

Article

Shared Space and Pedestrian Safety: Empirical Evidence from Pedestrian Priority Street Projects in Seoul, Korea

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Abstract: To provide safe and comfortable walking environments on narrow streets without sidewalks, the Seoul city government has implemented the Pedestrian Priority Street (PPS) projects. Based on Monderman’s “shared space” concept, the PPS involves applying diverse paving design techniques, particularly stamped asphalt pavement of various colors and patterns. This study investigated the effectiveness of the PPS for pedestrian safety. Data sources were (1) video recordings of the nine concurrent PPS in 2014 before and after the projects were completed and (2) a cross-sectional survey at the nine streets. Two groups of multiple regression models analyzed the objective safety, by using the variables, mean vehicle speed and change in mean speed, which were then compared with subjective safety through a questionnaire analysis. The results found that the design strategies reduced the vehicle speed and increased perceptions of pedestrian safety. These suggest that the PPS principles are practical and feasible ways to tackle the safety problems of narrow streets without sidewalks. Further, vehicle speeds increased on streets where the pedestrian zone was clearly distinguishable from the vehicular zone by applying PPS techniques only at the roadside. Thus, clearly separating pedestrians from vehicular zones, which is neither the original principle nor the intent of the PPS, should be avoided.

Keywords: Pedestrian Priority Street; shared space; paving design; pedestrian safety; walking environment

1. Introduction

Streets and their designs are essential elements of urban living in terms of walking [1–3]. Urban transportation planning has paid little attention to walking since motor vehicles became ubiquitous, but walking remains the main travel mode for the first and last miles of a trip. Beyond its transit functions, it enhances individuals’ physical and mental health and the environmental, social, and economic sustainability of cities [4–7]. By considering walking, city streets might be revitalized, declining economies might be revived, and the quality of life might be improved [8–10]. Giving streets back to pedestrians is a common goal of most urban design theories [11–13].

However, cars have long been central to urban transportation planning; therefore, in many cities, streets are hostile to pedestrians. The narrow asphalt streets without sidewalks that typically develop in urban areas are the representative legacy of “automobilism” [14]; they are obvious in the dense megacities of developing countries where infrastructure cannot keep pace with population growth and in the older districts of advanced countries where organic patterns remain, such as Beijing, Ho Chi Minh City, Kyoto, and Taipei. These streets tend to be alleys, back roads, or access streets to commercial buildings in urban residential areas. They are frequently used by pedestrians, who are forced to share them with cars under dangerous conditions.

Korea is no exception to the problem. Its typical urban neighborhoods include many narrow streets without sidewalks, named *i-myeon-do-ro* (back roads) (Figure 1). These streets (less than 12 m wide) comprise about 77.1% of Seoul's total street length [15]. Because they are not wide enough and, therefore, do not have sidewalks, pedestrians share them with cars, enduring unsafe conditions. About 73.7% of Korea's pedestrian traffic accidents between 2013 and 2015 occurred on streets less than 13 m wide [16]; as of 2016, pedestrian fatalities as a share of all street fatalities constituted 40%, the highest among the 34 OECD countries [17]. Even though this might indicate a relatively high share of walking for transportation [18], these figures demonstrate the quality of the usual walking environment in Korea.



Figure 1. Typical *i-myeon-do-ro* in Seoul, Korea (before the project: Sanggye-ro 5-gil in Nowon-gu); source: © Daum Roadview (<https://map.kakao.com/>).

To address this problem, the Seoul city government implemented Pedestrian Priority Street (PPS) projects, based on Hans Monderman's shared space approach [19,20]. The PPS uses stamped asphalt pavements of various colors and patterns, to alert drivers of theirs, and pedestrians' rights of way, and ensure safe and comfortable walking environments for pedestrians. The PPS are considered one of the government's most practical and feasible options in addressing the problems associated with narrow streets. The PPS projects are distinct in that they mainly target *organically* shared streets resulting from narrow widths. This is different from other shared space examples, such as Exhibition Road in London, which has a separate sidewalk and wide width [21]. Because the street space is limited, the PPS projects solely rely on the visual impacts of unique paving designs. However, little is known about the effects of the PPS and its design principles in Seoul.

In this context, this study investigated the effectiveness of the PPS's design strategies. We examined the influences of the various paving designs on changes in vehicle speed (objective safety), and on pedestrians' fears of possible car accidents (subjective safety). The eight PPS sites comprising nine streets in Seoul, that implemented the PPS designs in 2014 were analyzed. Video data were collected before and after implementation, and a cross-sectional questionnaire survey was conducted. We used the results to consider the potential of the PPS and policy directions, in order to enhance pedestrian safety and rights.

