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A Study on the Customized Design Criteria of Pedestrians' Specifications Using a Dimensionless Number

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Abstract: Worldwide, the population is aging at a gradually increasing speed, due to a decrease in the population and the development of medical facilities and technology. Due to the rapid aging of the population, social infrastructure will also need to be transformed into convenient facilities for the elderly. Walking facilities have been manufactured based on body size measured for general adults. Accordingly, it is necessary to prepare a new design standard suitable for the characteristics of the elderly. It is very difficult to establish standardized values for the elderly because there is a large difference in gait characteristics as well as body size. Therefore, in this study, gait characteristics were measured for the elderly with the standard physique of the elderly in Korea, and the measured gait characteristic variable values were converted into dimensionless numbers to calculate coefficients with more representativeness. The calculated coefficient is expected to be more universally applied and utilized because factors that may affect it depending on the size of the body are removed. When designing a walking facility, the average body size is applied to convert it back into necessary walking attribute information (including units), and this is presented as an example from Korea. It is expected that the presented results can be used to design more suitable and safe pedestrian facilities for an aging society.

Keywords: gait characteristics; elderly; ultra-aged society; pedestrian facilities; dimensionless number; standards

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1. Introduction

According to CNN Money [1], an aging society is one in which people over 65 years old constitute 7% of the total population, an aged society is one where this figure is over 14%, and a post-aged or super-aged society is one where it is over 20%. Since it qualified as an aging society in 2000, South Korea's population has been rapidly aging, and it became an aged society in 2017. The speed of aging is faster than in Japan, which became a super-aged society, and if the current progress continues, it is expected that South Korean society will become a super-aged society by 2025, as shown in Figure 1. As such, it is clear that the population of the elderly will continue to grow and, therefore, it is necessary to prepare social infrastructure and facilities for the elderly to ensure their safety and comfort.

(a) (b)

Figure 1. Configuration of motion capture system (infrared cameras): (**a**) Oespery; (**b**) Raptor-E.

In South Korea, transportation convenience facilities are assessed once every two years for improvement in transportation facilities for vulnerable road users. The survey on the current status of transportation convenience for vulnerable road users targets three areas: transportation means, passenger facilities, and roads (pedestrian environments). Roads (pedestrian environments) includes roads based on Art. 2, Clause 1 of the Roads Act (including appurtenances of the roads according to Clause 2 of the same article), as well as roads, underground passages, and pedestrian overpasses based on Art. 108 of the Roads Act [2].

The results of the most recent assessment, the survey on the current status of the transportation convenience for vulnerable road users [2], are as follows. The average share of transportation convenience facilities for vulnerable road users that met the standard was 78.3%, and that of the pedestrian environments was 78.0%. This value is an increase of 9.8% from 68.2% in 2014, indicating that a greater number of facilities have been improved to meet the standards. By contrast, the overall satisfaction rate of the elderly was 79.0 (out of 100); the satisfaction rate for pedestrian environments was 77.5, which was lower than that for other facilities (city buses, city railways, highway or intercity buses, airlines, or passenger ships). This means that despite more facilities meeting the standard, their relative contribution toward the satisfaction rate for pedestrian environments is low. There are 1.496 million vulnerable road users, among whom 49.2% are 65 years old or above; thus, these facilities would not satisfy half of the population of vulnerable road users. The reason for the low satisfaction rate for pedestrian environments despite the increase in the ratio of installed facilities meeting the standards may be due to the fact that the pedestrian facilities are not suited to the gait behavior of the elderly.

Walking is effective not only in reducing the risk of cardiovascular diseases, cancer, or stress, but also in improving lung capacity, lower body muscular strength, and physiological functions. Furthermore, it is reported that it is often recommended to the elderly as it imposes less of a burden on the body and causes less impact on musculoskeletal muscles and joints [3,4]. As such, walking is not merely a means to move around for the elderly; it also serves as a minimal bodily activity that can maintain or improve physiological functions.

It has been reported that an elderly person's gait differs from that of healthy adults in terms of a decrease in walking speed and step length; the operational scope of the hip, knee, and angle joints; the slope of the upper body; and pelvic rotation [5–8].

