Key Factors to Affect Elderly Pedestrian Travel Behavior Using a Multi-level Regression Model: A Case for Seoul

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Abstract: Nowadays the paradigm of urban planning has focused on sustainable development. Walking is emerging as sustainable personal mobility, because walking can improve the physical health of pedestrian without pollution. Therefore, diverse subjects related to pedestrian behavior and street design have been studied recently. In this regard, this study first identified the characteristics of elderly pedestrian's behavior. Then, a multi-level regression model was developed in order to explore key factors to affect elderly pedestrian's behavior, considering them as three levels; individual, household, and urban facility. The results showed that household and urban facility characteristics explained approximately 30% of total variance. Moreover, elderly pedestrian's activities are strongly affected by urban facilities such as level of mixed land use and commercial facilities, as well as individual and household characteristics. In light of such results, we can propose the street design for elderly people and strategies regarding development of downtown, or designate the pedestrian safety area.

Keywords: Elderly Pedestrian, Pedestrian Behavior, Multi-level Regression Model, Walking Frequency, Walking Time

1. INTRODUCTION

Recently, the paradigm of urban planning is changing to promote sustainable development against urban sprawl. With such trend, the government has also been encouraging energy-saving urban development to achieve the goal of "Green City with Low Carbon". There are five key components required for green city development: eco-friendly land use, green transportation system, natural ecology, efficiency of energy, and management of resources. As green transportation, walking is a promising strategy to represent all those factors.

Walking is an essential and indispensable transportation mode of and for humans because it encompasses every step of using various transportation modes (Lee *et al*., 2014). Therefore, there appears commonly a high pedestrian volume in areas where streets are active and transportation infrastructure is well developed due to diverse activities to require a certain amount of walking. Such areas may be defined as areas having remarkable urban functions; pedestrian volumes can be used as an index to estimate the level of pedestrian activity.

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For studying pedestrian behavior and forecasting pedestrian volumes, we need to consider elderly pedestrians and non-elderly pedestrians separately since they have different travel attributes. Our society has been getting older with the trend of rapid acceleration of an aging population. The proportion of the elderly aged 65 and over accounts for more than 10% in Korea and will increase significantly in the near future, showing even faster growth than other developed countries. Old people generally have no commuting trips, small income and physical limitation for long-distance trips. These circumstances may be connected with trip pattern changes in term of transportation modes and purposes of their trips, compared with younger cohorts. According to a former research (Lee *et al*., 2014), the percentage of walking trips was highest in the elderly, while personal vehicle trips the highest in the non-elderly. Also, one conventional purpose of elderly pedestrian travel was shopping or leisure, whereas the purpose of non-elderly pedestrian travel was typically commuting or business. Based on these trends, studying trip characteristics according to differentiated age groups and eventually establishing proper polices and strategies for convenient and safe elderly mobility are necessary. Up to now, many studies have been done regarding trip patterns of the non-elderly. Therefore, the paper focuses on analyzing walking behavior of the elderly and finding factors influencing their trips.

This study identifies the characteristics of elderly pedestrians; particularly through multi-level regression analysis which considers walking characteristics by hierarchy, developed in consideration of the difference in pedestrian behavior according to the features of urban facilities, individual characteristics, and household characteristics.

2. LITERATURE RIVIEW

Studies regarding characteristics of pedestrian behavior generally investigated how individual characteristics, household characteristics, and zone characteristics affect pedestrian behavior. Early studies which focused on individual characteristics mainly introduced variables including gender, age, features of residential area, level of income, etc (Boarnet *et al*., 1998; SANDAG, 1997; Sarmiento., 1995).

However, as the fact that pedestrian behavior is affected not only by individual characteristics but also by regional characteristics was revealed, various studies on pedestrian behavior according to regional characteristics have also been conducted. The most representative variables in these studies are land use, public transportation infrastructure, urban facility area and so on (Lee *et al*., 2014; Jo *et al*., 2009; Boarnet *et al*., 1996; Kim *et al*., 2011). In addition, there were also studies that analyzed the relationship between walking and accessibility to public transportation (Sung, 2013).