2. Literature Review

2.1. The Shared Space Concept and PPS Project

The shared space concept aims to ensure self-regulating streets, where various users, particularly pedestrians and vehicles, interact without physical segregation, traffic regulations, or control devices [19,22]. First proposed in the 1970s, by Hans Monderman, a traffic engineer from the Netherlands, the idea has spread throughout the world in response to the negative effects of motorization [20]. Other terms have been coined to define this concept, such as “simplified streets,” “naked streets”, and “shared streets”; although different, they all share certain schematic aspects [23]. The fundamental purpose of shared space is to improve pedestrian safety and mobility by reducing the traffic control features that tend to encourage drivers to assume their dominance on the street [23,24]. A core feature is to create some uncertainty in terms of priority for motorists by breaking away from segregating pedestrians from vehicles using barriers.

According to Engwicht, *mental speed bumps* encourage drivers to be more attentive to their surroundings and to slow down [25]. This is similar to John Adams’ risk compensation theory, which is applicable to a shared street environment [26–28]. According to this theory, street users can be encouraged to be careful on the street, by preventing them from relying on safety devices and regulations. Presumably, responsibility and conscientiousness occur only in states of uncertainty [26]. Hamilton-Baillie likened the shared space to an ice rink, where users negotiate their activities with “an intricate and unspoken set of protocols” [19] (p. 169). Ultimately, the shared space becomes a self-regulating street, creating a safe and efficient traffic environment that enhances public life [22].

To achieve the shared space goals, the Seoul PPS introduced various paving designs. The Seoul city government aimed to minimize the negative effects of excessive vehicle speed, inappropriate parking, and other reckless behaviors by preventing street users from perceiving the space as typical streets for vehicles. Accordingly, the government-run Architecture and Urban Research Institute (AURI) applied the following design principles when they drew up the PPS design alternatives. First, they used the pedestrian-friendly paving approach, which usually has been limited to sidewalks, for the entire street to encourage pedestrians and drivers to think about the entire street as a pedestrian-priority space. In addition to eliminating barriers such as curbs, fences, and street signs, integrated paving designs also helped to blur the boundary between the pedestrian and vehicular zones. However, the average 2014 budget for the projects in this study was about USD \$90,000 including planning and construction costs [29]. The Seoul city government encouraged lower level governments to use stamped asphalt, rather than block-type pavements, because it quickly accepts the desired diverse colors and complicated patterns at relatively low cost. Second, the PPS actively used lined patterns, which occasionally cross the streets at right or diagonal angles and, sometimes, section it to break up the driving space continuity. The lines on the colorful surfaces were intended to create visual impacts that cause deceleration. Although most of the PPS generally observed these principles, the final designs differed from each other. Thus, it is reasonable to expect that the effects of the PPS would vary by design type.

2.2. Optical Illusions to Induce Deceleration

Drivers are highly influenced by the various stimuli they see while driving. According to Cohen [30,31], drivers obtain about 90% of information visually. Because the PPS expected behavioral changes by using indirect approaches, it is important to understand the relationship between the visual elements on surfaces, driving behaviors, and travel speeds. In most shared spaces, pedestrian-friendly pavement materials such as square granite setts, bricks, and concrete blocks were used instead of conventional materials, such as asphalt. The differences in surface texture and color were used to encourage street users to visually distinguish the street from streets in general [32–34]. In addition, shared spaces extensively embrace flush surfaces and street furniture (e.g., benches), and minimize traffic control devices (e.g., signals, lane markings) to create seamless and abundant walking experiences.

These elements, including visual impacts, create a combined effect of deceleration, leading to enhanced walking environments [24,32–44].

Previous studies have also examined the influence of visual disturbances caused just by street surfaces. First, a concrete block pavement, the most widely used method to calm traffic [45], might lead to cautious driving and fewer traffic accidents by making drivers perceive specificity of the streetscape [46,47]. Second, regardless of the type of street markings available (e.g., center lines, peripheral transverse lines, or chevron patterns), previous studies revealed that a series of horizontal lines increased peripheral visual stimulation and caused drivers to instinctively slow down [48–53]. Street markings have been extensively used to slow down vehicles by distorting drivers' perceptions of their speed on a highway, particularly one that is curved [52,54]. Thaler and Sustein described this phenomenon as a representative example of the “nudge effect” in their book, *Nudge* [55].

However, the results might happen not only via an immediate intuition; they might be an alerting mechanism [52]. Zaidel et al. [56] and Chrysler and Schrock [57] suggested the drivers interpret painted stripes on street surfaces as warning signs and, therefore, make conscious decisions to drive slower and sharpen their attention. In other words, they might decide to ignore the stripes after the initial novelty of the lines has faded. On the basis of their research on the PPS, Kim and Shim determined that the visual elements were not sufficient to cause drivers to make decisive behavioral changes, although they contributed to creating a feeling of unfamiliarity [58]. Thus, although they might induce some extent of deceleration, the indirect and visual aspects of the PPS might not be effective in the long term - unless they consolidate their symbolic meanings at an early stage.

