An Analysis of Lane Position and Travel Speed of Bicycles and Pedestrians on Sidewalks Allowing Bicycle Use in Japan

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Abstract: In this study, the use of bicycle and pedestrian lanes on sidewalks designated for bicycle riding in Japan was surveyed in order to gain knowledge about lane usage variations in relation to the existence/absence and locations of physical separating structures, pavement markings, and signage, and with the bicycle and pedestrian traffic volumes. Furthermore, surveys of bicycle speed and lane position were conducted at two locations where separating structures had been installed in differing configurations. The influences of separating structure type and installation configuration on bicycle speed and lane position were analyzed. As results, cyclists were found to show the highest compliance in bicycle lane usage when physical separation was imposed by fencing, followed by planted trees and brick borders, planted trees only, and no separation. Pedestrians showed high compliance when lanes were separated with fences, but there was almost no difference in compliance among various separation types.

Keywords: Bicycle, Pedestrian, Lane Position, Travel Speed, Sidewalk Allowing Bicycle Use

1. INTRODUCTION

The use of bicycles as a means of transportation in urban areas has gained increasing attention in recent years in Japan as interest has grown in reducing environmental loads and in improving health consciousness. However, since most streets currently have no travel lanes set aside for bicycles, cyclists are without a safe or comfortable travel environment and must instead ride on roadway shoulders or sidewalks. Amidst reports pointing to increasing numbers of traffic accidents involving bicycles and pedestrians, and the ongoing chaos of bicycles on the sidewalks, improving sidewalk safety has become an essential goal.

With this background in mind, improvements to the bicycle traffic spaces are in progress in Japan. Specifically, some of the improvements are the laying of bicycle paths, designation of roadway sections as bicycle travel lanes, and the separation of bicycle paths placed on sidewalks from pedestrian-only sidewalk spaces. Many sidewalks along heavily traveled roadways and along highways with high speed limits have been opened to bicycle travel, and many sidewalks have been separated into bicycle paths and pedestrian paths.

Nevertheless, the original sidewalks must be fairly wide in order to permit division into bicycle paths and pedestrian spaces, and there are few actual roadways with adequate width for this. Therefore, traffic is most often guided by marked lane designations on roadway surfaces (pavement markings) or signage, rather than physical separating structures.

Currently, however, it remains unclear what pavement markings and signage are best for guiding cyclists and pedestrians, and different regions are using various approaches on a trial-and-error basis. Furthermore, many of the already-designated roadway spaces are not actually being used in accordance with the intentions of the authorities. Thus, in order to establish efficient traffic spaces, it will be necessary to analyze the characteristics of cyclist and pedestrian activities, determine what sort of traffic space is the most convenient for each, construct proper bicycle traffic spaces, and provide appropriate guidance to both cyclists and pedestrians.

In this study, the use of bicycle and pedestrian lanes on sidewalks designated for bicycle riding in Shiga, Kyoto and Osaka Prefecture in Japan was surveyed in order to gain knowledge about lane usage variations in relation to the existence/absence and locations of physical separating structures, pavement markings, and signage, and with the bicycle and pedestrian traffic volumes. Furthermore, surveys of bicycle speed and lane position were conducted at two locations where separating structures had been installed in differing configurations. The influences of separating structure type and installation configuration on bicycle speed and lane position were analyzed.

2. EXCISTING RESEARCH ON BICYCLE RIDING ENVIRONMENTS

Since bicycles are, after all, a type of vehicle, in principle, they should be ridden along the left side of roadways, and are only legally permitted on sidewalks with "Bicycles Permitted" signs posted. Those lanes also require cyclists to ride slowly and stay on the roadway side of the sidewalk.

However, despite regulations that permit bicycle riding on many roadways, many cyclists have an incorrect understanding of the traffic rules, and choose to ride on sidewalks regardless of the regulations. Often, because there is insufficient bicycle traffic space on roadways, cyclists ride on sidewalks even when there is also insufficient width there as well. This results in intermixing bicycle and pedestrian traffic on numerous sidewalks and has resulted in a growing number of traffic conflicts and accidents involving bicycles and pedestrians.