Winter, Patla, Frank and Walt [9] compared the gait characteristics of young adults and the elderly, and reported that while there was no distinctive difference in cadence, the elderly people's gait showed shorter step length, longer double support time, and smaller lower body power (which pushes the body from the ground in pre-swing). Ostrosky et al. [7] reported that the knee extension and stride length of an elderly person's gait were smaller than those of young adults and that their overall gait speed was slower. As a result, the flat ground gait of the elderly showed shorter step length as they moved a shorter distance with the same number of steps, and they could maintain a stable gait for a longer duration with two-feet support on the ground than with one-foot support [10]. Such gait changes in the elderly are natural and are caused by aging.

The flat ground gait behavior of the elderly is greatly influenced by internal as well as gait environment factors. Menz, Lord, and Fitzpatrick [11] stated that the complex interaction of physical and psychological factors leads to behavioral changes; in particular, the interaction between the retrogression in muscles, control capacity in the physical factors, and the consequent psychological fear and anxiety may cause the changes in gait behavior. Physical and psychological anxiety may result in an increase in the risk of injuries while walking, such as falling accidents; environmental factors, such as structural changes in pedestrian passages, obstacles, stairs, or ramps may also affect an elderly person's gait. Therefore, this study aimed to define the gait characteristics of the elderly by removing the risk factors involved in walking to achieve a more sustainable gait environment.

2. Review of Existing Studies and Necessity of the Elderly Standard Gait Model

2.1. Review of Existing Studies

Existing research has focused on the importance of the walking environment and the need for improvement. Pedestrian paths tend to target school-age children and the elderly, who use walking as their main movement method. This was reviewed in the center. The Sidewalk Condition Index (SCI) was presented for home-to-school routes, and one study conducted an analysis by selecting San Lorenzo as a test area [12].

For the aging population, the importance of the walking environment is generally recognized, and research has been conducted to produce more comfortable walking environments. In particular, the study that analyzed sidewalk maintenance to improve walking comfort for senior citizens suggests the SCI, and suggests a method to evaluate the walking path based on the analysis results. This includes the results of a review of physical pedestrian facilities that can affect pedestrians, such as road widths and damage to road facilities [13].

A characteristic of this study is that it provides a systematic methodology that can be evaluated in relation to external factors that can affect gait, that is, the physical environment. In this physical facility evaluation method, if a standard walking model that can evaluate individual pedestrians is prepared and applied, it is judged that a stronger pedestrian facility evaluation system can be prepared.

2.2. Design Standard Automobile

According to Explanation of the Rules on the Structural Facilities of Roads [14], the definition and the necessity for the design standard automobile are as follows: "There are various types of automobiles on the road. It is very complex to design roads according to each type of these automobiles, and in reality, as there are many types of automobiles, vehicles that represent the scope of each of these types of automobiles based on size and type should be classified and defined as 'design standard automobiles." Accordingly, when designing specific road zones, as shown in Table 1 or Table 2, the design standard automobile is defined as the largest sized automobile that would make frequent use of the road. Therefore, semi-trailers are defined as the design standard automobile for expressways and main arterial roads. The specifications by automobile type are presented in the Figure in Table 2.

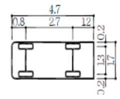
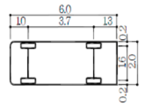
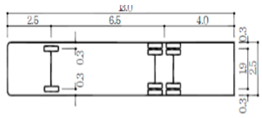
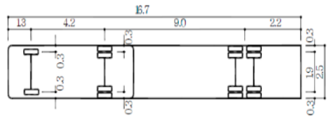
Table 1. Definition of the design standard automobile by road hierarchy.

Type of Road	Design Standard Automobile
Expressway and main arterial roads	Semi-trailer
Minor arterial roads and collector road	Semi-trailer or large vehicle
local roads	Large vehicle or passenger vehicle

This means that the selection and implementation of the design standard automobile aims to secure safe driving environments for all vehicle types frequently using the corresponding road by selecting the automobile type with the worst condition as the design standard automobile.