In short, previous studies have found that visual differentiation on the street surfaces influences instinctive driving behaviors. However, most of the previous studies about the block pavement and the transverse line markings were conducted on spaces exclusively designated for driving, such as highways, which are different from the narrow *i-myeon-do-ro* where the PPS is implemented. Therefore, we examined the visual impacts of these street surfaces on pedestrian safety. Unlike the previous studies, focusing on single sites, this study comprised all the sites transformed by the PPS in 2014 to strengthen interpretive generalization.

3. Materials and Methods

3.1. Study Area

This study investigated the entire 2014 PPS sites, which were concurrently completed: (1) Bukchon-ro 5ga-gil in Jongno-gu, (2) Dongho-ro 11-gil in Jung-gu, (3) Sanggye-ro 3-gil and Sanggye-ro 5-gil in Nowon-gu, (4) Yeonseo-ro 21-gil in Eunpyeong-gu, (5) Gyeongin-ro 15-gil in Guro-gu, (6) Geumha-ro 23-gil in Geumcheon-gu, (7) Bangbaecheon-ro 2-gil in Seocho-gu, and (8) Godeok-ro 38-gil in Gangdong-gu. Figure 2 shows them relatively evenly distributed in Seoul. Although Sanggye-ro 3-gil and Sanggye-ro 5-gil are one site, they are deemed different streets because of their distinct differences, and therefore nine streets actually were examined. The 2014 PPS design proposals initially were intended to extensively use stamped asphalt pavement with various colors and patterns, but some of them were altered by the *gu* (administrative districts) that wanted to reflect their residents' opinions. As a result, the design principles were more or less well expressed among the study sites.

Table 1 provides basic information on the study sites at both times of data collection. The streets were 8.6 m wide on average, which is relatively narrow. The average street length was 333.8 m, which is shorter than the standard walking distance (400 m). The mean traffic (vehicle) and pedestrian volumes of before implementation were 183 vehicles and 509 people per hour, respectively, indicating that more pedestrians than vehicles used the study sites.

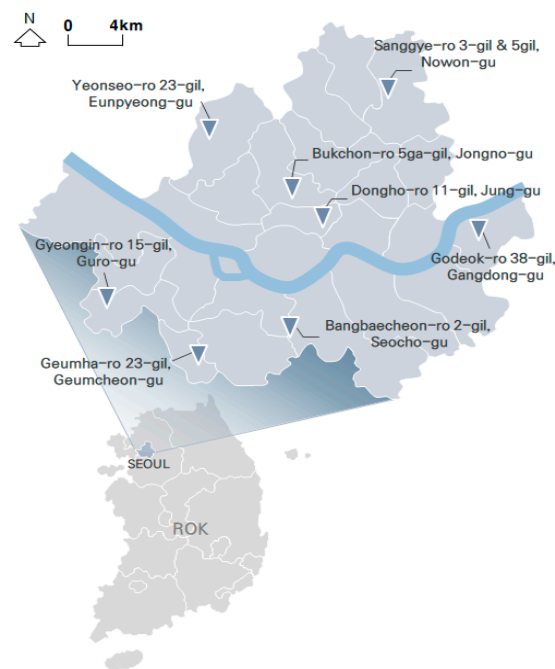


Figure 2. The eight study sites (2014 Pedestrian Priority Street (PPS)).

Table 1. Description of the study sites.

Site Code	Street Name	Street Width (m)	Total Length (m)	Traffic Volume Per Hour ¹		Pedestrian Volume Per Hour ¹		Mean Speed (km/h)	
				Before	After	Before	After	Before	After
1	Bukchon-ro 5ga-gil, Jongno-gu	6.5	240	24	17	628	560	14.86	15.25
2	Dongho-ro 11-gil, Jung-gu	7.5	500	111	61	420	564	18.10	16.97
3	Sanggye-ro 3-gil, Nowon-gu	8.0	150	40	40	1700	1432	13.86	13.11
4	Sanggye-ro 5-gil, Nowon-gu	8.0	220	67	61	269	243	16.47	18.58
5	Yeonso-ro 23-gil, Eunpyeong-gu	10.0	214	220	245	217	245	22.32	21.35
6	Gyeongin-ro 15-gil, Guro-gu	8.0	400	44	77	195	215	19.22	18.61
7	Geumha-ro 23-gil, Geumcheon-gu	10.0	420	227	223	233	273	23.69	22.84
8	Bangbaecheon-ro 2-gil, Seocho-gu	9.5	430	735	728	592	535	15.16	20.33
9	Godeok-ro 38-gil, Gangdong-gu	10.0	430	183	205	325	293	19.16	26.00
	Mean	8.6	333.8	183	184	509	484	18.09	19.23

¹ Traffic and pedestrian volumes are converted into 'per hour' unit based on the sums of the amounts measured during 15-min data collection periods from 8:30 to 8:45, 16:30 to 16:45, and 19:30 to 19:45; 45 min total time.