Accordingly, it is essential to investigate ways to establish proper bicycle traffic spaces that are large enough to accommodate both bicycle and pedestrian traffic demand while still keeping the roadway useable. Additionally, quantitative determinations of the dangers of bicycle traffic and mixed bicycle and pedestrian traffic will be needed in order to fulfill the task of efficiently providing both safety and comfort for cyclists and pedestrians. Safety must be assessed objectively in terms of bicycle traffic, mixed bicycle and pedestrian traffic, the behaviors of traffic space users in traffic, and traffic phenomena.

Previous studies have described safety analyses focusing on bicycle traffic and mixed bicycle and pedestrian traffic. They have examined relationships between bicycle and pedestrian evasion behaviors, traffic density, traffic volume, roadway effective width, and other factors, using video cameras and other tools to observe evasion behavior and traffic conflicts (Matsumaru *et al.*, 2001; Takagishi, 1984; Yamanaka *et al.*, 2001). Some safety indicators include the probability of near-miss occurrences when a cyclist and pedestrian pass each other in opposite directions and evaluations of "service levels" based on the speed reductions that result from traffic conflicts (Yamanaka, 2005; Yamanaka *et al.*, 2003). Other evaluation indicators for traffic conflict analyses are the time to collision (TTC) and the spaces reserved for bicycles or pedestrians (Ogawa *et al.*, 2006; Oshikawa *et al.*, 2004). Still, other issues in such analyses have been pointed out, including the lack of specific guidelines for methods of judging traffic conflicts, the high potential for measurement errors, and the lack of established standard evaluation values.

In order to establish an efficient travel environment and promote the proper use of the constructed traffic spaces, it will be essential to analyze cyclist activity characteristics, determine what sort of traffic space is the most convenient for cyclists, construct proper bicycle traffic spaces, and provide proper guidance to both cyclists and pedestrians.

Studies of cyclist route selection behavior include both comparatively wide-scale analyses such as roadway network route selection between starting points and destinations, and comparatively narrow-scale analyses such as where to ride on sidewalks or roadways. The former is necessary when investigating how bicycles are guided through wide areas, while the latter can be useful for investigating bicycle traffic space widths, and when determining how important it is to separate bicycle traffic from pedestrian traffic when constructing bicycle traffic spaces.

This study focuses only on the latter selection process. Specifically, lane usage by bicycles and pedestrians on sidewalks where bicycle riding is permitted was surveyed in order to gain an understanding of lane usage variations and their relationship to the existence/absence and locations of physical separating structures, pavement markings, and signage, as well as bicycle and pedestrian traffic volumes.

3. LANE USE BY BICYCLES AND PEDESTRIANS ON SIDEWALKS

3.1 Outline of Observational Survey

The observational survey was carried out at 14 bicycle or pedestrian lanes designated in some way by Shiga, Kyoto and Osaka Prefecture in Japan. The lanes were indicated by physical separating structures, pavement markings, signage, or some other manner. These are listed together with lane specifications for each of the survey locations in Table 1.

In this observational survey, the numbers of bicycles and pedestrians passing through bicycle and pedestrian lanes were counted for a range of separation methods. These data were then used to calculate the compliance by the cyclists and pedestrians based on the percentage of travelers actually using their correct designated lanes. The observational surveys of cyclists and pedestrians were carried out for 30 to 60 minutes at each location depending on traffic volume.

3.2 Lanes Used by Cyclists

Table 2 shows the results for compliance by the cyclists by individual lane. A large variation from location to location can be seen, between 29% and 99%. Table 3 shows how compliance varied by the method of physical separation, and Table 4 shows the variation by pavement markings or signage.

Here, it is clear that compliance decreased in the following order of physically separating structures: fences, planted trees and brick borders, planted trees only, and no separation. In the case of visual separation, the compliance decreased in the following order: pavement markings and signage, pavement marking alone, and no separation. In locations with visual separation instead of physical separation structures, compliance was high when there was a combination of pavement markings and signage, but pavement markings alone were not very effective.

As results of analyses of variance, differences of the compliance of cyclists by physical separating structures are statistically significant at a level of 10%. However, differences of the compliance of cyclists by pavement markings and signage are not statistically significant.

