cogitatio

Urban Planning (ISSN: 2183–7635)
2023, Volume 8, Issue 2, Pages 81–92
https://doi.org/10.17645/up.v8i2.6407

Article

The Smart City and Healthy Walking: An Environmental Comparison Between Healthy and the Shortest Route Choices

Eun Jung Kim * and Youngeun Gong

Department of Urban Planning, Keimyung University, Republic of Korea

* Corresponding author (kimej@kmu.ac.kr)

Submitted: 31 October 2022 | Accepted: 4 February 2023 | Published: 27 April 2023

Abstract

Walking is a means of health promotion, which is one of the main features of smart cities. A smart city's built environment can help people choose a healthy walking route instead of the shortest one. Our study investigated which environmental factors pedestrians who select healthy routes prefer and favored environmental factors in pedestrian navigation mobile applications. Survey data were collected from 164 residents in Daegu, South Korea, from October 12 to October 25, 2022. *t* and chi-square tests were used to compare perceptual differences between the healthy route and the shortest route preference groups. The results indicate that 56.7% of respondents preferred a healthy walking route over the shortest route. Pedestrians who chose the healthy route preferred to have less noise and more greenery along their commute and feel safer from traffic accidents and crimes than those who chose the shortest route. Moreover, people who favored healthy routes also considered the following environmental factors in pedestrian navigation mobile applications: (a) greenery and waterfront areas, (b) low traffic volume, and (c) safety from traffic accidents and crimes. The results suggest that urban planning and design policies support healthier and more active walking in smart cities.

Keywords

built environment; healthy walking; mobile applications; pedestrian navigation; smart city; walking route

Issue

This article is part of the issue "Smart Engagement With Citizens: Integrating "the Smart" Into Inclusive Public Participation and Community Planning" edited by Jin-Kyu Jung (University of Washington) and Jung Eun Kang (Pusan National University).

1. Introduction

Several studies have suggested that the built environment plays an important role in promoting walking behaviors (Hillnhütter, 2022; Panter et al., 2019; Sallis et al., 2009). Environments with more mixed land use, greenery, and less heat exposure facilitate increased walking (Basu et al., 2022; Taleai & Yameqani, 2018). People living in communities with good pedestrian amenities such as sidewalks and benches are more likely to walk than those living in other areas. Therefore, urban planners and designers are attempting to create an attractive and high-quality environment that will encourage pedestrians to walk (Rodríguez et al., 2009).

Understanding the environmental conditions that people want to walk in can help create a pedestrian-friendly built environment (Handy et al., 2006). Many researchers have investigated the walking routes chosen by pedestrians in their neighborhood environments to understand their preferred built environmental conditions. A majority of pedestrians tend to choose the shortest route to their destination (Borgers & Timmermans, 2005). However, this is not always the most preferred characteristic in walking route choice (Guo & Loo, 2013). Pedestrians are likely to choose a safe route to avoid crime or traffic accidents even if it means they need to take a detour to reach their destination (Bhowmick et al., 2021; Lee & Lee, 2021). Moreover, despite the extra distance, pedestrians may opt for a comfortable route with extensive greenery and fine views (Koh & Wong, 2013). In addition, sometimes people choose routes other than the shortest route to avoid certain obstacles, such as crosswalks or stairs (Guo & Ferreira, 2008; Olszewski & Wibowo, 2005). Based on this evidence, it is expected that active walking can be encouraged when pedestrians are provided their preferred built environments.

Recent studies have suggested that smart cities, which are attracting attention as a new urban planning paradigm in the 21st century, can improve walking quality and promote active walking (Jabbari et al., 2022; Line et al., 2011; Moreno et al., 2021). Visvizi et al. (2021) argued that information and communication technologies (ICT)-based systems in smart cities (e.g., sensor-based systems that adjust traffic lights according to the walking speed) have the potential to improve walking quality. Conticelli et al. (2018) also mentioned that applying ICT technology to pedestrian route planning and design would enable people to walk more and increase pedestrian satisfaction. In this context, a healthy walking route has been suggested as an element to improve smart cities (Novack et al., 2018; Pimpinella et al., 2019). Existing navigation services, such as Google Maps, provide routes based on the shortest distance and walking time (Siriaraya et al., 2020). However, recent technology can guide pedestrians to the optimal route by reflecting the built environmental conditions they prefer (Conticelli et al., 2018).

Pimpinella et al. (2019) proposed a routing system called Smart Urban Routing for Flesta-IoT for urban pedestrians and cyclists. The healthy routes offered by the system required an average of 10% longer walking time than the shortest route searched by Google Maps but had 25% less exposure to carbon monoxide. Novack et al. (2018) proposed a system that finds the most appropriate route when pedestrians select the factors they prefer for green areas (e.g., parks and trees), meeting places (e.g., cafes, restaurants, and shops), and quiet streets (e.g., less traffic volume). While the routes suggested by the system were slightly longer than the shortest routes, they were observed to be more social, comfortable, and quiet. Wakamiya et al. (2019) proposed a system that recommends a pleasant route with extensive greenery and pleasant views. Several studies have suggested systems that recommend shaded and cool routes on hot days (Deilami et al., 2020; Monreal et al., 2016; Rußig & Bruns, 2017). Regarding pedestrian safety, Pang et al. (2019) designed the safest PATH, an application that guides pedestrians to the safest routes with a lower risk of becoming a victim of crime. Similarly, Mishra et al. (2021) proposed a safe route design technique in light of the recent Covid-19 pandemic that enables pedestrians to bypass areas that would make them vulnerable to infection. Gani et al. (2019) proposed a system that suggests the optimal route by considering the presence of crosswalks or curbs, which are barriers to walking.

With the development of smart technology, pedestrian navigation mobile applications are actively being developed that allow pedestrians to navigate healthy walking routes in urban environments (Fonseca et al., 2021; Novack et al., 2018). To develop healthy ambulation into a major means of promoting people's health in smart cities, it is essential to understand pedestrians' perceptions and needs. Specifically, it is necessary to identify the environmental factors are key to inducing pedestrians to take healthier routes. In addition, when pedestrian navigation mobile applications that guide pedestrians to healthy routes are commercialized, the environmental factors and functions required by pedestrians must be identified. Therefore, this study aims to investigate the environmental factors preferred by pedestrians who choose healthy routes and to examine their preferred route search functions in mobile applications.