3.2. Data Collection

To test the effects of two design types in terms of their objective (observed) and subjective (stated) pedestrian safety, we analyzed video recordings made before and after implementation and conducted a cross-sectional questionnaire survey. The research data were collected by AURI (specifically, this paper's corresponding author collected the data as head of the Pedestrian Environment Research Center, AURI). The videos were recorded at every node and straight-link (between nodes) where the cameras could be installed in September 2014 (before) and June 2015 (after). We finally chose the nine spots on each of the nine streets, which have the straight segment and representative paving designs. The recordings occurred on weekdays when the weather and temperature were similar across days. Camera installation was pre-approved by the district office. The cameras were installed above eye-level to accurately capture all of the street users' activities and record the patterns in the pavement. The sites were continuously recorded from 06:00 to 21:00, and the recorded data, during the three 15-min peak periods, were extracted for analysis: morning (08:30 to 08:45), afternoon (16:30 to 16:45),

and evening (19:30 to 19:45). Using this data, vehicle speed was measured as a proxy of objective pedestrian safety. The speed of each vehicle was manually calculated by dividing the distance of the pre-designated section in each street by the time it takes for the vehicle to pass in the videos.

The questionnaire survey was administered once, approximately a year after the 2014 PPS projects were completed (30th September 2015—07th October 2015). Only the residents (70%) or business owners/employees (30%) who had lived or worked near the sites for at least two years were eligible to participate in the survey. The number of respondents per site was between 100 and 106, and the total sample size was 819 people. Because the questionnaire items were about the entire streets, rather than specific locations on the streets, Sanggye-ro 3-gil and 5-gil in Nowon-gu were treated as one location for the survey (but not for the video data). The questionnaire items mainly focused on changes in peoples' perceptions of traffic safety. Although the survey data on subjective pedestrian safety merely provided descriptive data, its function was important to the interpretation of the regression results on vehicle speed.

3.3. Methods of Analysis

Multiple regression analysis was used to assess the effectiveness of the PPS design types, considering the influences of other factors. Vehicle speed is the strongest influence on traffic safety [59], and accordingly, speed variables were used to assess pedestrian safety. We followed convention and assumed that the faster a vehicle moves, the greater the risk of traffic accidents and other threats to pedestrians. There were two groups of regression models, depending on the dependent variable.

3.3.1. Dependent Variables

The first group of the regression models used “mean vehicle speed” at a recording site as the dependent variable. Mean speed was the arithmetic average of the travel speeds of the individual vehicles in the recordings of the three extracted periods at each recording spot. Because there were just nine recording spots in total, the number of observations seemed too few to carry out stable multiple regression results. Therefore, we used the morning, afternoon, and evening recordings before (September 2014) and those after (June 2015) the PPS as separate samples. Thus, the first analysis had 54 observations ($9 \times 2 \times 3$). Gujarati argued that 40 observations would never be too small if a model specification is correctly done [60] (p. 484).

The second group of the regression models used “difference in the mean speed before and after the PPS” as the dependent variable. There were 27 observations (9×3), which did not meet the minimum sample size of 30 observations for regression analysis. However, the regression results were appropriate for verifying the causal relationships found in the first regression analysis.

3.3.2. Independent Variables

The key independent variable was the “type of paving design,” where vehicle speed was measured (recording spots). Two criteria for classifying the paving-design types were created, using the data at the recording spots. The first measure was the extent of “visual separation (VS)” between vehicles and pedestrians, which was created by the paving patterns. Three categories of visual separation were developed on the basis of the extent of stamped asphalt and the visual designs, which influence the extent of a sense of a barrier between vehicular and pedestrian zones. The three categories were as follows.

- VS-A: Stamped asphalt pavement covered the entire width of the street and there were no suggestions at the roadside of an exclusively pedestrian zone. This concept was interpreted to intend a genuine coexistence of pedestrians and vehicles.
- VS-B: Stamped asphalt pavement covered the entire width of the street, and there was some suggestion at the roadside of a pedestrian zone. This was interpreted as intending to protect a minimum area for pedestrians, while pursuing user coexistence.

- VS-C: Stamped asphalt pavement covered just a part of the street, which implied that pedestrians should walk within the paved area. This was interpreted as not pursuing coexistence.