In the case of a vehicle, the width and length have a very large influence on the design of the turning radius. Accordingly, there is no major problem in designing road facilities with only these design standards. However, in the case of pedestrian facilities, suggesting the height and width of a person may only affect the design of the vertical structure through which a person passes, and it will not at all affect the determination of the facility that must be actually stepped on or passed through in the process of walking. In addition, the walking speed used to determine the green time of the current traffic light is the average value for a general person, and walking speed is different even for people of the same height. The gait attribute data calculated by the average of a simple sample cannot be said to be representative. In particular, since the difference between the individual gait characteristics of elderly people is very large, it may be inappropriate to apply the simple calculated average to generalize it, so it needs to be supplemented.

Table 2. Specifications per the design standard automobile type.

Type	Width (m)	Height (m)	Length (m)	Axis Distance (m)	Minimum Rotational Radius	Specifications
Passenger vehicle	1.7	2.0	4.7	2.7	6.0	
Small vehicle	2.0	2.8	6.0	3.7	7.0	
Large vehicle	2.5	4.0	13.0	6.5	12.0	
Semi-trailer	2.5	4.0	16.7	Front: 4.2 Back: 9.0	12.0	

2.3. The Necessity for a Standard Gait Model

As with their application in the definition and implementation of the design standard automobile in road design, gait facilities are also used by people of different ages, with various disabilities or levels of discomfort, and different gait characteristics. Therefore, it is necessary to establish a standard and design a standard gait model similar to the design-standard automobile. However, it is very difficult to define the gait behavior of the elderly. Furthermore, gait characteristics are affected by individuals' physical traits and the characteristics of their living environments, which naturally result in physical changes. Thus, gait characteristics appear regardless of age or sex.

Aging in South Korea is the fastest among all countries. The elderly population, which accounts for 49.2% of the total number of vulnerable road users [2], continues to grow; in fact, South Korea qualified as an aged society in 2017, and it is projected to be a super-aged society by 2025 [15]. To support safe and comfortable gait for the elderly in keeping pace with rapid aging levels, the development of a standard gait model for the elderly is an urgent requirement.

3. Methodology

3.1. Selection of the Participants and Results

To develop a standard gait model for the elderly, the study recruited a total of 112 elderly participants. The participants were 70 years or older, with heights and weights within ±5 cm and ±5 kg of the national average values according to Korea Health Statistics [15]. The result of the measurements is shown in Table 3. The largest error is the height of the female participants, which is shown as 2.9% (4.5 cm), with an average error of 1.16%. Thus, it was determined that the body size of the participants was similar to the average body size of the elderly.

Table 3. Average body size of the elderly.

Type of Road	Sample Size	Average Age	Participant Group		Korea Health Statistics [13]		Error (Error Rate (%))	
			Height (cm)	Weight (kg)	Height (cm)	Weight (kg)	Height	Weight
male	52	74.38	165.81	62.93	164.2	63.9	1.6 (0.98)	−1.0 (−1.53)
female	60	75.52	154.69	56.62	150.2	55.4	4.5 (2.99)	1.2 (2.21)
total	112	74.99	160.27	60.05	-	-	-	-

3.2. Selection of the Participants and Results

A motion capture system is a device used for measuring physical and kinetic characteristics in medicine, rehabilitation medicine, sports kinematics, and kinetics, as well as for special effects in film. This device measures kinematic data and kinetic data through markers attached to each joint in the body. Due to the characteristic of the system that acquires and utilizes objective data compared to the existing video analysis methods, it is also increasingly used in determining the location and shape of the parts that people use in product design, such as handles or knobs.

A motion capture system generally consists of two parts: an infrared (IR) camera that acquires the 3D coordinates of markers attached to the body, and a ground reaction force plate that measures the ground reaction force. This study aimed to measure and analyze only the spatiotemporal parameters while walking and, accordingly, it used only the data acquired from the IR camera for analysis. As shown in Figure 1, the IR cameras used in this study were four Raptor-E cameras and eight Oespery cameras manufactured by Motion Analysis.

The camera setting for gait analysis was 120 frames per second. During the analysis, the 3D coordinate data taken from the cameras passed through a smoothing process (Cortex 6.0 S/W) using a cut-off frequency of 6 Hz. As shown in Figure 2, a gait passage of 4 m × 10 m was created, and infrared cameras were installed at a height of approximately 2 m. The camera installation gap was adjusted to capture at least three markers attached to the participants from all locations.

Figure 2. Motion capture analysis environment.