As mentioned above, there are many studies that dealt with the characteristics of pedestrian behavior and pedestrian's safety, but a very few studies consider the causal relationship among independent variables of pedestrian behavior. Previous studies only considered multicollinearity using VIF (Variance Inflation Factor). However, the independent variables such as characteristics of individual, household, land use, transportation service, etc., which are considered in these studies, are in an inter-correlation or have a particular hierarchy. Therefore, a multi-level analysis is required to consider the hierarchical characteristics and intra-correlation among independent variables to verify the characteristics of elderly pedestrians.

3. METHODS

In this study, walking frequency and walking time were selected as the dependent variables, which reveal the key characteristics of elderly pedestrian travel behavior. Walking frequency implies the number of trips on foot for a day, and walking time means the total travel time by walking for a day.

The independent variables related to the pedestrian characteristics are defined by three groups: individual, household and urban facilities. There are hierarchical relationships among the three groups as shown in Figure 1 (Sung *et al*., 2012). A three-level modeling structure is defined considering variable interactions. Individual variables are at the upper level; household variables are at the middle level; urban facility variables are at the lower level. An individual is included in a household and each household located at the same region is included in an urban facility. Thus, urban facilities affect the household and individual respectively, and the household influences the individual as shown below.

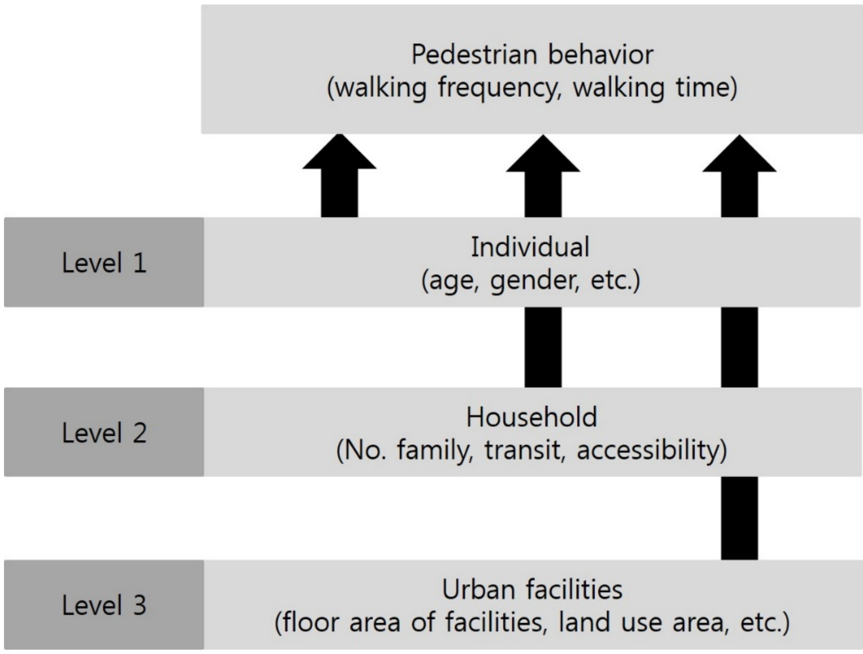

Figure 1. Structure of multi-level regression model

Therefore, the research estimates a multi-level regression model and then compares the results with multiple linear regression models. A general formula of the multi-level regression model is as follows: *i* is individual in household j, β_0 is intercept at level i, β_1 is a regression coefficient at level i, β_2 is a regression coefficient at level j, δ_j is the random intercept at level j, e_{ij} is the random error component at level *i*.

$$y_{ij} = \beta_0 + \beta_1 x_{ij} + \beta_2 x_j + \delta_j + e_{ij} \quad (1)$$

Seoul, the capital city in Korea, has been chosen as the study area where various urban facilities and functions are concentrated, and thereby diverse pedestrian behavior can be observed.

4. DATA COLLECTION

4.1 Pedestrian characteristics

This study collected data on elderly pedestrian characteristics from a national travel diary survey conducted in 2010. The travel diary survey provides useful data to investigate the characteristics of individuals, households and trips. The method of the survey is as follows: a diary would be recorded for each of the household members, and a survey would be conducted every 5 years, with the scope set as the whole country of South Korea.