Table 1. Method of separation of bicycle paths from pedestrian paths

Location	Pedestrian width (cm)	Bicycle width (cm)	Pavement coloring	Border	Physical separating structure	Pavement markings/ signage
A	450	180	Yes	No	Planted trees	Pavement markings
B	270	210	Yes	White bricks	No	No
C	180	190	No	White lines	No	Pavement markings and signage
D	220	220	Yes	Brick borders	Planted trees and brick borders	Signage
E	135	145	Yes	White lines	No	No
F	140	120	Yes	White bricks	No	Pavement markings
G	360	180	No	White dashed lines	No	Pavement markings
H	150	190	No	Blue dashed lines	No	No
I	220	220	Yes	No	Fences	Signage
J	275	200	Yes	Brick borders	Planted trees and brick borders	Signage
K	200	210	Yes	White bricks	No	Pavement markings
L	130	280	Yes	White bricks	No	No
M	215	170	No	White lines/ blue lines	No	Pavement markings
N	130	170	No	White lines/ blue lines	No	Pavement markings and signage

Next, to examine the relationships between bicycle or pedestrian traffic volumes and compliance, compliance by the cyclists was plotted against the ratio of the bicycle traffic volume to the pedestrian traffic volume (Fig. 1). The results show a tendency for cyclist compliance to increase as the ratio of cyclists to pedestrians increases.

3.3 Lanes Used by Pedestrians

Table 5 shows the survey findings regarding pedestrian compliance. As shown, compliance ranged between 47% and 93%, which is fairly wide range (just as was found for cyclists). As with cyclists, these are broken down in terms of physically separated lanes and lanes indicated by pavement markings or signage, in Tables 6 and 7, respectively.

Table 2. Compliance of cyclists by location

Location	Time (min)	Total traffic volume	Obeying	Disobeying	Compliance
A	40	144	114	30	79%
B	30	100	29	72	29%
C	30	125	103	22	82%
D	30	139	131	8	94%
E	30	98	43	45	44%
F	60	72	40	32	56%
G	30	100	33	67	33%
H	60	50	28	22	56%
I	30	165	164	1	99%
J	45	100	91	9	91%
K	60	72	49	23	68%
L	60	77	58	19	75%
M	60	66	45	21	68%
N	60	75	42	33	56%

Table 3. Comparison of compliance of cyclists (physical separating structures)

Lane separation method	Cyclist compliance
Fences	99%
Planted trees and brick borders	93%
Planted trees only	79%
No separation	53%

Table 4. Comparison of compliance of cyclists (pavement markings, signage)

Lane separation method	Cyclist compliance
Pavement markings and signage	69%
Pavement markings only	56%
No separation	51%

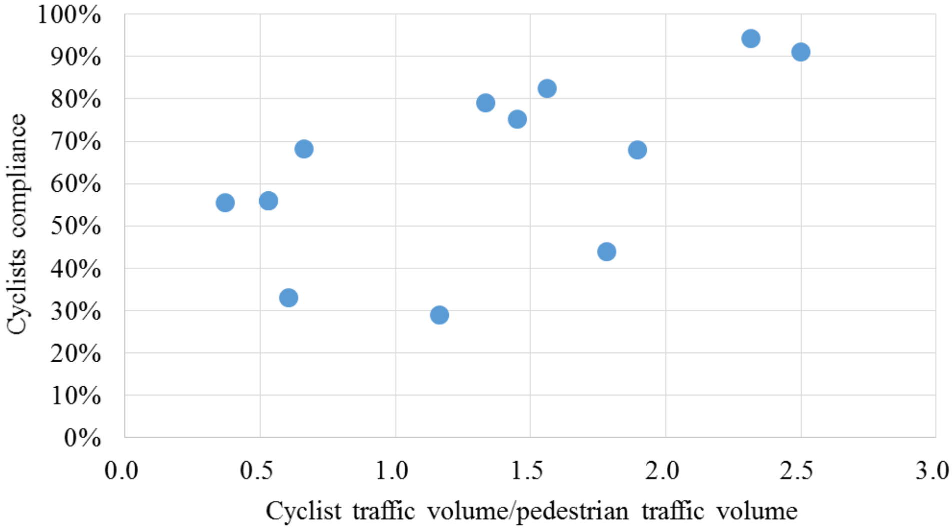

Figure 1. Compliance by cyclists versus traffic volume of cyclists relative to pedestrians