2. Materials and Methods

2.1. Study Area

This study covers the Ayang Bridge and its surrounding neighborhood in the Dong-gu region in Daegu, South Korea. This neighborhood is rich in green areas and has good access to the Geumho River; therefore, it has good environmental conditions for this study design. As shown in Figure 1, the starting point of the route (origin) is the Dong-gu Health Center and the arrival point (destination) is the Ayanggyo intersection. The red-colored route (1.1 km) is the shortest path found on Google Maps, whereas the green route (1.3 km) is the healthy route defined in this study. A healthy route requires walking a greater distance to reach the destination than the shortest route but has less traffic and better access to greenery and rivers.

2.2. Data

To compare people's perceptions between the healthy and the shortest walking routes, this study employed survey data generated from a large project (the Healthy Walking Project). The study was approved by the institutional review board of the research team and conducted from October 12–25, 2022, and all participants were aged 18 years or older. The survey was designed to ask participants to report their demographics and individual characteristics and their perceptions of walking route choice, walking behavior, attitudes toward health, preferred environmental factors in walking route choice, and preferred functions in pedestrian navigation mobile applications. The survey was conducted on residents living around the study areas of Ayang Bridge, and the data was used of 164 people who answered all the questions.

With regard to demographics and individual characteristics, this study used age, gender, car ownership, neighborhood residence duration, and the degree of familiarity with the neighborhood. For the walking route choice, we included the choice of walking route (the shortest route and healthy route) and satisfaction with the chosen walking route. Participants were shown Figure 1 and were asked to choose a walking route for

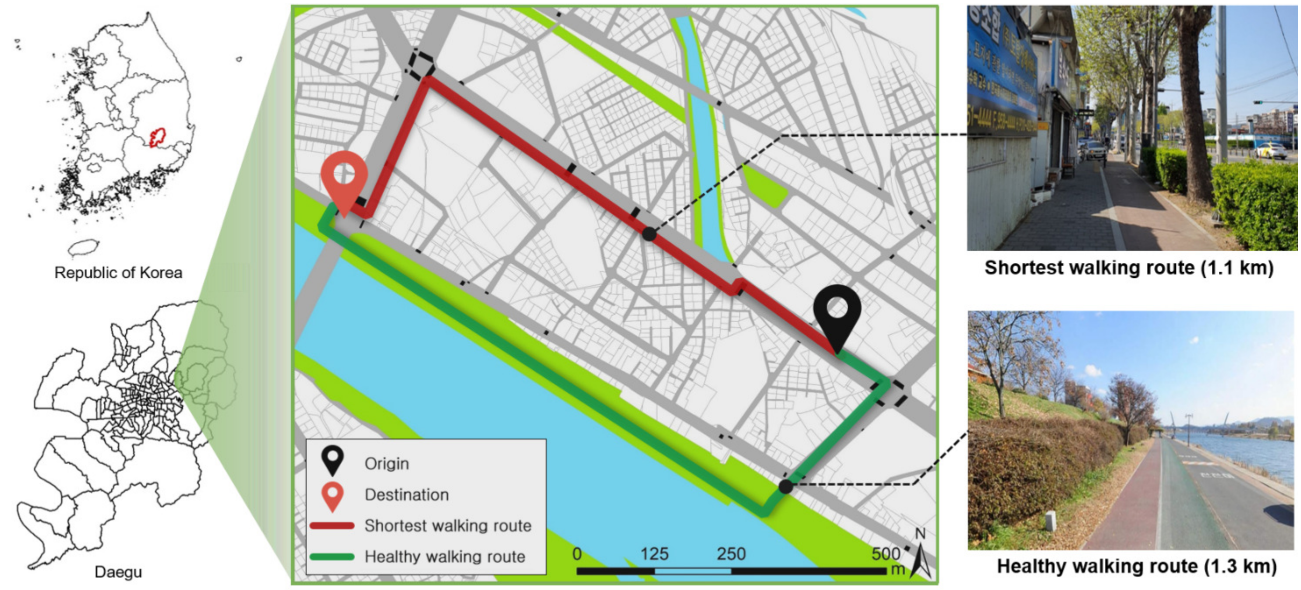


Figure 1. Study area and route setting.

leisure purposes. Satisfaction with the selected walking route was measured on a scale of 1 to 10 points.

For walking behavior, we considered the number of walking days per week and the average number of walking minutes for both recreation and transportation. Participants answered the question "How many days have you walked for more than 10 minutes for recreation/transportation purposes in the past week?" with the range from "not walking (0 days)" to "7 days." They also answered the question "How may minutes does it take on average to walk for recreation/transportation purposes?" in the range between "less than 10 minutes" and "more than 60 minutes."

Three attitudes toward health variables were considered: preference for walking to prevent chronic diseases, preference for walking to relieve stress and depression, and preference for walking to promote quality of life. For the preferred environmental factors for walking route choice, we used four categories (accessibility, convenience, pleasantness, and safety) and 11 types of corresponding variables. The corresponding variables used for each category were as follows: (a) accessibility: distance to destination; (b) convenience: flat terrain, presence of street amenities such as benches, and presence of retail stores; (c) pleasantness: low noise level, good air quality, presence of greenery and waterfront areas, and presence of tree shade; and (d) safety: low level of traffic speed and presence of traffic safety facilities, presence of crime prevention facilities (e.g., CCTV, streetlights), and environment with less contact with people. To measure participants' opinions, we used a 5-point Likert scale.

For the preferred environmental factors in pedestrian navigation mobile applications, we used 12 options, such as street connectivity, noise level, and greenery. By examining these items, we try to examine what factors should be considered in the development of pedestrian navigation mobile applications. The 12 options were constructed with reference to previous studies, and participants could choose one or more options without limiting the number.

In particular, for the preferred environmental factors, this study tried to compare people's perceptions from the survey with geographic information system (GIS)-measured environmental conditions. In other words, this study attempted to verify whether there was a difference between subjectively measured and objectively measured variables. For example, if we tried to compare in between the two groups (the shortest vs. healthy route) for the variable "presence of greenery and waterfront areas," the normalized difference vegetation index (NDVI) and the percentage of route length adjacent to the river could be employed for the objectively measured variables.