The individual survey data were used to investigate the age, gender, address, occupation, income, car ownership, driver's license, etc. The household survey data were utilized to analyze the number of household members, the number of preschool children, transit accessibility, etc. The travel survey is used to find the trip pattern of each household on a specific day, including the total number of trips, origin and destination, departure and arrival time, transportation mode, fare, etc.

Another type of data from floating population survey by Seoul Metropolitan Government is also available for investigating pedestrian characteristics. However, the travel diary survey data might be more suitable to analyze walking pattern of the elderly in detail. The advantages of the travel diary survey data are shown below.

First, specific data for individual's characteristics such as pedestrian's age, gender, income, address, etc. could be collected. Since the floating population survey focuses on its purpose of counting the pedestrian volume, attributes of individual or household pedestrians are not captured in detail. For example, one survey only recorded each pedestrian's age and gender. Thus, we apprehended that information and conclusions made by analyzing a floating population survey was not reliable.

Second, with a travel diary survey, the characteristics of pedestrian behavior like the origin and destination of a trip, walking time, and travel purposes could be identified in detail. A floating population survey would only count the number of pedestrians passing the investigation point, thus detailed information related to pedestrian behavior could be obtained. Therefore, we came to a minor conclusion that data from a travel diary survey would be more appropriate when identifying the characteristics of pedestrian behavior.

The variables selected from the travel diary survey would be used to explain pedestrian behavior in only two of the three analytical levels discussed in this paper; level 1 includes individual characteristics such as age, gender, car ownership, driver's license, etc., and level 2 contains household characteristics such as the number of household members, residential types, transit accessibility, the number of preschool children, etc.

4.2 Urban facility

The urban facility variables represent the residence characteristics of the elderly pedestrian based on zoning system. Therefore pedestrians who live in the same zone have the same indexes for urban facility exactly. Level 3 variables are classified into 3 groups: floor area of facility, , transportation service, and socio-economic index. The facilities which belong to the group of floor area of facility are residential, neighborhood, retail, medical, elderly, leisure and sports facilities. Neighborhood facility classified into two types; neighborhood (Ⅰ) and neighborhood (Ⅱ). Retail facility means the retail and wholesale facilities which are not included in neighborhood facilities. Medical facility includes the general hospital, private hospital and isolation hospital. Elderly facility is the amenities for social welfare of children and senior citizens. Leisure facility includes the outside theater and music hall, add-on facilities of the park, and children's hall. Sports facility is the small scale sports facilities that stand capacity is within 1,000m^2.

The land use mixed index (LUM), which means the mixed level of land use and urban functions in each zone, is defined as the equation below. In this equation, i indicates the land use such as residence, commerce, industry, green zone, etc., p_i indicates the area ratio of the corresponding land use, n means the number of land use (Choi *et al.*, 2013).

$$LUM = -\frac{\sum_{i=1}^{n} p_i \ln p_i}{\ln n} \tag{2}$$

Transportation service variables contain the total road area, the number of bus stops, a subway catchment area, and the number of cars per 1,000 people. The subway catchment area implies the area within 500m radius of a subway station in each zone. In the large subway catchment area, people can use the subway system more conveniently, and it also means people are provided with high quality subway services.

For the variables of socioeconomic index, some representative variables related to the pedestrian behavior were collected. Those variables are the number of households, the number of economically active population, the number of students and schools that can describe the trip purpose related to school and education trips, and the number of workers and employees that can represent the purpose of work and business trips.

