and train station/bus stop	29	11.3	16	7.4	2.47(122)*	

* $p \leq .05$, ** $p \leq .01$.

4.2 Evaluation of Usage Intention

The results concerning the usage intention of the self-balancing two-wheeled PMV, represented by the Winglet, are summarized in Table 2. Usage intentions were evaluated by

presenting the participants with multiple choices regarding the use of the vehicles. There were 256 choices among the 62 respondents in the control group. In all, 37 people (14.5%) chose the self-balancing two-wheeled PMV as a mode of transportation for tourism and excursions. In addition, 36 people (14.1%) preferred the vehicle for short-distance trips in downtown areas. Moreover, 33 people (12.9%) favored the vehicle for traversing within buildings. Only 7 people (2.7%) believed that the self-balancing two-wheeled vehicle would be useful for an extended travel as car for elderly people. Additionally, only 3.5% of respondents in the control group believed that the vehicle could be used for medium-distance commutes, transportation on hiking trails, and transportation for disabled or elderly people.

Among the 217 choices reported by the experimental group, the top three uses of self-balancing two-wheeled PMVs were the same as those for the control group: tourism and excursions (17.5%), short-distance trips in downtown areas (13.8%), and traversing within buildings (12.0%). Fewer respondents considered "transportation on hiking trails", "medium-distance commutes", and "extended travel as car for elderly people" to be suitable uses of PMVs, with 4 people (1.8%), 7 people (3.2%), and 12 people (5.5%), respectively, selecting these uses. Furthermore, usage intentions concerning "access between destination and train station/bus stop" and "business travel in urban areas" were significantly reduced after the respondents experienced using the vehicle.

5. MEASUREMENT OF ACCEPTABILITY

5.1 Hypotheses and Methods

In this study, acceptability reflects an attitude toward self-balancing two-wheeled vehicles. Moreover, based on the planned behavior theory (Ajzen, 1991; Eagly and Chaiken, 1993), attitudes are defined as the belief that people hold concerning various aspects of the vehicles. Thus, three hypotheses are made based on the existing literature (Shaheen *et al.*, 2005; Miller *et al.*, 2008; Nakagawa *et al.*, 2010; Schuitema *et al.*, 2010, Ando and Li, 2012). First, the acceptability of the self-balancing two-wheeled vehicles is expected to be higher after driving the PMV than before. Second, attitudes reflecting the acceptability of the self-balancing two-wheeled vehicles can be divided into three categories: attitudes toward the vehicle itself, attitudes toward the use of the vehicle in buildings, and attitudes toward the use of the vehicle on roads. Third, it is assumed that attitudes toward the vehicle itself are determined by people's attitudes toward its design, size, passenger capacity, and environmental friendliness. Moreover, attitudes concerning the use of these vehicles both in buildings and on roads are highly influenced by attitudes concerning whether they are safe, useful, and harmonious.

As the evaluation methods, we adopted the technique proposed by Likert (1932), a five-rank measurement. That is, the highest rank was +2, and the lowest rank was -2, with 0 in the middle. Furthermore, structural equation modeling (SEM) was applied as the approach to measure the hypotheses about the relationship between the acceptability of and attitudes toward the self-balancing two-wheeled PMV. SEM was used in this study because the statistical methodology typically takes a hypothesis-testing approach, which is suitable for analyzing causal relationships concerning a particular phenomenon. The Likert and SEM measurements were proposed in 1932 and 1921, respectively, and both measurements are considered to have high reliability.

Table 3. Means, standard deviations and paired t-test of the acceptability and attitudes of the control group and the experimental group

	Control group N=62	Experimental group N=62		
	M (SD)	M (SD)	*t*	*df*
Attitudes toward self-balancing two-wheeled personal mobility vehicle				
－Design [a]	1.1 (1.05)	1.6 (0.70)	-2.6*	58
－Size [a]	1.1 (1.00)	1.5 (0.73)	-2.9**	58
－Passenger capacity [a]	1.3 (0.83)	1.6 (0.68)	-1.9	58
－Environmental friendliness [a]	1.5 (0.75)	1.6 (0.70)	-1.0	57
－Safety on roads [b]	-0.6 (1.16)	-0.3 (1.16)	-1.1	57
－Safety in buildings [b]	0.0 (1.36)	0.1 (1.39)	-0.3	55
－Usefulness on roads [b]	0.7 (1.09)	1.1 (0.96)	-2.1*	55
－Usefulness in buildings [b]	0.9 (1.24)	1.1 (0.97)	-0.8	54
－Harmoniousness on roads [b]	-0.1 (1.20)	0.6 (1.14)	-3.1**	55
－Harmoniousness in buildings [b]	0.4 (1.30)	0.9 (1.17)	-2.1*	53

* $p \leq .05$, ** $p \leq .01$.
[a] Scores ranged from -2 (very bad) to +2 (very good).
[b] Scores ranged from -2 (very unlikely) to +2 (very likely).