2.3. Analytical Methods

The analytical methods used in this study are as follows. First, participants were divided into two groups based on route selection (the shortest route vs. healthy route), and compared whether there were differences in individual characteristics and environmental perceptions. The *t* and chi-square tests were used to compare group differences between the shortest route and the healthy route. The *t*-test was used for continuous variables (i.e., satisfaction with the chosen walking route, weekly minutes of walking), whereas the chi-square test was employed for the ordinal scale of variables. Second, this study compared subjectively measured and objectively measured environmental conditions between the shortest route and healthy route groups. GIS software was used to capture the objectively measured environmental conditions. Third, this study investigated the preference of routing application functions in pedestrian-preferred environments, and the frequency bar charts were used. SPSS 26 and ArcGIS 10.5 were employed for this study.

3. Results

3.1. Differences in Walking Choice Between the Shortest Route and the Healthy Route by t *and Chi-Square Tests*

Table 1 shows the differences in demographics and individual characteristics and perceptions between the group that chose the shortest route and the group that chose the healthier route. Of the respondents, 71 (43.2%) chose the shortest route and 93 (56.7%) chose the healthy route. All variables from the demographics and individual characteristics (i.e., age, gender, car ownership, resident period, and familiarity with a neighborhood) of the two groups were not significantly different.

For walking route choice and walking behavior, the *t*-test was used due to the continuous variables. The satisfaction level with the selected walking route was found to be significantly higher in the group that chose the healthy route than in the group that selected the shortest route ($p < 0.001$). From the survey items, the number of days walked per week was multiplied by the average walking time to calculate the weekly minutes of walking. There were no significant mean differences in the total weekly minutes of walking for both recreation and transportation between the two groups (i.e., the shortest route vs. healthy route).

For an efficient chi-square test, the variables measured by the 5-point Likert scale in the survey were

Table 1. Comparison of individual characteristics and perceptions between healthy and the shortest route choices using *t* and chi-square tests.

Class	Variable		Measure	Shortest route ($N = 71$)	Healthy route ($N = 93$)	p *
				Count (%)	Count (%)	
Demographic/ Individual characteristics	Age		19 or younger	6 (8.5)	8 (8.6)	0.209
			20–29	22 (31.0)	31 (33.3)	
			30–39	16 (22.5)	16 (17.2)	
			40–49	6 (8.5)	16 (17.2)	
			50–59	12 (16.9)	19 (20.4)	
			60 or older	9 (12.7)	3 (3.2)	
	Gender		Male	25 (35.2)	29 (31.2)	0.586
			Female	46 (64.8)	64 (68.8)	
	Car ownership		Yes	35 (49.3)	40 (43.0)	0.423
			No	36 (50.7)	53 (57.0)	
	Period of residence in the neighborhood		Less than 1 year	13 (18.3)	13 (14.0)	0.742
			1–5	26 (36.6)	29 (31.2)	
			6–10	12 (16.9)	18 (19.4)	
			11–15	7 (9.9)	9 (9.7)	
			More than 16 years	13 (18.3)	24 (25.8)	
	Familiarity with the neighborhood		Not familiar	6 (8.5)	7 (7.5)	0.455
			Average	20 (28.2)	14 (15.1)	
			Familiar	45 (63.4)	72 (77.4)	
				Mean (SD)	Mean (SD)	
Walking route choice	Satisfaction with selected walking route		Continuous: 1 (dissatisfied)—10 (satisfied)	6.5 (1.8)	8.9 (1.3)	< 0.001 ***
Walking behavior	Recreation walk	Total weekly minutes of walking for recreation	Continuous: minutes	115.8 (92.4)	126.6 (113.2)	0.510
	Transportation walk	Total weekly minutes of walking for commuting and to retail services	Continuous: minutes	142.2 (111.7)	141.3 (111.0)	0.960

Table 1. (Cont.) Comparison of individual characteristics and perceptions between healthy and the shortest route choices using *t* and chi-square tests.

Class	Variable		Measure	Shortest route (*N* = 71)	Healthy route (*N* = 93)	*p* *
				Count (%)	Count (%)	
Attitude toward health	Preference for walking to prevent chronic diseases		Disagree Neither agree nor disagree Agree	4 (5.6) 21 (29.6) 46 (64.8)	1 (1.1) 8 (8.6) 84 (90.3)	< 0.001 ***
	Preference for walking to relieve stress and depression		Disagree Neither agree nor disagree Agree	3 (4.2) 13 (18.3) 55 (77.5)	2 (2.2) 4 (4.3) 87 (93.5)	0.009 ***
	Preference for walking to promote quality of life		Disagree Neither agree nor disagree Agree	2 (2.8) 23 (32.4) 46 (64.8)	2 (2.2) 11 (11.8) 80 (86.0)	0.005 ***
Preferred environmental factors in walking route choice	Accessibility	Distance to destination	Not important Average Important	3 (4.2) 13 (18.3) 55 (77.5)	8 (8.6) 19 (20.4) 66 (71.0)	0.479
	Convenience	Flat terrain	Not important Average Important	7 (9.9) 14 (19.7) 50 (70.4)	4 (4.3) 14 (15.1) 75 (80.6)	0.232
		Presence of street amenities such as benches	Not important Average Important	17 (23.9) 21 (29.6) 33 (46.5)	20 (21.5) 25 (26.9) 48 (51.6)	0.808
		Presence of retail stores	Not important Average Important	15 (21.1) 23 (32.4) 33 (46.5)	24 (25.8) 31 (33.3) 38 (40.9)	0.713
	Pleasantness	Low noise level	Not important Average Important	12(16.9) 11 (15.5) 48 (67.6)	5 (5.4) 11 (11.8) 77 (82.8)	0.034 **
		Good air quality	Not important Average Important	4 (5.6) 12 (16.9) 55 (77.5)	6 (6.5) 7 (7.5) 80 (86.0)	0.178
		Presence of greenery and waterfront areas	Not important Average Important	6(8.5) 22 (31.0) 43 (60.6)	3 (3.2) 6 (6.5) 84 (90.3)	< 0.001 ***
		Presence of tree shade	Not important Average Important	3 (4.2) 14 (19.7) 54 (76.1)	2 (2.2) 14 (15.1) 77 (82.8)	0.519
	Safety	Low level of traffic speed and presence of traffic safety facilities	Not important Average Important	4 (5.6) 10 (14.1) 57 (80.3)	1 (1.1) 7 (7.5) 85 (91.4)	0.083 *
		Presence of crime prevention facilities (e.g., CCTV, streetlights)	Not important Average Important	6 (8.5) 6 (8.5) 59 (83.1)	1 (1.1) 11 (11.8) 81 (87.1)	0.059 *
		Environment with less contact with people	Not important Average Important	8 (11.3) 26 (36.6) 37 (43.3)	17 (18.3) 27 (29.0) 49 (52.7)	0.365