Table 1. Independent variables by level

Variable			Note
Individual level (lelvel 1)	Age		· Continuous variable
	Gender		· Dummy (male:1 / female:0)
	Car ownership		· Dummy (yes:1 / no:0)
	Driver's license		· Dummy (yes:1 / no:0)
Household level (level 2)	Nu. of household members		· Continuous variable
	Residential type		· Dummy (Apartment/townhouse/multiplex/single/others)
	Transit accessibility (m)		· Distance from residence to bus/subway station
Urban facility level (level 3)	Land use	Floor area of facility (㎢)	· Facilities include neighborhood, cultural and meeting, retail, medical, elderly, leisure, sports facility
		LUM	· Continuous variable between 0 and 1
	Transpor-tation service	Total road area (㎢)	· Continuous variable
		No. of bus stops	· Continuous variable
		Subway catchment area	· Radius of influenced area is 500m
		No. of cars per 1,000 people	· Continuous variable

	Socio economic Index	No. of students	・Continuous variable
		No. economically active population	・Continuous variable
		No. of employees	・Continuous variable
		No. of schools	・Continuous variable

4.3 Descriptive analysis

We conducted descriptive analysis focused on key factors of each level. Key factors included from dependent variables (walking frequency and walking time) to independent variables such as elderly pedestrian's age, the number of household members, the number of preschoolers, transit accessibility, urban facilities and land use.

Table 2. Descriptive analysis results

Variable		Average	Standard deviation	Min	Max	Skewness	Kurtosis
Age		72.636	6.814	65	109	1.097	0.981
No. of family members		3.548	1.514	1	8	-0.186	-1.186
No. of preschool children		0.075	0.294	0	3	4.185	18.638
Access time to subway (min)		10.960	7.878	0	90	2.209	10.018
Access time to bus (min)		5.535	3.686	0	60	2.943	24.501
Floor Area (㎢)	Neighborhood (Ⅰ) facility	0.093	0.070	.0171	.4276	1.203	.957
	Neighborhood (Ⅱ) facility	0.090	0.095	.0135	.6656	4.470	24.525
	Cultural and meeting facility	0.002	0.004	0	0.02	2.744	7.052
	Retail facility	0.010	0.024	0	.2171	3.920	18.745
	Medical facility	0.006	0.012	0	.0694	3.680	15.061
	Elderly facility	0.009	0.046	0	.3731	7.440	55.583
	Leisure facility	0.001	0.001	0	.0081	4.567	20.653
	Sports facility	0.001	0.001	0	0.012	11.556	170.296
LUM		.305655	.2313094	0	.7918	.366	-.853
No. of bus stops		35.35	20.559	7	200	2.909	17.019
Subway catchment area		.710586	.4720314	0	1.6825	.778	-.426
total road area (㎢)		.352459	.2081003	.0935	.8775	1.025	-.035
No. of students		4,724	6,611.019	0	29,731	2.558	6.235

No. of economically active population	14,944	4,444.039	8,041	24,694	0.021	-1.120
Walking frequency (trip)	2.19	.882	1	12	1.814	5.959
Walking time (min)	41.75	29.802	2	235	2.065	6.126

There is, however, a considerable amount of omitted pedestrian volumes because extremely short distance trips such as visiting a convenience store are hardly reported. Therefore, this study collected the samples that are made at least one trip for a day in order to prevent the distortion of analysis results.

The results of descriptive analysis are shown in Table 2. The average age of elderly pedestrians was 72, with a standard deviation of 6.8. Distribution of age was skewed to the right slightly. The average number of household members was 3.5, with a standard deviation of 6.8. Distribution of the number of household members was skewed to the left slightly and similar to normal distribution. Distribution of the number of preschoolers was a more extreme shape. There were rarely any elderly pedestrians who lived with preschoolers; the average value was 0.08 with a standard deviation of 0.3. Considering skewedness and kurtosis, the distribution of the number of preschoolers is right - skewed and leptokurtic. The average access time to bus and subway were 5 minutes and 10 minutes with a standard deviation of 3.6 and 7.8 respectively. It seems that distributions of these two variables were very similar referring to the skewedness and kurtosis. In this regard, access to bus is easier than that to subway relatively. Also, most elderly pedestrians could access public transport within 10 minutes.

In case of floor area of facilities, the average value of neighborhood facilities had a larger area and the standard deviation of neighborhood facilities was wider than other facilities. Distribution of most variables was skewed to the right. Distribution of three variables including neighborhood (Ⅱ), elderly, sports facilities were skewed to the right extremely and peaked in shape. Distribution of land use area seemed like normal distribution overall. The residenctial area is the largest, whereas the general commerce area has the smallest. In case of the semi-residential area, the shaped was skewed to the right and peaked.