Table 5. Compliance of pedestrians by location

Location	Time (min)	Total traffic volume	Obeying	Disobeying	Compliance
A	40	108	70	38	65%
B	30	86	76	10	88%
C	30	80	73	7	91%
D	30	60	29	31	48%
E	30	55	30	15	55%
F	60	194	108	86	56%
G	30	165	129	36	78%
H	60	94	44	50	47%
I	30	30	28	2	93%
J	45	40	30	10	75%
K	60	38	26	12	68%
L	60	53	29	24	55%
M	60	100	72	28	72%
N	60	141	66	75	47%

Table 6. Comparison of compliance of pedestrians (physical separating structures)

Lane separation method	Pedestrian compliance
Fences	93%
Planted trees and brick borders	62%
Planted trees only	65%
No separation	66%

Table 7. Comparison of compliance of pedestrians (pavement markings, signage)

Lane separation method	Pedestrian compliance
Pavement markings and signage	69%
Pavement markings only	69%
No separation	61%

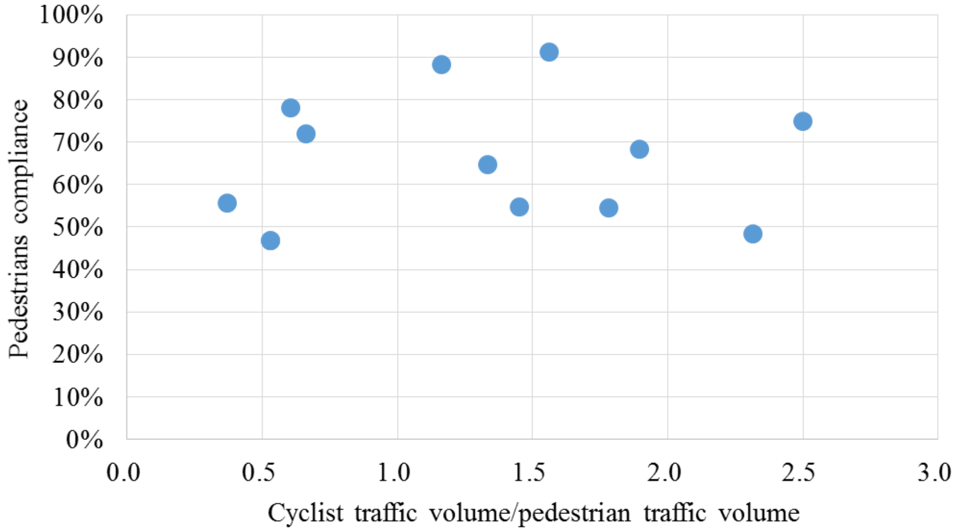

Figure 2. Compliance by pedestrians versus traffic volume of cyclists relative to pedestrians

An examination of these results shows that, in terms of physical separating structures, compliance was high in lanes separated by fences, but considerably lower in the lanes separated by other means and there was not much difference between the compliance observed in lanes marked by pavement markings or signage. Thus, when lanes are not physically separated from each other, pavement markings or signage tends not to be very effective.

As results of analyses of variance, differences of the compliance of pedestrians by physical separating structures are statistically significant at a level of 5%. However, differences of the compliance of pedestrians by pavement markings and signage are not statistically significant.

In contrast with the results for cyclists, no differences in pedestrian compliance were found with variations in the relative volumes of cyclist and pedestrian traffic (Fig. 2).

4. BICYCLE TRAVEL SPEED AND LANE POSITION WITH THE STRUCTURES

4.1 Outline of Observational Survey

Locations in Shiga Prefecture (Location A) and Osaka Prefecture (Location B) in Japan were selected as they had structures with different configurations separating bicycle and pedestrian pathways. The width of the bicycle traffic space in Location A was 2.3 m and was separated from the roadway by a raised curb, and from the sidewalk by a 0.85 m fence. In Location B, the bicycle traffic space was 2.0 m wide and separated from the roadway by a fence (0.90 m) and from the sidewalk by a planting strip.

The survey was carried out over seven observation periods in Location A and six observation periods in Location B, during which 196 bicycle passages were observed in Location A and 189 passages were observed in Location B.