We expected that VS-A and VS-B would improve pedestrian safety more effectively than VS-C, because VS-C restricted the pedestrian area and reinforced the idea that street use was exclusively for driving. However, assessing the differences between VS-A and VS-B was complex. Although VS-A more closely adhered than VS-B to the integrative design principle of shared space, VS-B might be more effective under certain conditions. Kaparias et al. suggested that introducing a “safe zone” at the roadside, just for pedestrians, might play an important part in the successful operation of a shared space by increasing pedestrians’ mobility and walking freedom [24] (p. 20).

The second measure of the type of paving design was the extent of visually interrupting “driving continuity (DC),” which was based on variation in the transverse and diagonal line designs. The nine study sites were categorized into three groups based on the expected effects of the transverse lines or surface designs as visual interference on consistent driving speed: Specifically, to cause drivers to decelerate. The three DC types are described below.

- DC-A: The lines and surface designs visually impacted drivers by giving the appearance that the street was segmented. We expected that the transverse design would trigger deceleration.
- DC-B: There were some transverse design elements, but they were relatively few; a weaker effect than that of DC-A was expected.
- DC-C: There was no transverse design at the study site; therefore, no segmenting effect was expected.

We expected that DC-A and DC-B would induce more speed deceleration than DC-C. However, similarly to VS, DC had problems in the comparisons between DC-A and DC-B. Kim and Shim argued that drivers cognize the entire change created by a PPS, and the surface design details do not significantly influence their behaviors [58]. Considering that argument, there might be little difference in the effects of DC-A and DC-B on speed.

The method used to categorize the VS and the DC design types was a focus group interview with three experts on 11 January 2019, to eliminate researcher bias. The three interviewees were highly qualified professionals with PhD degrees in the field, who teach urban design as a full-time faculty. We outlined the project and the PPS designs’ goals to them, and we showed them pictures of the paving status at each site.

3.3.3. Statistical Analysis

Because of the relatively small sample size, the three dummy variables, which depended on each criterion for classification, were used in both groups of the regression models. Altogether, four regression analyses were estimated. First, a dummy indicator of “before implementation” was used as a reference variable. In the change analysis, the VS-C or DC-C was regarded as a reference variable.

We controlled for the effects of factors expected to influence vehicle speed on shared streets (i.e., street width, traffic volume, and pedestrian volume), with the assumption that the narrower the street and the larger the volume of street users, the slower the vehicle speed. In addition, we controlled for traffic calming devices that might directly influence vehicle speed. The only traffic-calming device at the study sites was a speed bump, which we used as a control variable. To account for factors related to the filming location (intersection or mid-block), a variable, indicating the distance from the recording spot to the nearest intersection entrance, was included (“distance to closest intersection”). Last, dummy variables, indicating “morning” or “afternoon,” were included (“evening” was the reference group) to control for the effects of the recording periods. The second regression analysis was about change and it used difference (change) values instead of absolute values for the time-variant variables (i.e., “ Δ traffic volume,” “ Δ pedestrian volume,” and “ Δ number of speed bumps”).

4. Results

4.1. Design Type Classification

Table 2 shows the results of categorizing the nine study sites in the two three-category design type variables. Most, but not all, the VS and DC types were clearly defined. Geumha-ro 23-gil, Bangbaecheon-ro 2-gil, and Godeok-ro 38-gil were obviously VS-C because the stamped asphalt was paved only at the roadside, which created a clear distinction between pedestrian and vehicular zones. Sanggye-ro 5-gil and Gyeongin-ro 15-gil were ambiguous in relation to the pedestrian zone. Sanggye-ro 5-gil had a zigzag design with triangular shapes drawn in a row at the roadside. Gyeongin-ro 15-gil did not have an obvious design, but there was a strip of bright color in the middle in sharp contrast to the color used on the rest of the street. The three experts considered Sanggye-ro 5-gil as VS-B and Gyeongin-ro 15-gil as VS-A.

Table 2. Paving design classifications.

Paving Design	VS Type	DC Type	Paving Design	VS Type	DC Type
	A	C		A	B
Bukchon-ro 5ga-gil, Jongno-gu			Gyeongin-ro 15-gil, Guro-gu		
	B	A		C	C
Dongho-ro 11-gil, Jung-gu			Geumha-ro 23-gil, Geumcheon-gu		
	A	B		C	C
Sanggye-ro 3-gil, Nowon-gu			Bangbaecheon-ro 2-gil, Seocho-gu		
	B	B		C	C
Sanggye-ro 5-gil, Nowon-gu			Godeok-ro 38-gil, Gangdong-gu		
	A	B			
Yeonseo-ro 23-gil, Eunpyeong-gu					

Source: © Daum Roadview (<https://map.kakao.com>).