Notes: * $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$.

converted into a 3-point Likert scale. For all three variables derived from the attitude toward health, the group that selected a healthy route showed significantly higher levels of perception, while the group who chose a healthy route showed higher levels of preference for walking to prevent chronic disease ($p < 0.001$), to relieve stress and depression ($p = 0.009$), and to promote quality of life ($p = 0.005$) than the group that chose the shortest route. Approximately 64.8% of the shortest route choice group and 90.3% of the healthy route choice group agreed that they preferred walking to prevent chronic disease, which was the most statistically different perception across the groups.

From the preferred environmental factors in walking route choice, four variables were statistically different between the two groups (shortest route vs. healthy route). There were significantly different perceptions of pleasantness, including a low level of noise and the presence of greenery and waterfront areas. Approximately 67.6% of the shortest route choice group and 82.8% of the healthy route choice group agreed that they consider the lower noise level when selecting a walking route ($p = 0.034$). Similarly, the healthy route group was more likely to consider the presence of greenery and waterfront areas than the shortest route group, at the 0.001 level of significance (90.3% vs. 60.6%).

There was also a statistically significant difference in the perception of environmental safety between the two groups. It was found that the group that chose a healthy route considered the lower level of traffic speed, presence of traffic safety facilities ($p = 0.083$), and presence of crime prevention facilities (e.g., CCTV, streetlights; $p = 0.059$) more than the group that chose the shortest route.

3.2. Comparison of Subjectively and Objectively Measured Environmental Conditions Between the Shortest Route and the Healthy Route Groups

As shown in Table 1, pleasantness and safety were important environmental factors for those who chose the healthy route. Specifically, respondents who elected for a healthy route had a greater preference for greenery and waterfront areas, a lower traffic speed, traffic safety facilities, and more crime prevention facilities than those who chose the shortest route. As objectively measured variables, we used the NDVI and the ratio of contact with waterfront for the presence of greenery and waterfront areas, while the ratio of arterial roads and the number of streetlights were used for low traffic speed, traffic safety facilities, and crime prevention facilities, respectively. NDVI is a popular index for vegetation, with higher values indicating greener vegetation conditions (Candiago et al., 2015; Pettorelli et al., 2005). We used the Landsat-8 OLI scene from July 1, 2022, from the United States Geological Survey website (https://earthexplorer.usgs.gov). Data on waterfronts and arterial roads were obtained from the National Spatial Data Infrastructure Portal (2022) and streetlight data were obtained from the D-data hub (2022).

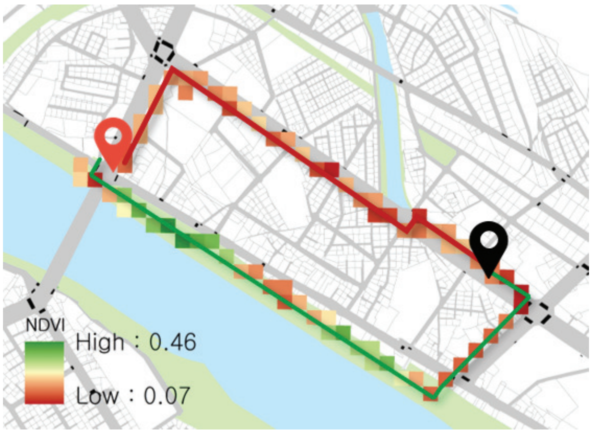
The results using the objectively measured variables are shown in Tables 2 and 3. The average NDVI (ranging from −1 [no vegetation] to 1 [green vegetation]) of the healthy route and the shortest route was 0.25 and

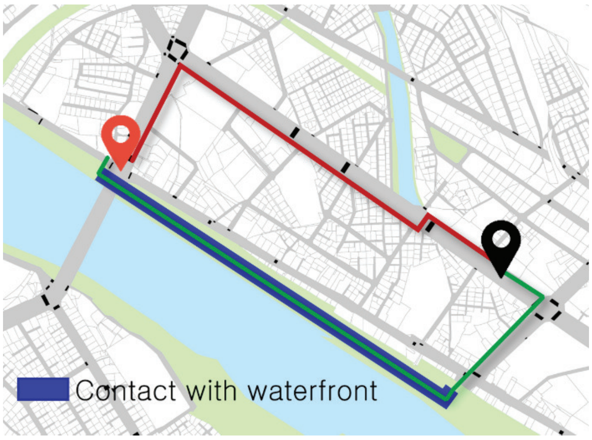
Table 2. Comparison of subjectively and objectively measured environmental conditions between the shortest route and healthy route groups.

Subjectively measured variables from the survey				Objectively measured variables using GIS		
Variable		Descriptive statistics		Measure	Descriptive statistics	
		Shortest route	Healthy route		Shortest route	Healthy route
Presence of greenery and waterfront areas	Not important (%)	8.5	3.2	NDVI (ranging from −1 to 1)	0.16	0.25
	Average (%)	31.0	6.5			
	Important (%)	60.6	90.3	Ratio of contact with waterfront (%)	0.00	68.95
Low level of traffic speed and presence of traffic safety facilities	Not important (%)	5.6	1.1	Ratio of arterial road (%)	100.00	28.46
	Average (%)	14.1	7.5			
	Important (%)	80.3	91.4			
Presence of crime prevention facilities	Not important (%)	8.5	1.1	Number of streetlights (n/km)	21.10	22.80
	Average (%)	8.5	11.8			
	Important (%)	83.1	87.1			

Table 3. Environmental conditions of objectively measured variables using GIS.