4.2. Comparison of Bicycle Speeds

Figures 3 and 4 show the mean bicycle speeds in Location A and B, respectively. These present the following mean speeds for cyclists: Left-biased riders (left side/sidewalk side of the bicycle path) when they have the path to themselves and right-biased riders (right side/roadway side) when they have the path to themselves; cyclists passing each other travelling in opposite directions (passing); and cyclists side-by-side travelling in the same direction (overtaking). Cyclists move to either the sidewalk or the roadway when passing or overtaking. These figures demonstrate how the configuration of the separating structure affects their speed while doing so. (Automobile traffic in Japan travels in the left side of a roadway.)

Comparing Figs. 3 and 4, the reader can see that, overall, the cyclists in Location A tended to ride faster. The overall mean speed in Location A was 11.92 km/h, while it was 11.08 km/h in Location B. This seems likely to be due to the slightly wider bicycle traffic space in Location A, which was 2.3 m, in comparison to the 2.0 m width in Location B.

Tables 8 and 9 show the passing speeds normalized to the speeds when the cyclists had the bicycle path to themselves. The reader can see that the cyclists reduced their speeds when passing someone on both the 2.3 m and the 2.0 m wide bicycle traffic spaces. Since the values differ for the sidewalk and roadway sides, it is also apparent that the installation configuration of the separating structure affected the cyclists' speeds. The speed reductions are particularly marked on the sidewalk side in Location A (separation by a fence) and on the roadway side in Location B (separation by a fence). Thus, cyclists tended to slow down more during passing when near a fence.

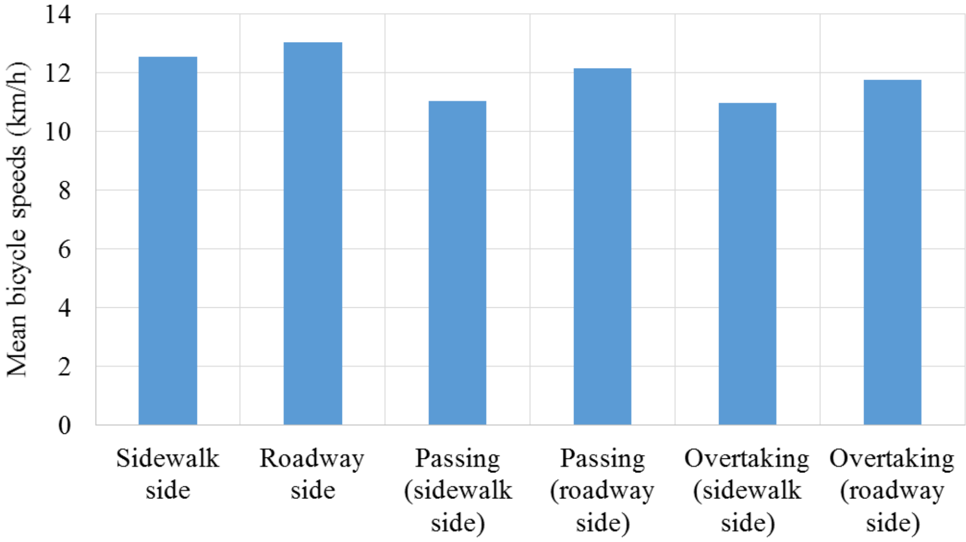

Figure 3. Mean speed comparison (Location A)