Finally, we conducted the descriptive analysis for two dependent variables: walking frequency and walking time. The average walking frequency per person was 2.2 with a standard deviation of 0.8. Distribution of walking frequency was skewed to the right and peaked shape. Average walking time per person was 41mins with a standard deviation of 29.8. Distribution of walking frequency was right-skewed and leptokurtic.

5. RESULTS

5.1 Multiple linear regression models

The Multiple linear regression model is estimated for identifying the key factors related to pedestrian behavior. If the correlation of dependent and independent variables defines as linear, this model can describe the level of influence from each independent variables to one dependent variable.

This study selected the walking frequency and walking time of elderly pedestrian as the dependent variables. Independent variables included the floor area of facilities, individual characteristics, transportation services, and socio economic indexes. The estimation results are illustrated in Table 3. All coefficients in the models are statistically significant.

It is revealed that elderly pedestrian's behavior affected floor area of facility, individual characteristic, transportation service, and socio-economic index variables. Adjusted R^2 which means the goodness of fit of a model ranges from 0.257 to 0.436. Therefore, this model is suitable considering adjusted R^2 of existing studies ranged from 0.1 to 0.3.

Gender, cultural and meeting facility, elderly facility, sports facility, LUM and the number schools significantly influenced both of the two dependent variables; walking frequency and walking time. First, cultural and meeting facility, elderly facility and sports facility were positively associated with walking, since these three facilities attracted the elderly pedestrian and led people to social activities.

Gender and LUM had opposite signs between the two dependent variables. Male's walking frequently is higher than female, but walking time is shorter than female. In case of LUM, elderly pedestrians who lived in a high level mixed land use region could walk frequently due to the diversity of urban facilities. On the contrary, walking time could be reduced because more levels of mixed land use increased, resulting in a shorter travel distance.

It is found that the number of schools also affected the elderly walking positively. This may be due to the trend that the elderly people accompany school children (i.e. their grandchildren) on trips to school. In this regard, if there are many schools, the travel of children who need adult care on their way to school increases. Simultaneously, elderly pedestrian travel to protect school children also increases.

Table 3. Estimation results of multiple linear regression models

Variable		Walking frequency		Walking time	
		Coef.	Beta	Coef.	Beta
Constant		2.016*		42.823*	
Individual variable	Age			-0.139	-0.042
	Gender	-0.125*	-0.031	3.384*	0.153
	Car ownership			-2.407	-0.320
	Driver's license			-2.680	-0.328
Household variable	Access time to subway			0.184*	0.097
	Access time to bus			0.389	0.181
	No. of household members			-2.446	-0.294
Urban facility variable	Neighborhood (Ⅰ) facility	1.481	0.228		
	Neighborhood (Ⅱ) facility	2.010	0.310		
	Cultural and meeting facility	3.966	0.452	9.658	0.440
	Medical facility	0.926	0.284		
	Religious facility				
	Retail facility	-2.511	-0.310		

	Elderly facility	1.485	0.426	6.418	0.651
	Sports facility	4.603*	1.182	13.620*	1.224
	LUM	1.213*	0.225	-4.058*	-0.247
	Subway catchment area	0.081	0.240		
	No. of schools	0.046*	0.469	2.068*	0.525
Adjusted R^2		0.257		0.436	

Note: All coefficients area statistically significant at a level of significance, α=0.05 and '*' means α=0.01

In addition, neighborhood facility, cultural and meeting facility and subway catchment area were positively associated with walking frequency. On the contrary, floor area of retail facility and gender had negative effect on walking frequency.

In case of walking time, cultural and meeting facility, industrial facility, gender, and transit accessibility positively affect walking time. On the other hand, car ownership, driver's license, number of household members and subway catchment areas are negatively associated with dependent variables.

There are two implications related to the results. First, most independent variables had the relationship on the same direction with two variables except for LUM. Second, urban facility characteristics had a strong relationship with walking frequency and walking time was affected by the individual and household characteristics.