3.3. Selection of the Participants and Results

The most basic gait factors in flat ground walking are gait speed, step length, stride length, and step width, as shown in Figure 3. The aforementioned factors are greatly influenced by the physical traits of a person, such as their height and weight. In other words, a tall person has a greater chance of possessing a wider step length and stride length, which are length-related gait parameters, than a shorter person, resulting in a relatively high gait speed [16]. Accordingly, merely implementing the average values from the measurements in the pedestrian facility design can lead to distorted results due to the varying characteristics of different groups. As such, to minimize the potential distortion due to physical traits such as height or weight, this study used a method of standardizing gait factors through the dimensionless number proposed by Hof [17], as shown in Table 4.

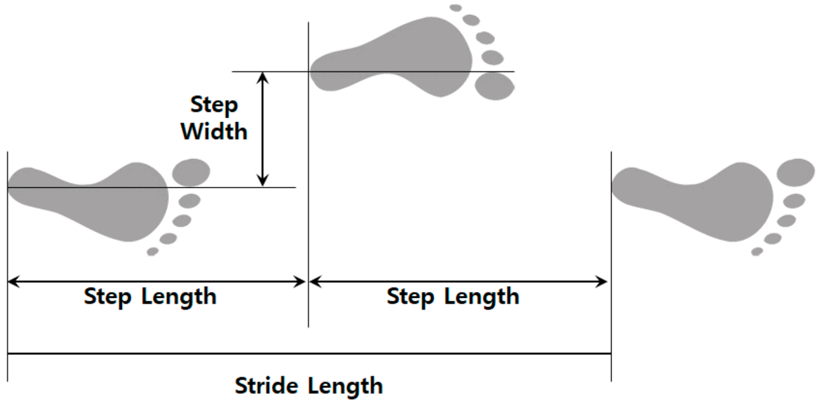


Figure 3. Gait factor.

Table 4. Dimensionless Number Conversion Method.

Type of Type	Symbol	Dimension	Dimensionless Number
Speed, velocity	$v = \dot{x}$	LT^{-1}	$\hat{v} = \frac{v}{\sqrt{g \times l_0}}$
Length, distance	l, x	L	$\hat{l} = \frac{l}{l_0}$
Frequency	F	T^{-1}	$\hat{f} = \frac{f}{\sqrt{g/l_0}}$
Time	T	T	$\hat{t} = \frac{t}{\sqrt{l_0/g}}$

(g acceleration of gravity (=9.81 m/s^2 on earth), l_0 length (height)).

The method proposed by Hof [17] is used for removing the unit by each gait factor from physical traits such as weight or height, through which the removal of the effects of the height and weight can be performed. Among the gait factors, this study aimed to propose the standard gait model (value) based on the following five factors: gait speed, step length, stride length, step width, and cadence (number of steps per minute).

4. Measurement and Analysis of Gait Characteristics

4.1. Measurement of Gait Characteristics

The participants wore sleeveless shirts and shorts so as to expose their joints for the measurement of gait characteristics; they did not wear shoes, in order to allow accurate measurement of the movement of ankle joints. Because this clothing may have differed from the participants' usual clothing, and to prevent abnormal gait behaviors that might be caused by the measurement environment, the participants' age and medical history were recorded, and after measuring their height and weight, they were asked to walk the pedestrian passage back and forth three to five times. Those whose gait behavior showed a marked difference from their natural gait (which was observed when they first entered the measurement room) were asked to walk repeatedly in order for them to achieve their natural gait and to become psychologically relaxed.

To measure the participants' gait factors while they were walking repeatedly on the pedestrian passage, a total of 29 markers were attached to each of them, as shown in

Figure 4. The 3D coordinates of these markers were first acquired with the participants staying still and standing straight on the ground reaction force plate. Based on these data, the 3D location of the joints was calculated and the body movement and load on each body part were measured. After acquiring the coordinates of the joints, a total of four markers that could cause discomfort while walking, each of which was attached to the knee and the inside of the ankle, were removed, and the main measurement of the gait characteristics was conducted, as shown in Figure 2.