Pleasantness





NDVI (ranging from –1 to 1)

Route	Mean (SD)	Min	Max
Shortest route	0.16 (0.04)	0.07	0.27
Healthy route	0.25 (0.11)	0.08	0.46

Ratio of contact with waterfront (%)

Route	Total length	Length with waterfront	Ratio of waterfront
Shortest route	1,090 m	0 m	0%
Healthy route	1,272 m	877 m	68.95%

Safety

Ratio of arterial road (%)

Route	Total length	Length with arterial road	Ratio of arterial road
Shortest route	1,090 m	1,090 m	100%
Healthy route	1,272 m	362 m	27.46%

Number of streetlights (n/km)

Route	Total length	Number of streetlights	n per km
Shortest route	1,090 m	23	21.10
Healthy route	1,272 m	29	22.80

Legend

Origin Destination Shortest walking route Healthy walking route 0 125 250 500 m N

0.16, respectively, demonstrating that the greenery level of the healthy route was better than that of the shortest route. Healthy routes accounted for approximately 69% of the rate of contact with the waterfront, so much of the route could be walked along the river, but the shortest route did not align with the waterfront. For the arterial road ratio, only about 28% of the healthy route was on the arterial road, while the shortest route fully followed the arterial road. This showed that the pedestrians who chose the healthy route were relatively safer from vehicular incidents than those who chose the shortest route. As for the number of streetlights, there was no significant difference in the number of streetlights at approximately 22 per km for the healthy route and 21 per km for the shortest route.

3.3. Preferred Environmental Factors in Pedestrian Navigation Mobile Applications

This study also sought to investigate routing application functions in pedestrian-preferred environments. The participants were able to choose from among multiple selections with 12 environmental factors. A total of 527 samples were selected from 164 participants, with an average of 3.2 environmental factors selected per person. Figure 2 shows the preferred pedestrian navigation functions for mobile applications. The most preferred environmental factor was "greenery and waterfront areas," accounting for 14.6% of the total. The ratios for "low traffic volume" and "safety from traffic accidents and crimes" were 14.2% and 13.7%, respectively.

Figure 3 shows the preferred environmental factors by classifying the participants who chose the healthy and shortest routes. The rate of choosing "greenery and waterfront areas" was the highest at 19.3% in the healthy route selection group, but only 8.9% in the shortest route selection group, which only ranked 6th. In other words, those who chose the healthy route were most

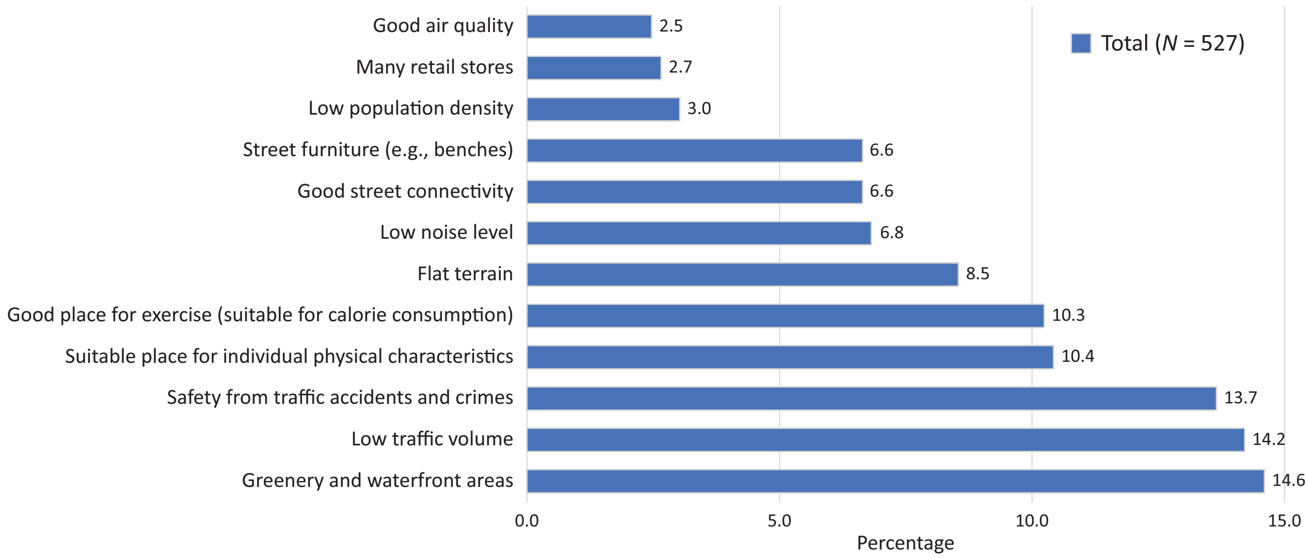


Figure 2. Preferred environmental factors in pedestrian navigation mobile application for the total sample.