5.2 Multi-level regression model

We analyzed the relationship between pedestrian behavior and each group of three levels first prior to developing the multi-level regression model. Therefore, variances for the null model of each level are calculated, then estimated ICC (intra class correlation). ICC is the descriptive statistic that can be used when quantitative measurements are made on units that are organized into groups. It describes how strongly units in the same group resemble each other.

The estimation results of ICC at level 2 and 3 are illustrated in Table 4. Characteristics of household (level 2) and urban facility (level 3) explained 27% and 33% of total variance in the walking frequency model and 32% and 35% of total variance in the walking time model. In this result, we can confirm the necessity for the multi-level regression model. If we do not consider hierarchical characteristics among independent variables, the results would be biased without explaining the difference of variance for each level.

Table 4. Variance and ICC of null models by level

	Walking frequency		Walking time	
	Level 2 (Household level)	Level 3 (Urban facility level)	Level 2 (Household level)	Level 3 (Urban facility level)
Variance	0.092	0.113	3.784	4.153
ICC	24.83%	31.27%	32.02%	36.55%

Walking frequency and walking time of elderly pedestrians are selected as the dependent variable of the multi-level regression model. Independent variables consists of three levels; individual, household, urban facility. The estimation results are illustrated in Table 5. All coefficients in the models are significant statistically.

Elderly pedestrian behaviors are affected by each level of independent variables; individual, household, and urban facility. The results are somewhat similar to the multiple linear regression model, but some variables changed their size of effect and signs. It also revealed that several other variables associated with walking.

There were two variables at level 1 which affected the two dependent variables; gender and car ownership, and two variables at level 2; number of household members, access time to subway, and six variables at level 3; neighborhood (Ⅰ) facility, elderly facility, sports facility, LUM, subway catchment area, and number of schools.

However, gender, neighborhood (Ⅰ) facility, LUM, and subway catchment area had the opposite signs between two models. Gender is negatively associated with frequency and

Table 5. Estimation results of multi-level regression models

Variable		Walking frequency		Walking time	
		Coef.	Beta	Coef.	Beta
Constant		1.384		38.278	
Individual level (lelvel 1)	Age			-0.450	-0.053
	Gender	-0.043*	-0.027	3.419*	0.146
	Car ownership	-0.021	-0.031	-2.054	-0.287
	Driver's license			-2.508	-0.302
Household level (level 2)	Access time to subway	0.029	0.149	0.289	0.158
	Access time to bus			0.361	0.244
	No. of household members	-0.013	-0.085	-1.920	-0.088
Urban facility level (level 3)	Neighborhood (Ⅰ) facility	1.108	0.220	-5.183	-0.667
	Neighborhood (Ⅱ) facility	1.361	0.352		
	Leisure facility			4.504	0.489
	Retail facility	-2.348	-0.318		
	Elderly facility	1.689	0.352	7.789*	1.040
	Sports facility	3.188	0.945	11.258	1.168
	LUM	1.241	0.280	-5.049*	-0.307
	Subway catchment area	0.039	0.153	-0.861	-0.170
	No. of schools	0.158*	0.607	1.243*	0.541
Variance at level 2		0.084		3.414	
Variance at level 3		0.107		3.819	
Log likelihood		-13,106.471		-15,581.544	

Note: All coefficients area statistically significant at a level of significance, α=0.05 and '*' means α=0.01

positively associated with time. In other words, male is more likely to make less trips and travel longer than female.

Neighborhood (Ⅰ) facility, LUM, and subway catchment area variables represent the level of vitalization for business district. It can be interpreted as the same way of multiple linear regression model. That is, elderly people who live in a high level mixed land use region are likely to walk frequently due to the diversity of urban facilities. On the contrary, elderly people who have private vehicles are less likely to walk.

In addition, neighborhood (Ⅱ) facilities are positively associated with walking frequency. In case of walking time, access time to bus, floor area of leisure facility positively affect walking time. On the other hand, age, driver's license, access time to bus, land use area related to commerce and residence, number of bus stops are negatively associated with the dependent variables.