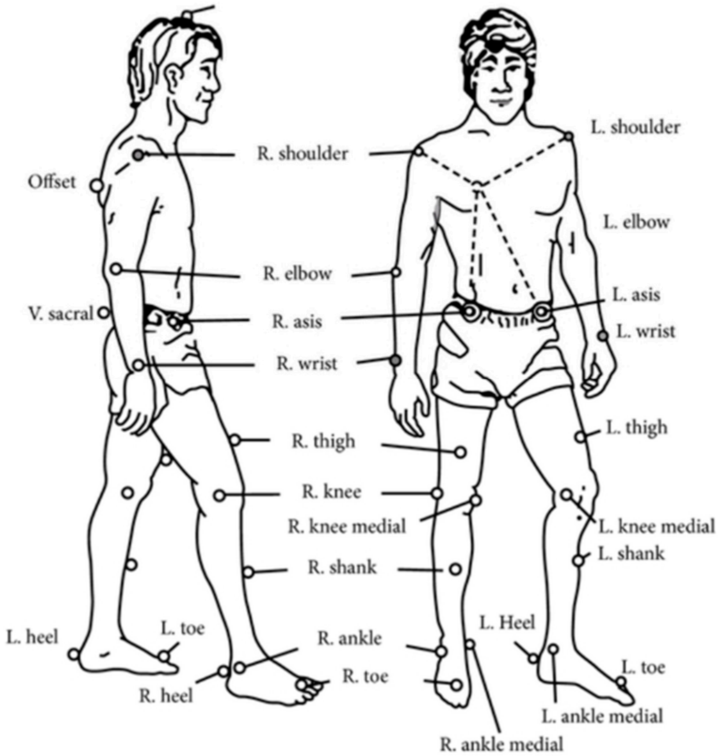


Figure 4. Modified Helen Hayes marker arrangement utilized for 3D motion analysis.

4.2. Standardization of the Gait Characteristics

Based on the gait characteristics measurement from a total of 112 elderly participants, the data of 77 participants (40 male and 37 female participants) were selected for the final analysis. Participants with existing conditions such as arthritis, rheumatism, or other conditions that affect walking were excluded, as well as those whose gait behavior showed a marked difference between the initial and final measurements caused by degradation in physical strength due to repeated walking.

The five aforementioned gait factors were divided according to male and female groups; Table 5 shows the average, standard deviation, and average standard error by factor. Table 6 shows the standardized gait factors obtained after converting the measurements of the physical traits (weight and height) affecting the gait factors with the dimensionless number (Table 4).

Table 5. Gait factor before standardization.

	Gender	Sample Size	Average	Standard Deviation	Standard Error of Mean
Gait speed	male	40	100.23	16.97	2.68
(cm/s)	female	37	94.84	15.41	2.53
Step length	male	40	53.68	7.52	1.19
(cm)	female	37	48.37	10.13	1.67
Stride length	male	40	107.71	14.62	2.31
(cm)	female	37	100.91	10.33	1.70
Step width	male	40	12.66	3.01	0.48
(cm)	female	37	11.42	2.80	0.46
Cadence	male	40	112.32	9.76	1.54
(step/min)	female	37	112.46	11.19	1.84

Table 6. Gait factor after standardization (dimensionless numbering coefficients for normalization of gait properties).

	Gender	Sample Size	Average	Standard Deviation	Standard Error of Mean
Gait speed	male	40	0.25	0.04	0.01
	female	37	0.24	0.04	0.01
Step length	male	40	0.32	0.04	0.01
	female	37	0.31	0.07	0.01
Stride length	male	40	0.65	0.09	0.01
	female	37	0.65	0.07	0.01
Step width	male	40	0.08	0.02	0.00
	female	37	0.07	0.02	0.00
Cadence	male	40	0.77	0.06	0.01
	female	37	0.75	0.07	0.01

For the dimensionless number conversion using gait factor, gait speed used the dimensionless number conversion equation of speed, where g is gravitational acceleration (9.8 m/s^2) and l_0 is the height of each participant. Step length, stride length, and step width used the dimensionless number conversion equation of length. The $\hat{l}$ of each participant (step length, stride length, and step width in Table 6 are length values) was derived by substituting for the measurement by each factor, and substituting the height of each participant to l_0. As cadence is the number of steps per minute, it was derived by applying both the frequency and time dimensionless number conversion equations. Assuming cadence as a fractional number with 1 as the denominator, the steps corresponding to the fraction were standardized using the frequency conversion equation, and the denominator (1) was standardized using the time conversion equation; the number after the frequency conversion was divided by the number after the time conversion to derive the cadence dimensionless number.