5.2 Empirical Results Regarding Differences in Acceptability before and after Using the PMV

The results concerning differences in acceptability before and after using the Winglet are summarized in Table 3. Regarding the control group, attitudes toward the PMV's "design", "size", "passenger capacity", "environmental friendliness", "usefulness on roads", "usefulness in buildings", and "harmoniousness in buildings" are positive. In contrast, attitudes toward the PMV's "safety on roads" and "harmoniousness on roads" were negative. In the experimental group, however, only attitudes toward "safety on roads" were negative. Furthermore, of these, the most positive attitudes for both groups were toward "environmental friendliness", "passenger capacity", "design" and "size". People have more positive attitudes toward the self-balancing two-wheeled vehicle itself compared to use of the vehicle.

The empirical results also indicate that attitudes increased after the respondents experienced using the vehicle compared to their attitudes before. Additionally, the t-test results show that there are statistically significant differences at the 5% level between the two groups regarding attitudes toward the PMV's "design", "usefulness on roads", and "harmoniousness in buildings", and there are differences at the 1% level between the two groups regarding attitudes toward the PMV's "size" and "harmoniousness on roads". Thus, compared to the control group, respondents in the experimental group reported more positive attitudes toward self-balancing two-wheeled PMVs' usefulness on roads, harmoniousness both inside buildings and on roads, design and size.

5.3 Model Analysis of the Relationship between Acceptability and Attitudes

In this section, we turn our focus to the assumed relationships related to the acceptability of the self-balancing two-wheeled PMV and apply SEM to identify the relationships between the acceptability of PMVs and attitudes toward various characteristics of PMVs. A schematic representation of the estimation results is shown in Figure 1. Two kinds of variables are used in the modeling, i.e., observed and latent variables. The observed variables in the rectangles,

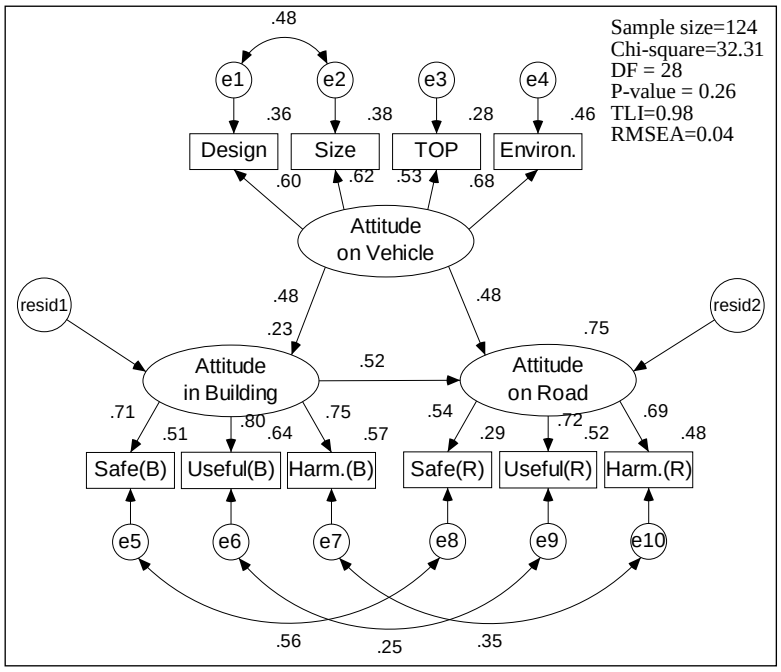

Figure 1. Estimated parameters of structural equation model

which are the attitudes toward self-balancing two-wheeled PMVs, are obtained directly from the questionnaire. The latent variables in the ellipses, which are attitudes reflecting acceptability, are composed of multiple observed variables. The variables are connected by arrows called “paths”. Each arrow indicates a causal relationship between variables. If the absolute value of the path is greater, there is a stronger relationship between the variables.