On the whole, multilevel regression model is more effective to describe the pedestrian behavior than multiple linear regression model. It is confirmed that the variance between levels exist through the ICC index and the variance of each level can explain about 30% of total variance. There is a contrasting travel behavior pattern in multilevel regression model. It seems that travel frequency is higher and travel time is shorter when elderly pedestrian lives in high level mixed land use area because it is easy to access the various facility when people lives in high level mixed land use area. In addition, there is more significant variables in multilevel regression model.

6. CONCLUSIONS

This study explored the characteristics of elderly pedestrians using the data of a 2010 travel diary survey. Ever since Korea approached the aging society in 2000, the relative population of the elderly has been increasing every year. At the present, where in-depth consideration and discussion about the socio-economic activities of elderly people is required, this study proves the causal relationship between the characteristics of elderly walking and various relevant factors such as individual, house, urban facility attributes. Particularly, the multi-level regression model, which considers the hierarchy and correlation between the independent variables, was selected. Conclusions and implications of this study are summarized as follows.

First, this study explored the characteristics of elderly pedestrians generally. The elderly's average walking frequency was 2.19 trips/day and average walking time was 42 mins/day. Distribution of walking frequency and time resembled normal distribution with a peaked shape slightly. It is also shown that elderly pedestrians are relatively inactive compared to adults under the age of 65 in that the average walking frequency of an adult is 2.59/day and walking time is 48 mins/day. Average age was 72 with a standard deviation of 6. Average number of bus stops was 35 and average subway influenced area was 0.7 in each administrative district.

Secondly, manifold key factors that affect elderly walking frequency and walking time were selected using the multi-level regression model. To find out such factors, the independent variables were classified into 3 levels: individual, household and urban facility.

In level 1, the individual level, it is found that both gender and car ownership affect the walking frequency and walking time of the elderly. It is also seen that males make less trips, but have longer travel time compared to females, and car ownership has a negative effect on the elderly walk trips. Based on those results, it is inferred that there is relatively more pedestrian activity in the area with less car ownership.

In level 2, the household level, it is found that the number of household members and transit accessibility affect the walking frequency and time. It is also revealed that the number of household members is negatively associated with pedestrian behavior including walking frequency and walking time, because other household members tend to walk for the elderly members as the elderly have physical difficulties in walking and doing activities. In contrast, transit accessibility has positive influence on elderly walking.

In level 3, the urban facility level, causal relationship between the urban function and pedestrian behavior is identified. The results showed that urban gets more complex with high density, thus walking frequency gets increased but walking distance becomes shorter generally. In addition, the area of elderly facilities and sports facilities which are related to the elderly's activities are positively associated with elderly walking. The number of schools also affects elderly walking behavior in a positive way. In light of those results, we can see that urban functions and facilities actually control elderly walking. Such facts can be used for studies on improvement of street design, ensuring pedestrian safety and invigoration of street and urban regeneration.

For instance, considering that elderly facilities and sports facilities have a positive influence on elderly walking, we can designate pedestrian safety areas around elderly facilities or sports facilities to prevent the car accidents. Also, various strategies for development of downtown can be established based on the fact that elderly walking frequency increases, but walking time decreases in high density downtown where many facilities are concentrated.

Thirdly, it showed the superiority of the multi-level model compared to the multi linear model. The estimation results of ICC at level 2 and 3 showed that characteristics of household (level 2) and urban facility (level 3) explained 27% and 33% of total variance in the walking frequency model and 32% and 35% of total variance in the walking time model. Moreover, the estimation results of the model illustrated that age, commercial area, residential area, and number of bus stops variables are not statistically significant in the multiple linear model. Therefore, if we do not consider hierarchical characteristics among the independent variables, the results cannot explain the difference of variance for each level.

This study actually has a limitation that it only focused on Seoul as the spatial area for this study. If all the variables of Seoul metropolitan area are collected and pedestrian characteristics in the entire Seoul metropolitan area are reviewed in the further studies, more factors can be identified. Moreover, it is expected that the studies comparing the characteristics of elderly pedestrians according to the time series changing can contribute to the forecast of elderly walking in the future and establishment of the countermeasures as well.

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