The average value by each gait factor in Table 5 is the mean average value that includes all the factors pertaining to body size resulting from individual differences in weight and height. It is difficult to establish that the determination of elderly people's gait characteristics based on this value is the standard data for the facilities, even if this data on the elderly resulted from the standard body size of the elderly in South Korea. However, as shown in Table 6, the values obtained after the dimensionless number conversion cancel out the effect of the weight and height. Therefore, it can be said that these values are standardized values regardless of the person's height and weight. The study derived the standard gait model of the elderly by inverse operation of the derived values by using the standard weight and height of the elderly in South Korea.

5. Standard Gait Model of the Elderly Using Dimensionless Numbering Coefficients in South Korea

5.1. Derivation of the Standard Gait Model of the Elderly in South Korea

The mean values in Table 6 are the average values without a unit, derived from the dimensionless number conversion of the individual gait factors measurements. To implement the mean values to the design of pedestrian facilities and to determine how the elderly with the average walking capacity and physical size walk, the unit by gait factor was re-applied based on the standard physical measurements. To this end, this study conducted the inverse operation of the applied dimensionless number conversion equation, which was used for the standardization, to derive the final value by the standardized gait factor. For example, the mean (x) of the dimensionless number of gait speed was derived as follows:

$$\bar{\hat{v}} = \frac{\sum_{n=1}^{n} \frac{v}{\sqrt{g \times l_0}}}{n} \tag{1}$$

Here, the standardized gait speed ($v_{\text{standardization}}$) with a unit was derived by the following equation:

$$v_{\text{standardization}} = \bar{\hat{v}} \times \sqrt{g \times l_0} \tag{2}$$

With the same method, the average physical measurements of the elderly South Koreans were applied to the mean average value by gait factor, which was converted to the dimensionless number shown in Table 6, to derive the final standard gait model value. These data were presented by classifying the participants into male and female groups, and the mean average values of the integrated physical measurements were not separately presented. Thus, the weighted means of the integrated physical measurements, which were used to calculate the standard physical measurements, were used to derive the gait model values. The number of the samples used to derive the standard height of the elderly of and over 70 years old in National Health Statistics 2015 [18] was 404 male and 585 female participants, and the value was derived by using the following equation:

$$\begin{aligned} &\textit{Weighted average height from the standard size} \\ &= \frac{(\textit{Average height of male} \times \textit{sample size of male}) + (\textit{Average height of female} \times \textit{sample size of female})}{\textit{Sample size of male} + \textit{sample size of female}} \end{aligned} \tag{3}$$

Table 7 shows the values by male, female, and integrated standard gait factors (standard gait model) derived by the above method. The data from the participants with physical characteristics close to the standard physical measurements were collected separately, and the accuracy of the measurement values was determined by motion analysis. Furthermore, the errors from the differences in physical measurements were minimized using the dimensionless number conversion method.

5.2. Comparison of Results with the Gait Characteristics of Normal Adults

Table 8 shows the comparison of the gait characteristics between the elderly, the normal adults presented by Roh et al. [19] and the standard gait model of the elderly proposed by this study. It is shown that compared to previous studies, the results from this study showed relatively better gait capacity in four gait factors except cadence. The elderly participants' gait speed was faster (2%) and step width was narrower (7%) than those of the normal adults. Wider step width means toe-out gait, which would make it relatively difficult to maintain balance. On the other hand, cadence was increased by 4%. This means that while the stride length was similar, the number of steps taken increased, suggesting that the elderly participants moved in smaller steps.

Table 7. Standard gait model of the elderly in South Korea.