Regarding the DC types, Sanggye-ro 5-gil and Dongho-ro 11-gil had transverse lines; however, only Dongho-ro 11-gil was classified as DC-B. The experts determined that the triangular features of Sanggye-ro 5-gil stood out more than the transverse lines, which weakened the lines' impacts. In addition, Sanggye-ro 3-gil and Yeonso-ro 21-gil were identified as DC-B. Although Sanggye-ro 3-gil had an "X" mark across the street, the experts believed that drivers were unlikely to sense the segmented-street effect because the lines were too close to each other. The effects of the transverse lines at Yeonso-ro 21-gil were also believed to be marginal because the lines were at the speed bumps.

Because the questionnaire survey covered the entire area of each site, the classification results were changed for Sanggye-ro 3-gil and Sanggye-ro 5-gil, which originally were one site; so, the VS type was merged with VS-B.

4.2. Before and After Comparisons of Speed by Paving Design Type

Table 3 presents the *t*-test results, which compare the mean speeds before to those after the PPS. Regarding VS-C and DC-C, the fastest speeds were observed after the PPS. This is an unintended effect of PPS, which could occur when there is an exclusive driving zone or a lack of transverse designs. This result is still valid when we consider the mean speed of the control group, although it has not been statistically tested due to the limited data.

Table 3. Comparison of speed before to that after the PPS was implemented by design type.

Criteria	Type	Target Group						Control Group ¹		
		Number of Cases		Mean Speed (km/h)				Mean Speed (km/h)		
		Before	After	Before	After	Change Rate (%)	<i>t</i> -Value	Before	After	Change Rate (%)
VS	A	246	285	20.33	19.64	-3.39	1.16	17.90	16.58	-7.33
	B	133	92	17.49	17.46	1.54	-0.33	15.92	18.25	14.66
	C	858	867	17.49	21.82	24.76	-11.37***	18.86	21.67	14.87
DC	A	83	46	18.10	16.97	-6.24	0.90	18.57	23.23	25.13
	B	278	318	19.99	19.67	-1.60	0.58	17.08	15.07	-11.76
	C	876	880	17.43	21.72	24.61	-11.38***	18.28	21.08	15.32

¹ The control groups were selected for each target site where the mean speed can be extracted through Seoul TOPIS (Transport Operation and Information Service) among the streets most similar and nearest to the target sites. Since it is not possible to obtain individual vehicle speed of control group, only average values are presented. (<http://topis.seoul.go.kr>). * = $p < 0.10$, ** = $p < 0.05$, *** = $p < 0.01$.

4.3. Multiple Regression Results on Paving Design Types

Tables 4 and 5 show the multiple regression results. The adjusted R^2 values of mean vehicle speed models were 0.71 and 0.70, which is relatively high; those of the change in speed models were 0.34 and 0.29. All of the variance inflation factors were less than 10 (data not shown). The results are explained in two table sections depending on the two classification methods (VS and DC).

Table 4. Multiple regression analysis by design type (dependent variable: mean vehicle speed at recording sites); $n = 54$.

Variable	By VS Type			By DC Type		
	B	t-Value	p-Value	B	t-Value	p-Value
<i>VS Types: "before implementation" is reference variable.</i>						
VS-A	-0.752	-0.770	0.446			
VS-B	-0.359	-0.276	0.784			
VS-C	3.189	2.758	0.009 ***			
<i>DC Types: "before implementation" is reference variable.</i>						
DC-A				1.202	0.653	0.517
DC-B				-1.103	-1.122	0.268
DC-C				2.171	2.260	0.029 **
<i>Time Slot: "evening" is reference variable.</i>						
Morning	3.886	3.983	0.000 ***	4.037	4.103	0.000 ***
Afternoon	-0.158	-0.172	0.864	0.068	-0.073	0.942
Street width (m)	1.470	3.708	0.001 ***	1.887	4.853	0.000 ***
Distance to the closest intersection (m)	0.023	0.420	0.676	-0.001	-0.022	0.983
Traffic volume (vehicles/15 min)	-0.020	-2.292	0.027 **	-0.021	-2.315	0.025 **
Pedestrian volume (people/15 min)	-0.017	-5.052	0.000 ***	-0.016	-4.677	0.000 ***
Existence of speed bumps	0.580	0.670	0.506	1.019	1.213	0.232
(Constant)	6.405	1.781	0.082	2.943	0.862	0.394
Adjusted R ²		0.71			0.70	
D-W		1.93			1.96	
F		13.70			13.42	

* = $p < 0.10$, ** = $p < 0.05$, *** = $p < 0.01$.**Table 5.** Multiple regression analysis by design type (dependent variable: differences in the mean speeds before and after the PPS); $n = 27$.