From the estimated results, the RMSEA of 0.04 and TLI of 0.98 for the model indicate an appropriate statistical goodness-of-fit of the estimated SEM. Moreover, nearly all of the parameters are statistically significant at the 5% level. The empirical results indicate that strong relationships exist among the various attitudes toward different characteristics of the vehicles. Furthermore, the value of “attitudes toward the use of the vehicle road”, which reflects the acceptability of using self-balancing two-wheeled vehicle on roads, indicates that “attitudes toward the vehicle” and “attitudes toward the use of the vehicle in buildings” account for 75% of the variance of “attitudes toward the use of the vehicle on roads”. Figure 1 also shows that the observed variables are reliability estimates for the ten individual subtests.

The values for the paths between “attitudes toward the vehicle” and “attitudes toward the use of the vehicle in buildings” and between “attitudes toward the vehicle” and “attitudes toward the use of the vehicle on roads” are 0.48 and 0.48, respectively. That is, the attitudes toward the vehicle have direct and equal effects on attitudes toward the use of the vehicle in buildings and on roads. Moreover, the value of 0.52 for the paths between “attitudes toward the use of the vehicle in buildings” and “attitudes toward the use of the vehicle on roads” reveals that the attitudes toward the use of the vehicle in buildings directly affect attitudes toward the use of the vehicle on roads.

Furthermore, attitudes toward the vehicle itself significantly depend on attitudes toward the vehicle’s “design”, “size”, “TOP (passenger capacity)” and “environmental friendliness”. Moreover, the value of 0.68 for “environmental friendliness” is the highest among the attitudes toward “design”, “size”, “passenger capacity” and “environmental friendliness”. Attitudes toward “environmental friendliness” are thus more important in determining the attitudes toward the vehicle itself than attitudes toward other characteristics of the vehicle. Similarly, the values for “usefulness in buildings” and “usefulness on roads” were 0.80 and

0.72, respectively. Therefore, attitudes toward "usefulness" have a greater effect on overall attitudes than attitudes toward "safety" and "harmoniousness".

6. CONCLUSIONS

This study examined attitudes of the general public toward self-balancing two-wheeled PMVs. The study specifically explored the causal relationships between the acceptability of self-balancing two-wheeled vehicles and attitudes toward various characteristics of these vehicles and differences in people's acceptance of the vehicles before and after using them. As the result of the analysis, the following conclusions were made.

- Although recognition of self-balancing two-wheeled vehicles is relatively low, the desire to test drive the vehicles in high.
- Experience using the vehicles had a positive impact on the willingness to drive the self-balancing two-wheeled vehicle.
- The top three usage intentions for the self-balancing two-wheeled vehicle were tourism and excursions, short-distance trips in downtown areas, and traversing within buildings.
- The usage intentions concerning "access between destination and train station/bus stop" and "business travel in urban areas" were significantly reduced after the respondents experienced using the vehicle.
- People with experience driving the vehicle tend to have a higher acceptability of self-balancing two-wheeled vehicles.
- Causal relationships between the acceptability of and attitudes toward self-balancing two-wheeled vehicles can be used to illustrate the acceptability of self-balancing two-wheeled vehicles.

In summary, self-balancing two-wheeled PMVs are a new type of transportation device that offer several potential benefits to solve current transportation-related problems. To introduce the PMV to the public, more public trials should be carried out to raise people's acceptance of the vehicles. In addition to use by security guards or for guided tours in shopping malls, airports, and sightseeing spots, self-balancing two-wheeled PMVs could be used by short-distance trips in downtown areas and for traversing within buildings in the near future. Based on the causal relationships between the acceptability of and attitudes toward self-balancing two-wheeled vehicles demonstrated in this study, improving peoples' attitudes (impressions) will lead to greater acceptance of the vehicles.

However, respondents also expressed concerns regarding the safety of using self-balancing two-wheeled PMVs on roads. Thus, as a further topic of study, the safety of self-balancing two-wheeled vehicles should be tested in future research. Furthermore, this study was conducted in a controlled environment, i.e., the participants tested the vehicle in short period of time. Studying participant's attitudes after long-term driving may offer different results; therefore, analyses need to be carried out in real world settings for the future introduction and implementation of these vehicles.

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