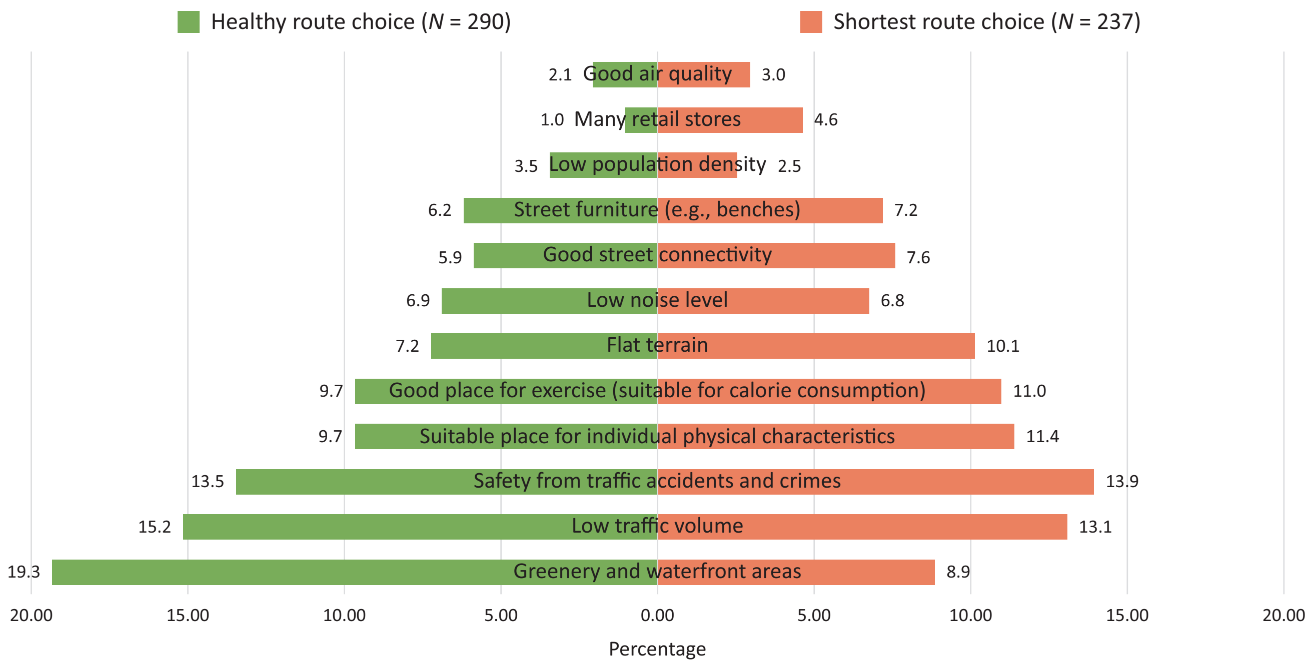


Figure 3. Preferred environmental factors in pedestrian navigation mobile application of the subsamples (the shortest route group vs. healthy route group).

interested in having pleasant environmental conditions while those who chose the shortest route were most interested in safety.

4. Discussion

Smart cities are increasingly recognized as important for creating sustainable and livable environments. The smart city environment can help people choose a healthy walking route. In this study, participants" walking route choices were investigated by setting the shortest route and the healthy route. Moreover, we compared the preferred environmental factors and pedestrian navigation application functions for the two groups. Approximately 56.7% of participants chose the healthy route and were more satisfied with it. Those who chose the healthy route had a higher health awareness and considered it to be more important in terms of the pleasantness and safety of the environment. In addition, those who chose a healthy route preferred having pleasant environmental conditions (e.g., greenery and waterfront areas, low traffic volume) as a pedestrian navigation mobile application function.

Based on the findings of this study, several observations can be made. First, we found that pedestrians were likely to choose healthy routes (more pleasant and safer routes), even if they took more time. This shows that a pedestrian navigation mobile application that guides people to healthy walking routes can be a useful and effective means of promoting citizens' health in smart cities. With the development of technology, walking route search systems that consider various environmental conditions have been developed (Conticelli et al., 2018). Recently, with the technological advancements of various mobile devices, such as smartphones and smartwatches, it has become easier to implement healthy walking using mobile applications (Rodrigues et al., 2019). Therefore, more attention to develop a system that searches for a healthy route and active support for related research are required.

Second, we found consistency between subjectively measured and objectively measured preferred environmental conditions among those who chose healthy route. According to the results, those who chose the healthy route placed more importance on the following environmental conditions than those who chose the shortest route: presence of greenery and waterfront areas, low level of traffic speed, and presence of traffic safety facilities. When measuring a healthy route using GIS, it had more greenery and more contact with the waterfront than the shortest route. In addition, there were much fewer sections facing arterial roads with heavy traffic. This study found that the objectively measured variables using GIS could explain the subjectively measured perceptions of pedestrians. Therefore, using both subjectively and objectively measured variables in these empirical studies can be an important approach to increase research validity.

Third, we found that the environmental conditions with rich in greenery and waterfront areas, and safe from cars and crime were important factors in promoting healthy walking. The environmental factors that people who chose a healthy route considered important and actually wanted to be guided in the pedestrian navigation mobile applications were the environmental conditions rich in greenery and safety. Several previous studies have shown that green and blue spaces are important factors in improving people's physical activity and health conditions (Gaikwad & Shinde, 2019; Lee et al., 2015; Vert et al., 2020). In addition, some studies have reported that people walk more and engage more in physical activity in areas with low crime rates and safe from car accidents (Oyeyemi et al., 2012; Rees-Punia et al., 2018). Therefore, this study could support the results of previous studies and showed that a pleasant and safe environment can encourage pedestrians to walk longer. Urban planners and policy makers can promote people's walking by providing green and blue areas, and safe streets in their neighborhoods. Moreover, the pedestrian navigation mobile application will help to promote healthy and active walking by providing a function that meets the needs of pedestrians (i.e., a function that guides a pleasant and safe environment).

Fourth, there is a need for information technology that collects, analyzes, and provides environmental information in real time so that people can effectively use pedestrian navigation mobile applications. Environmental sensors can measure various types of data such as noise, airborne pollen, floating population, and traffic volume in real time, as well as air pollutants such as PM_{10}, $PM_{2.5}$, CO, NO_2, and O_3 (Rußig & Bruns, 2017). In addition, it is possible to collect image and video data from streets using CCTV. A large amount of real-time big data collected from sensors and monitors can be utilized to search for healthy walking routes with the help of various technologies, such as ICT and ubiquitous technology (Cardozo et al., 2015; Nallur et al., 2015; Papageorgiou et al., 2020). For this, it is necessary to establish sensors and an ICT-based network infrastructure that can record and measure various detailed data in urban environments.

This study has several limitations, and directions for future research to address them are as follows. First, it investigated the route selection of participants for a specific area. Future studies can examine many case areas of various environments (e.g., high-density areas with buildings vs. low-density areas with open spaces). Second, it is difficult to generalize people's route selection results because the survey was conducted only during a specific period. Therefore, additional research is needed on which routes pedestrians choose for leisure under various environmental conditions such as season, weather, and time of day. Third, this study compared individual characteristics and perceptions of the environment between the two groups using *t* and chi-square tests. Some multivariate analyses, such as the spatial regression model and multi-level regression approach, can be employed to examine the association between environmental factors and walking selection in future studies. Finally, this study examined the functions preferred by people in pedestrian navigation mobile applications. When the application is commercialized in the future, it is expected allow for more diverse and in-depth studies using the data produced. For example, it would be possible to compare objective environmental conditions, people's perceptions of the environment, and their health status using real-time data between those who practice healthy walking and those who do not.