Variable	By VS Type			By DC Type		
	B	t-Value	p-Value	B	t-Value	p-Value
<i>VS Types: "VS-C" is reference variable.</i>						
VS-A	-7.200	-3.041	0.007 ***			
VS-B	-5.772	-1.893	0.076 *			
<i>DC Types: "DC-C" is reference variable.</i>						
DC-A				3.139	0.584	0.567
DC-B				-3.694	-2.162	0.045 **
<i>Time Slot: "evening" is reference variable.</i>						
Morning	0.155	0.096	0.925	0.403	0.238	0.815
Afternoon	0.936	0.611	0.550	0.901	0.566	0.579
Street width (m)	0.074	0.092	0.928	1.404	2.030	0.058 *
Distance to the closest intersection (m)	-0.177	-1.634	0.121	-0.294	-2.251	0.038 **
Δ Traffic volume (vehicles/15 min)	0.050	0.391	0.701	0.032	0.249	0.807
Δ Pedestrian volume (people/15 min)	-0.032	-1.975	0.065 *	-0.039	-2.181	0.044 **
Δ Number of speed bumps	-3.087	-1.756	0.097 *	-0.641	-0.258	0.800
(Constant)	7.953	0.990	0.336	-4.758	-0.766	0.454
adjusted R ²		0.34			0.29	
D-W		1.59			1.47	
F		2.50			2.19	

* = $p < 0.10$, ** = $p < 0.05$, *** = $p < 0.01$.

4.3.1. Results by VS Type

As expected, only VS-C was positively and significantly associated with mean speed ($p < 0.10$) after controlling for the effects of other factors. The finding indicates that vehicle speed was faster on average as the distinctions between the vehicular and pedestrian zones became more obvious. Moreover, VS-A and VS-B were negatively associated with the change in traffic speed, compared to VS-C (Table 5), meaning that VS-C had the smallest influence among the three levels of distinction in

improving pedestrian safety. It also supports the contention that the application of the PPS design principles was effective.

The survey results further support this interpretation (Table 6). The percentage of respondents who answered that they experienced a decrease in vehicle speeds, collision risks, and the number of vehicles overtaking pedestrians were the lowest in the VS-C group, whereas the percentage of negative responses to these items was the highest. However, the number of positive responses on pedestrian safety was higher at VS-B sites, which ambiguously indicate pedestrian zones, than at VS-A sites, which more closely reflects the PPS principle of coexistence. There are some possible reasons for this finding. First, residents' subjective perceptions are from the pedestrian's perspective, but the change in speed reflects changes in driving behavior. In other words, even if the PPS induced deceleration, pedestrians might not perceive an improvement in safety. Moody and Melia found similar results [42,43]: Despite a significant reduction in average traffic speed and the number of traffic accidents after the shared space concept was implemented at Elwick Square in Ashford, UK, most of the pedestrians perceived that the situation was safer before the change, or they were still concerned about being hit by cars. Moreover, regardless of speed change, the respondents seemed to prefer a somewhat segregated walking space. Kaparias et al. proposed a "safe zone" in shared spaces to encourage walking freedom by increasing pedestrians' comfort [24] (p. 20). In other words, the perception of safety supposedly offered by a designated pedestrian zone might influence people's perceptions of safety.

Table 6. Survey result: Perceptions of pedestrian safety by Visual Separation (VS) types.

Category	Strongly Agree/Agree	Neutral	Strongly Disagree/Disagree	<i>n</i>
<i>1. As a Pedestrian, I Feel the Vehicle Speed has Decreased.</i>				
VS-A	31%	33%	36%	309
VS-B	38%	20%	41%	206
VS-C	27%	12%	61%	304
<i>2. As a Pedestrian, I Feel the Risk of Collision with the Vehicle has been Reduced.</i>				
VS-A	31%	36%	33%	309
VS-B	46%	32%	22%	206
VS-C	28%	31%	41%	304
<i>3. As a Pedestrian, I Feel the Number of Vehicles Overtaking Pedestrians has Decreased.</i>				
VS-A	31%	36%	33%	309
VS-B	48%	31%	21%	206
VS-C	28%	27%	45%	304

4.3.2. Results by DC Type

Table 4 shows that DC-C, which had no transverse designs, was statistically significant and positively related to speed change ($p < 0.10$), and Table 5 shows that DC-B was negatively associated with the differences in the mean speeds, compared to DC-C (reference group). These results suggest that transverse markings were important in achieving the PPS goals. However, only Dongho-ro 11-gil was in the DC-A category, which may have influenced the statistical non-significance. Even so, the presence of the transverse lines seems to contribute to improving the walking environment more than their absence. A comparison of the average speed changes at the study sites after the PPS to before it was implemented, considering only the presence or absence of these lines, shows a significant speed reduction where the transverse lines were applied.