	Gender	Sample Size	D.N. Mean	Standardized Value	Comparison Value (Average of Measured)
Gait speed (cm/s)	male	40	0.25	100.29	100.23
	female	37	0.24	92.08	94.84
	total	77	0.24	93.82	-
Step length (cm)	male	40	0.32	52.54	53.68
	female	37	0.31	46.56	48.37
	total	77	0.32	49.89	-
Stride length (cm)	male	40	0.65	106.73	107.71
	female	37	0.65	97.63	100.91
	total	77	0.65	101.35	-
Step width (cm)	male	40	0.08	13.14	12.66
	female	37	0.07	10.51	11.42
	total	77	0.07	10.91	-
Cadence (step/min)	male	40	0.77	112.87	112.32
	female	37	0.75	114.95	112.46
	total	77	0.76	114.32	-

Table 8. Comparison of gait characteristics between the elderly and normal adults.

	Gender	This Study		Previous Study [20]	
		Standardization Result	The Average	The Elderly (66+)	Normal Adults (Age 20–30)
Gait speed (cm/s)	male	100.29	100.23	91.86	137.30
	female	92.08	94.84		
	total	93.82	-		
Step length (cm)	male	52.54	53.68	49.61	57.10
	female	46.56	48.37		
	total	49.89	-		
Stride length (cm)	male	106.73	107.71	100.87	129.80
	female	97.63	100.91		
	total	101.35	-		
Step width (cm)	male	13.14	12.66	11.78	12.00
	female	10.51	11.42		
	total	10.91	-		
Cadence (step/min)	male	112.87	112.32	109.75	109.50
	female	114.95	112.46		
	total	114.32	-		

As a result of comparing the control group in their 20s from a previous study with the results from this study, it was inferred that the gait capacity of the elderly was approximately 78% of the control group. In particular, the gait speed was very low, at 68% of that of the normal people. When the crossroad signal decision time (1.0 m/s) is applied, this means that the elderly may not be able to cross an entire crossroad within the given time despite having the general gait capacity and physical conditions. Considering the step length (87%) and stride length (78%), wide projections or low steps which normal adults could easily pass may cause difficulty for the elderly. In the case of the male elderly, the step width was wider than that of the normal adults, and the cadence was approximately 104%, with a small increase in the number of small steps.

6. Conclusions and Applications

6.1. Definition of the Standard Gait Model for the Elderly in South Korea

The standard gait model for the elderly defined in this study for the application of the pedestrian facilities design to prepare for super-aged society conditions is as follows.

The average height and weight of elderly South Korean males are 164.2 cm and 63.9 kg, respectively, and those of elderly South Korean females are 150.2 cm and 55.4 kg, respectively. The gait characteristics of the elderly in South Korea with the average weight and height who could walk independently without a walk-assisting equipment are as following Table 9:

Table 9. Standard gait model.

	Gender	Gait Characteristic Value	Percentage of Walking Ability Compared to Adults in Their 20s [20]
Gait speed (cm/s)	male	100.29	73%
	female	92.08	67%
	total	93.82	68%
Step length (cm)	male	52.54	92%
	female	46.56	82%
	total	49.89	87%
Stride length (cm)	male	106.73	82%
	female	97.63	75%
	total	101.35	78%
Step width (cm)	male	13.14	110%
	female	10.51	88%
	total	10.91	91%
Cadence (step/min)	male	112.87	103%
	female	114.95	105%
	total	114.32	104%

The gait speed is 68%, step length is 87%, stride length is 78%, and step width is 91% compared to young adults. Cadence is approximately 104%, walking in small steps.

In summary, the elderly were shown to have a lower gait capacity than young adults, as is commonly understood. Considering this relative gait capacity, the standards were either merely moderated to some degree or were assumed to be the same as those for young adults in the design of pedestrian facilities, resulting in continuous discomfort for the elderly. There has been a consensus on the need for legal and systemic infrastructure to prepare for the aged and super-aged society, and the improvement in social infrastructure toward the support of the elderly's social and economic activities; thus, relevant standards for the design of pedestrian facilities for the elderly are essential. If there are no standard values that could be implemented in adjusting the facility limits for the elderly, more practical and applicable legal and systemic standards can be prepared if precise and objective bases of the type presented in this study are established.

However, it is recommended that a greater number of flexible design standards than those strictly based on the results shown in this study be prepared by establishing buffers based on concepts such as safety rate. For example, as shown in the terminology, gait speed is a scalar value. Thus, if it is applied as it is currently understood, it can satisfy the speed requirements only under the assumption that the person moves in a straight line. However, as shown in the values of step width, the elderly often walk with a toe-out gait or cannot maintain good balance, making straight walking more difficult than it is for young adults. Therefore, if the velocity, a vector concept, is measured, a lower value may be obtained.