5. Conclusions

Encouraging walking is an essential requirement for creating a healthy city and is line with the UN's sustainable development goals (Cerin et al., 2022; Visvizi et al., 2021). The smart city, a new urban planning paradigm, contributes to improving neighborhood walkability (Conticelli et al., 2018). In this context, this study investigates the environmental factors that make people walk healthier in smart cities. The results revealed that the participants in this study tended to choose routes with comfortable and safe environmental conditions, even if this meant that they had to walk longer distances. In addition, they expressed a desire to find a pleasant and safe route by using pedestrian navigation mobile applications. Accordingly, urban planners are trying to create a pleasant and safe environment that promotes healthy walking. This study can be employed to suggest urban planning and design policies that support healthier and more active walking in smart cities.

Acknowledgments

This research was funded by a National Research Foundation (NRF) of Korea grant funded by the Korean government (No. NRF-2021R1A2B5B01002628).

Conflict of Interests

The authors declare no conflict of interests.

References

Basu, N., Oviedo-Trespalacios, O., King, M., Kamruzzaman, M., & Haque, M. M. (2022). The influence of the built environment on pedestrians' perceptions of attractiveness, safety and security. *Transportation Research Part F: Traffic Psychology and Behaviour*, *87*, 203–218.

Bhowmick, D., Winter, S., Stevenson, M., & Vortisch, P. (2021). Investigating the practical viability of walk-sharing in improving pedestrian safety. *Computational Urban Science*, *1*(1), Article 21.

Borgers, A. W. J., & Timmermans, H. J. P. (2005). Modelling pedestrian behaviour in downtown shopping areas. In *Proceedings of CUPUM 05: Computers in Urban Planning and Urban Management, 30-Jun-2005, London* (pp. 1–15). University College London.

Candiago, S., Remondino, F., De Giglio, M., Dubbini, M., & Gattelli, M. (2015). Evaluating multispectral images and vegetation indices for precision farming applications from UAV images. *Remote Sensing*, *7*(4), 4026–4047.

Cardozo, N., Nallur, V., & Clarke, S. (2015). Enabling participatory routing using a smart routing platform. In *2015 IEEE First International Smart Cities Conference (ISC2)* (pp. 1–2). IEEE. https://doi.org/10.1109/ISC2.2015.7366180

Cerin, E., Sallis, J. F., Salvo, D., Hinckson, E., Conway, T. L., Owen, N., van Dyck, D., Lowe, M., Higgs, C., Moudon, A. V., Adams, M. A., Cain, K. L., Christiansen, L. B., Davey, R., Dygrýn, J., Frank, L. D., Reis, R., Sarmiento, O. L., Adlakha, D., . . . Giles-Corti, B. (2022). Determining thresholds for spatial urban design and transport features that support walking to create healthy and sustainable cities: Findings from the IPEN adult study. *The Lancet Global Health*, *10*(6), 895–906.

Conticelli, E., Maimaris, A., Papageorgiou, G., & Tondelli, S. (2018). Planning and designing walkable cities: A smart approach. In R. Papa, R. Fistola, & C. Gargiulo (Eds.), *Smart planning: Sustainability and mobility in the age of change* (pp. 251–269). Springer.

D-data hub. (2022). *Daegu metropolitan city: Status of security lights (SHP)* [Data set]. https://data.daegu.go.kr/open/main.do

Deilami, K., Rudner, J., Butt, A., MacLeod, T., Williams, G., Romeijn, H., & Amati, M. (2020). Allowing users to benefit from tree shading: Using a smartphone app to allow adaptive route planning during extreme heat. *Forests*, *11*(9), Article 998.

Fonseca, F., Conticelli, E., Papageorgiou, G., Ribeiro, P., Jabbari, M., Tondelli, S., & Ramos, R. (2021). Use and perceptions of pedestrian navigation apps: Findings from Bologna and Porto. *ISPRS International Journal of Geo-Information*, *10*(7), Article 446.

Gaikwad, A., & Shinde, K. (2019). Use of parks by older persons and perceived health benefits: A developing country context. *Cities*, *84*, 134–142.

Gani, M. O., Raychoudhury, V., Edinger, J., Mokrenko, V., Cao, Z., & Zhang, C. (2019). Smart surface classification for accessible routing through built environment: A crowd-sourced approach. In *BuildSys '19: Proceedings of the 6th ACM International Conference on Systems for Energy-Efficient Buildings, Cities, and Transportation* (pp. 11–20). Association for Computing Machinery. https://doi.org/10.1145/3360322.3360863

Guo, Z., & Ferreira, J., Jr. (2008). Pedestrian environments, transit path choice, and transfer penalties: Understanding land-use impacts on transit travel. *Environment and Planning B: Planning and Design*, *35*(3), 461–479.

Guo, Z., & Loo, B. P. Y. (2013). Pedestrian environment and route choice: Evidence from New York City and Hong Kong. *Journal of Transport Geography*, *28*, 124–136.

Handy, S., Cao, X., & Mokhtarian, P. L. (2006). Self-selection in the relationship between the built environment and walking: Empirical evidence from Northern California. *Journal of the American Planning Association*, *72*(1), 55–74.

Hillnhütter, H. (2022). Stimulating urban walking environments—Can we measure the effect? *Environment and Planning B: Urban Analytics and City Science*, *49*(1), 275–289.

Jabbari, M., Ahmadi, Z., & Ramos, R. (2022). Defining a digital system for the pedestrian network as a conceptual implementation framework. *Sustainability*, *14*(5), Article 2528.

Koh, P. P., & Wong, Y. D. (2013). Influence of infrastructural compatibility factors on walking and cycling route choices. *Journal of Environmental Psychology*, *36*, 202–213.

Lee, A. C., Jordan, H. C., & Horsley, J. (2015). Value of urban green spaces in promoting healthy living and wellbeing: Prospects for planning. *Risk Management and Healthcare Policy*, *8*, 131–137.

Lee, S., & Lee, M.-H. (2021). Impact of neighborhood environment on pedestrian route selection among elementary schoolchildren in Korea. *International Journal of Environmental Research and Public Health*, *18*(13), Article 7049.

Line, T., Jain, J., & Lyons, G. (2011). The role of ICTs in everyday mobile lives. *Journal of Transport Geography*, *19*(6), 1490–1499.

Mishra, S., Singh, N., & Bhattacharya, D. (2021). Application-based Covid-19 micro-mobility solution for safe and smart navigation in pandemics. *ISPRS International Journal of Geo-Information*, *10*(8), Article 571.