The survey data revealed a high percentage of positive opinions about safety at DC-A sites, which clearly emphasized the transverse designs (Table 7). In relation to DC-B, where the transverse designs had a smaller visual impact than DC-A, the responses were less positive about safety than they were for DC-C, which has no transverse line designs. Most of the study sites in the DC-C category were

also in the VS-C category, which presents an exclusively pedestrian zone. Thus, people's preference for clearly marked pedestrian areas might have influenced these results.

The effects of the control variables generally were as expected. Study sites with narrow street widths and large traffic and pedestrian volumes experienced slower average driving speeds after the PPS were implemented. In addition, the farther the distance to the intersection and the more speed bumps, the stronger the impact of speed change in the negative direction.

Table 7. Survey result: Perceptions of pedestrian safety by driving continuity (DC) type.

Category	Strongly Agree/Agree	Neutral	Strongly Disagree/Disagree	<i>n</i>
<i>1. As a Pedestrian, I Feel the Vehicle Speed has Decreased.</i>				
DC-A	43%	9%	48%	100
DC-B	28%	32%	40%	313
DC-C	31%	18%	51%	406
<i>2. As a Pedestrian, I Feel the Risk of Collision with the Vehicle has been Reduced.</i>				
DC-A	53%	33%	14%	100
DC-B	26%	36%	38%	313
DC-C	34%	31%	35%	406
<i>3. As a Pedestrian, I Feel the Number of Vehicles Overtaking Pedestrians has Decreased.</i>				
DC-A	57%	26%	17%	100
DC-B	26%	39%	36%	313
DC-C	35%	27%	38%	406

5. Conclusions and Policy Recommendations

This study examined the influences of the PPS paving design types on safety and the perception of safety (the main goals of PPS), using video analysis and survey research. The results suggested several things. First, even when there was a difference by type of paving design, traffic speeds were slower at the study sites where the PPS paving strategies were faithfully applied. Where the pedestrian and vehicular zones were clearly distinguished using PPS techniques, however, vehicle speeds were faster after than before the PPS were implemented. Vehicles traveling at high speeds are more dangerous to pedestrians when the level surfaces are used for pedestrian zones. In sum, the PPS design principles should be followed to avoid adverse outcomes.

These findings are useful for informing government officials and residents about the value of PPS paving designs. When the PPS projects were implemented in 2014, it was difficult to persuade residents of the value of the designs because they did not understand the projects and there were no empirical data to prove its effectiveness [29]. Most of the survey respondents wanted a completely independent pedestrian zone in the final design plan, which changed the original plans for several sites [29]. The municipal governments, which prioritized the local residents' opinions, ultimately used stamped asphalt pavement only for the parts of the street that would create exclusive pedestrian zones. This study's results provide evidence for avoiding that approach, which conflicts with the PPS's original intention, in future projects.

The PPS approach might be useful to other metropolitan cities with narrow asphalt streets without sidewalks. The low cost and rapid construction time are obvious advantages of using stamped asphalt pavement. Moreover, the shared space concept, which causes a paradigm shift toward coexistence among street users, might be a feasible option for solving problems with sidewalk installation. In this sense, the PPS is a reasonable transitional solution to achieve pedestrian-friendly environments, although, on the basis of our findings, its benefits might be realized only when its principles are followed.

Last, related policies are needed to ensure appropriate PPS implementation, as Kim and Shim argued, regarding promotion, speed control, guidance, and the physical improvements [58]. It is

most important to legally ensure safe and convenient walking on shared streets. Currently, Korean legislation does not guarantee or protect pedestrians' rights on these streets. The Road Traffic Act (Article 8) states that, "on a road that is not divided into a sidewalk and a roadway, pedestrians shall walk on the fringe of the road in the direction opposite to horses and vehicles or the side of the road" [61]. Until the law protects pedestrians' right to unrestricted walking on *organically* shared streets, people are compelled to walk defensively, even on the PPS streets.

Despite its contributions, this study has several limitations. Although we obtained speed data on every vehicle that passed through the recording spots of the study sites, we had to average them, and other information about individual vehicles, such as driver characteristics, travel purposes, and so on was not available. This limitation might have created an ecological fallacy. Because the number of values decreased by using the mean, it was difficult to simultaneously verify all the types of PPS designs. To overcome these limitations, we analyzed separate regression models. We also could not fully control for the effects of natural changes over time because the design and data did not allow for testing a control group; however, we minimized the effects of these limitations by using the nine PPS sites that were concurrently completed.

More discussion is needed regarding the establishment of distinct pedestrian zones at PPS sites. We tried to inform this discussion by classifying the design types in two ways, but conflicting results were found depending on the perspective. Although safety was objectively determined as better when the PPS principles were followed, there was a gap between the objective results and the residents' subjective perceptions about safety. It would be helpful to harmonize these points through future research, in order to help improve future PPS plans.

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