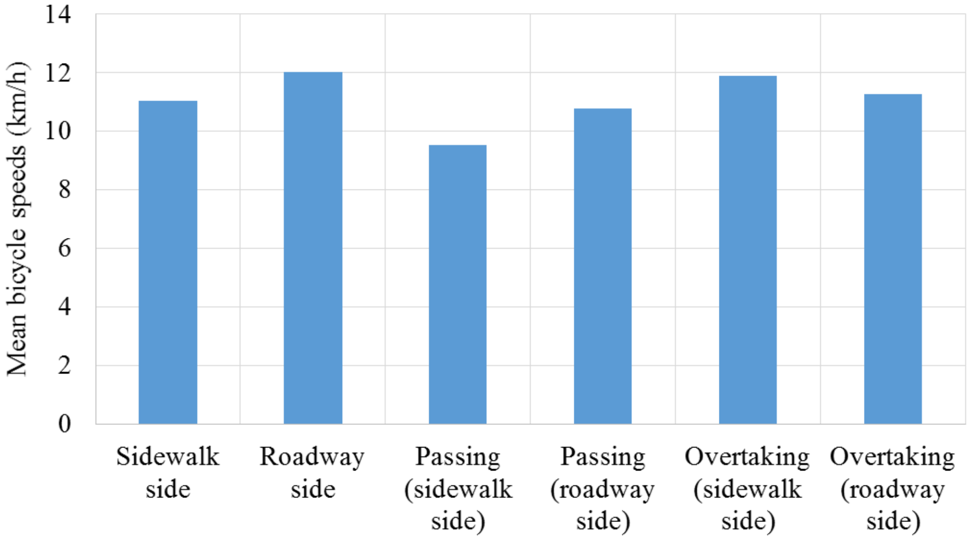

Figure 4. Mean speed comparison (Location B)

Table 8. Reduction in mean speed during passing (Location A)

Sidewalk side	1.0	Roadway side	1.0
Passing sidewalk side	0.88	Passing roadway side	0.93

Table 9. Reduction in mean speed during passing (Location B)

Sidewalk side	1.0	Roadway side	1.0
Passing sidewalk side	0.97	Passing roadway side	0.89

4.3 Comparison of Bicycle Lane Positions

Figures 5 and 6 show the mean lateral positions (lane positions) of the bicycle trajectories in the bicycle traffic spaces in Location A and B, respectively. Here, the value of the lane position is relative to the border of the bicycle traffic space with the roadway. Just as was seen in the speed examination, these are the mean lane positions of the values in each survey location when the cyclists had the bicycle path to themselves by the left side/sidewalk side and the right side/roadway side during passing and overtaking.

In Fig. 5, it can be seen that there was a high tendency for cyclists to ride closer to the roadway side than the centerline of the bicycle traffic space, at the 115 cm lane position. In Fig. 6, however, most of the cyclists rode closer to the sidewalk side of the centerline of the bicycle traffic space, at the 100 cm lane position.

Table 10 provides a comparison of the number of cyclists preferring the sidewalk or roadway side at each survey location when they have the path to themselves. In Location A, the structure separating the path from the sidewalk was a fence, and that separating the path from the roadway was a raised curb. In contrast, the structure separating the path from the sidewalk in Location B was a planting strip, while that separating the path from the roadway was a fence. This suggests that when cyclists had the bicycle path to themselves, they tended to select positions away from the fences.

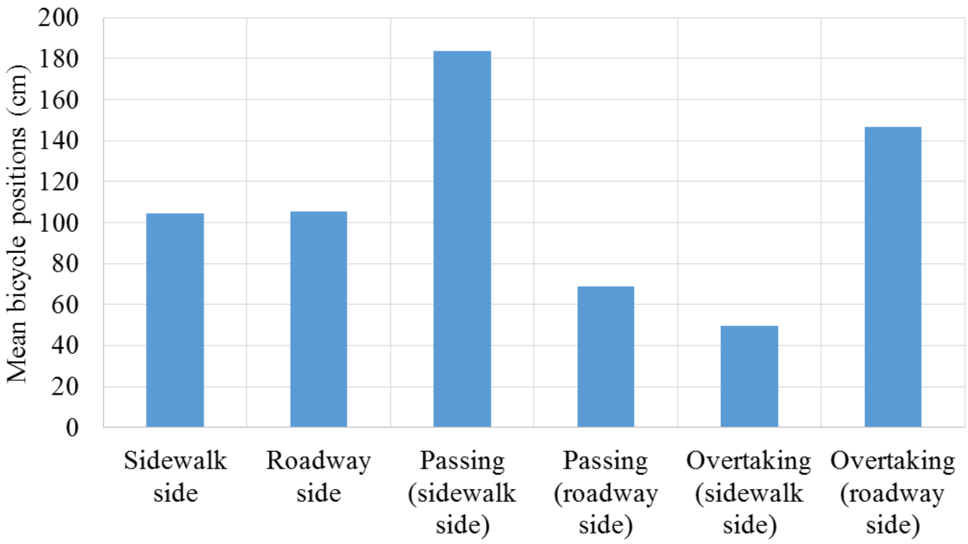

Figure 5. Comparison of lane positions (Location A)