Monreal, C. O., Pichler, M., Krizek, G., & Naumann, S. (2016). Shadow as route quality parameter in a pedestrian-tailored mobile application. *IEEE Intelligent Transportation Systems Magazine*, *8*(4), 15–27.

Moreno, C., Allam, Z., Chabaud, D., Gall, C., & Pratlong, F. (2021). Introducing the "15-minute city": Sustainability, resilience and place identity in future post-pandemic cities. *Smart Cities*, *4*(1), 93–111.

Nallur, V., Elgammal, A., & Clarke, S. (2015, May 16–17). Smart route planning using open data and participatory sensing. In *Open systems: Adoption and impact: 11th IFIP WG 2.13 International Conference, Florence, Italy* (pp. 91–100). Springer. http://hdl.handle.net/2262/73955

National Spatial Data Infrastructure Portal. (2022). *Land characteristics information* [Data set]. http://openapi.nsdi.go.kr/nsdi/index.do

Novack, T., Wang, Z., & Zipf, A. (2018). A system for generating customized pleasant pedestrian routes based on OpenStreetMap data. *Sensors*, *18*(11), Article 3794.

Olszewski, P., & Wibowo, S. S. (2005). Using equivalent walking distance to assess pedestrian accessibility to transit stations in Singapore. *Transportation Research Record*, *1927*(1), 38–45.

Oyeyemi, A. L., Adegoke, B. O., Sallis, J. F., Oyeyemi, A. Y., & De Bourdeaudhuij, I. (2012). Perceived crime and traffic safety is related to physical activity among adults in Nigeria. *BMC Public Health*, *12*(1), Article 294.

Pang, Y., Zhang, L., Ding, H., Fang, Y., & Chen, S. (2019). Spath: Finding the safest walking path in smart cities. *IEEE Transactions on Vehicular Technology*, *68*(7), 7071–7079.

Panter, J., Guell, C., Humphreys, D., & Ogilvie, D. (2019). Can changing the physical environment promote walking and cycling? A systematic review of what works and how. *Health & Place*, *58*, Article 102161.

Papageorgiou, G., Hadjigeorgiou, K., & Ness, A. N. (2020). Exploring the prospects of developing a smartphone application for pedestrians. In *2020 19th International Symposium INFOTEH-JAHORINA (INFOTEH)* (pp. 1–5). IEEE. https://doi.org/10.1109/INFOTEH48170.2020.9066287

Pettorelli, N., Vik, J. O., Mysterud, A., Gaillard, J.-M., Tucker, C. J., & Stenseth, N. C. (2005). Using the satellite-derived NDVI to assess ecological responses to environmental change. *Trends in Ecology & Evolution*, *20*(9), 503–510.

Pimpinella, A., Redondi, A. E. C., & Cesana, M. (2019). Walk this way! An IoT-based urban routing system for smart cities. *Computer Networks*, *162*, Article 106857.

Rees-Punia, E., Hathaway, E. D., & Gay, J. L. (2018). Crime, perceived safety, and physical activity: A meta-analysis. *Preventive Medicine*, *111*, 307–313.

Rodrigues, M., Santos, R., Queirós, A., Silva, A., Amaral, J., Simoes, P., Gonçalves, J., Martins, C., Pereira, A., & da Rocha, N. P. (2019). Supporting better physical activity in a smart city: A framework for suggesting and supervising walking paths. *Advances in Science, Technology and Engineering Systems Journal*, *4*(4), 404–413.

Rodríguez, D. A., Brisson, E. M., & Estupiñán, N. (2009). The relationship between segment-level built environment attributes and pedestrian activity around Bogota's BRT stations. *Transportation Research Part D: Transport and Environment*, *14*(7), 470–478.

Rußig, J., & Bruns, J. (2017). Reducing individual heat stress through path planning. *GI_Forum*, *1*, 327–340.

Sallis, J. F., Saelens, B. E., Frank, L. D., Conway, T. L., Slymen, D. J., Cain, K. L., Chapman, J. E., & Kerr, J. (2009). Neighborhood built environment and income: Examining multiple health outcomes. *Social Science & Medicine*, *68*(7), 1285–1293.

Siriaraya, P., Wang, Y., Zhang, Y., Wakamiya, S., Jeszenszky, P., Kawai, Y., & Jatowt, A. (2020). Beyond the shortest route: A survey on quality-aware route navigation for pedestrians. *IEEE Access*, *8*, 135569–135590.

Taleai, M., & Yameqani, A. S. (2018). Integration of GIS, remote sensing and multi-criteria evaluation tools in the search for healthy walking paths. *KSCE Journal of Civil Engineering*, *22*(1), 279–291.

Vert, C., Gascon, M., Ranzani, O., Márquez, S., Triguero-Mas, M., Carrasco-Turigas, G., Arjona, L., Koch, S., Llopis, M., Donaire-Gonzalez, D., Elliott, L. R., & Nieuwenhuijsen, M. (2020). Physical and mental health effects of repeated short walks in a blue space environment: A randomised crossover study. *Environmental Research*, *188*, Article 109812.

Visvizi, A., Abdel-Razek, S. A., Wosiek, R., & Malik, R. (2021). Conceptualizing walking and walkability in the smart city through a model composite w^2 smart city utility index. *Energies*, *14*(23), Article 8193.

Wakamiya, S., Siriaraya, P., Zhang, Y., Kawai, Y., Aramaki, E., & Jatowt, A. (2019). Pleasant route suggestion based on color and object rates. In *Proceedings of the 12th ACM International Conference on Web Search and Data Mining* (pp. 786–789). Association for Computing Machinery. https://doi.org/10.1145/3289600.3290611

About the Authors

Eun Jung Kim is an associate professor in the Department of Urban Planning at Keimyung University, South Korea. Her research interest is the promotion of citizens' health by creating walkable and livable communities. She mainly studies how to create healthy communities from an urban planning perspective. Before joining Keimyung University, she worked as an associate research fellow at the Korea Research Institute for Human Settlements, South Korea, and a postdoctoral research fellow at Texas A&M University, USA.

Youngeun Gong holds a master's degree in urban planning and transportation engineering from Keimyung University. Her research interests are pedestrian-friendly urban environments in relation to urban planning and public health. Her most recent research focused on the perceived built environment correlated to route choice for healthy walking, and the built environment associated with increased leisure walking time in the neighborhood.