6.2. Discussion and Conclusions

Existing studies also suggest that different pedestrian facility design standards should be prepared according to the purpose and environment of walking. Recently, research [21] into the construction of pedestrian-friendly cities has also been conducted. Some studies also analyzed the effect of walking density on walking [22] and suggested that walking accessibility has an effect on travel decisions [23]. As described above, walking is a transportation method that is always used at the beginning and end of each means despite using various means such as car, train, and air when moving. Some make up the entire trip just by walking. In the case of the elderly, the proportion of walking as a means of transportation is higher than that of other age groups [20]. Therefore, it can be said that the influence of the walking environment on mobility is greater for the elderly.

However, pedestrian facilities are designed based on the general adult and are constructed in order to eliminate inconvenience for general adults when moving. This makes the elderly feel uncomfortable when using the stairs or using the escalator. In other words, they use facilities that do not fit their body size and walking characteristics, and they complain of discomfort. Such inappropriate facilities can be directly related to safety accidents that can occur while walking for the elderly.

Therefore, it is judged that research on how to design facilities suitable for the elderly is necessary. In order to design a facility suitable for the elderly, it is fundamentally necessary to know the size of the elderly person's body. This is achieved through the analysis of national statistics. In Korea, there is a Statistical Yearbook [15] that presents the average body size by age. However, it is difficult to publish statistics on how older people walk. This is because even people of the same height and weight demonstrate different gait speeds, step lengths, stride lengths, step widths, and cadences. If the average value of these gait variables is used, the effect caused by the height and the length of the lower extremities cannot be removed, and a kind of collinearity problem may occur. Therefore, in this study, we tried to solve this problem by applying a dimensionless number. The numerical value with the unit removed can be used for a more objective design of facilities because it can remove the factors that affect the height or the length of the lower extremities. By applying the average height to the gait variable values derived in this way, it was possible to derive a more objective average gait variable value for the elderly in that age group. Of course, there may be differences by country, but it is expected that standard gait variable values for each country can be derived if this method is applied. The results obtained in this way are expected to be applicable to the design of new pedestrian facilities.

6.3. Applications

For determining the duration of green lights at traffic junctions, the current standards set 1.2 m/s for normal crossroads, and 1.0 m/s or 0.8 m/s for those in elderly protection zones (silver zones). However, it is difficult to find the standards from which these values were derived. Even the normal crossroad setting was taken from standards used in other countries, and the standards for the elderly protection zone are merely a moderate version of the standards for young adults. As such, there are no gait models for determining pedestrian facilities standards and, as a result, foreign standards have often been borrowed.

Pedestrian passages in urban environments mostly comprise flat ground, ramps, and steps; therefore, this study proposed a standardized gait model (based on the gait factors) that can be applied to flat grounds and low steps. Table 10 shows this study's scope of application. It is expected that the development of the proposed standard gait model into models determined by situation, age, and facility so as to be implemented in the facilities standards and design would lead to higher user satisfaction, as well as safer and more comfortable walking. As a method through which to achieve this, in this study, the gait attribute coefficient calculated as a dimensionless number was presented, and a method for calculating the average value of the gait attribute data with the required unit was experimentally calculated. Since there is no value that can be called the true value, it is difficult to make a clear comparison, but a comparison with the existing value used in

Korea, which measured and analyzed the data, is presented. Considering the prospect of a super-aged society, and in light of this method, it is expected that studies on more representative standards and the development of facilities for safe walking for the elderly will be conducted continuously.

Table 10. Applications of the standard gait model by factor.

	Define	Applicable Facilities	Contents
Gait speed	gait speed	crossroads and other pedestrian facilities	duration of signal time
Step length	steps per minute	escalator, moving walk	speed of escalator or moving walk
Stride length	distance from the heel of the front foot to the heel of the back foot	steps	establishment of the appropriate design standards for facilities affected by steps, such as the width and height of stairs on pedestrian roads
Step width	distance between the two consecutive heels performed by the same foot		
Cadence	distance between the center of the heel of both feet while walking		

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