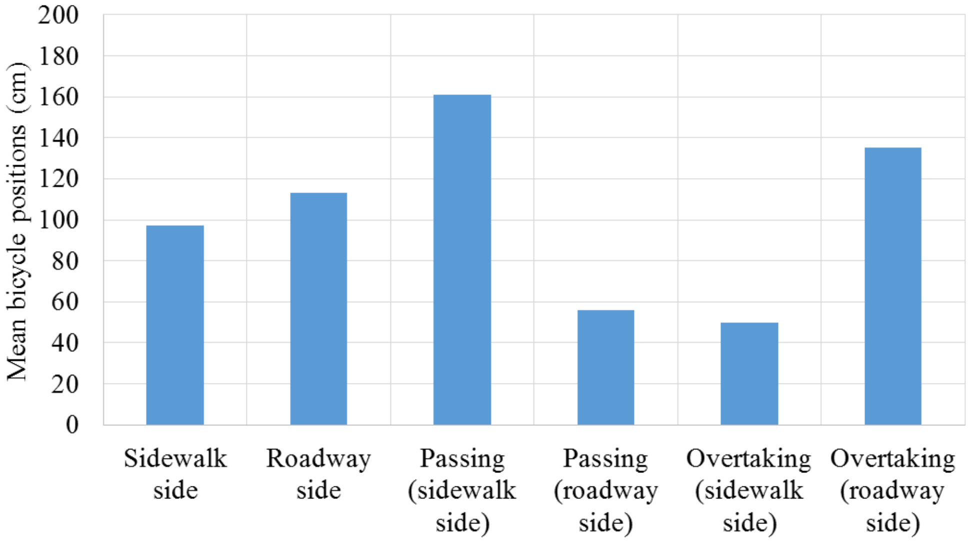

Figure 6. Comparison of lane positions (Location B)

Table 10. Trends in lane position when they have the path to themselves

When they have the path to themselves	Location A	Location B
Sidewalk side	54 cyclists	103 cyclists
Roadway side	98 cyclists	74 cyclists

5. CONCLUSION

The lanes actually used by cyclists and pedestrians on sidewalks where bicycle riding is allowed were surveyed in Shiga, Kyoto and Osaka Prefecture in Japan. The variations in the actual lane according to cyclist and pedestrian traffic volumes and versus the presence or absence of physical separation or visual separation of the lanes via pavement markings and signage.

As results, cyclists were found to show the highest compliance in bicycle lane usage when physical separation was imposed by fencing, followed by planted trees and brick borders, planted trees only, and no separation. Compliance when the lanes were separated by visual markings was highest with pavement markings and signage, followed by pavement markings only, and no separation. In other words, when no physical separation was imposed, compliance was high when both pavement markings and signage were used, but pavement markings were not very effective by themselves. Examination of compliance by cyclists for different cyclist and pedestrian traffic volumes indicates a tendency for relatively high compliance by cyclists when they are present in greater numbers, although still a minority compared to pedestrians.

Pedestrians showed high compliance when lanes were separated with fences, but there was almost no difference in compliance among various separation types, and not much difference from separation with pavement markings or signage. Thus, it was found that pavement markings or signage were not particularly effective when lanes are not physically separated from each other.

Cyclists tended to slow down more during passing when near a fence. When cyclists had the bicycle path to themselves, they tended to select positions away from the fences.

As future researches, more data must be collected for the various cases. In addition to validating the results of the present study, factors other than the physical separating structures, pavement markings, and signage examined in this study must be investigated. Investigations must be made of more than just simple throughways in methods of separation of lanes. The trajectories of bicycles and pedestrians in separated lanes can be expected to vary as they pass through entrances into and exits from those lanes (depending on the layouts), in entrances and exits for adjacent roadways, and also depending on the attributes of the bicycles and pedestrians (i.e., whether they are through traffic or otherwise).

It will be essential to investigate methods for guiding bicycles and pedestrians in order to reduce the frequency of traffic conflicts by using previous analyses of traffic conflicts between bicycles and pedestrians, as well as cyclist route selection behaviors.

Furthermore, future research must examine a greater number of survey locations and seek a quantitative grasp of the differences in influence of the type of separating structure on the effective bicycle path width. It will be essential to clarify how the separating structures relate to the width of a bicycle traffic space in the preparation of future bicycle riding environments.

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