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Developing elderly men's footwear sizing system based on their foot shapes

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Abstract

The purpose of this study was to develop a shoe sizing system for elderly men in Korea based on previous studies which analyzed aspects and shapes of the sole of those who aged 60 years or more. The sizing system creation process included natural log-transformation, principle component analysis, multivariate linear regression, size range determination, and measurements calculation. Measurement interval was set up based on Korea standard (KS). Cross analysis was conducted for basic items to select an interval which indicated frequency of more than 5% by type. A measurement system was then established by type. As results of this study, a shoe sizing system was developed with an interval of 5 mm for foot length, an interval of 3 mm for the circumference of the top of the foot, and an interval of 6 mm for the circumference of the top of the foot within the same foot length standard. To reflect characteristics by type, respective shoe sizing systems in accordance with type were developed. 12 types of shoe sizing systems were suggested for elderly men. Our results indicate that shoe sizing system for elderly men by foot type could improve the suitability of shoes. They could give wider range of shoe sizes and high satisfaction. They can help shoe makers produce shoes with various purposes and functions for seniors.

Keywords: Korean elderly man, Shoes sizing system, Foot shape, Foot measurement

Introduction

The elderly population is growing due to the improvements of their quality of life through the advancement of science and technology and an awareness of health and well-being in accordance with economic growth. According to a recent report from Moody's, an international credit rating company, Japan, Germany, and Italy have already entered into a super-aged society with the elderly comprising more than 20% of the population by 2013, and by 2030, it is predicted that 34 countries will enter into this super-aged society (Park 2015). Currently, the elderly have more economic power and time and better health compared to those in the past. As opportunities for social activity increase, they actively engage in greater consumption because of their economic independence. This trend has led various industries to target this elderly consumer market when presenting new products. This is quite buoyant in line with developing their product planning and marketing strategies for the elderly. Therefore, it is crucial to understand the personal characteristics of these aging adults and their product needs, e.g., closely aligning products with the distinctive physical changes over their lifespan.

One in three men of elderly men has addressed foot and shoe related complaints such as stiffness, pain, or achiness (Alpert 2016) due to foot disease or wearing ill-fitting shoes. Approximately 87% of elderly men living in the US are affected by some types of foot-related complaints at least once in their lives. Foot pain interferes with their independent living, physical activity, and overall quality of life (Alpert 2016).

Foot conditions, such as calluses, corns, hallux valgus, ulcers, and pressure sores, most commonly observed in elderly men, are associated with many years of wearing ill-fitting shoes. It is important to educate this population in the choice of proper footwear, for example, wearing a prescription-based orthotic or made-to-fit shoes based on their present foot condition for their healthy living. Alpert (2016) argues that it is critical to maintain healthy feet while elderly men are walking, in order to maintain their independence and improve their quality of life. According to the National Foot Health Assessment questionnaire for adults aged 21 years and older (Institute for Preventive Foot Health 2012), 54% of respondents were experiencing foot pain, followed by 26% who were experiencing foot fatigue and pain, which represents an increase of 5% since 2009. Therefore, a steady increase in the number of consumers seeking comfortable shoes can be anticipated.

The footwear market is segmented and diversified, and footwear products with designs and functions that reflect these local trends are being produced. Recently, footwear products incorporating advanced materials and information technology (IT) have been introduced (Park 2014). For example, shoes equipped with individual health management systems (e.g., Nike Plus, Adidas miCoach, talking shoes, and Lechal smart shoes), which analyze walking conditions and calculate the amount of exercise for the elderly, are currently available in the footwear market (Kim 2016; Lechal n.d.). Moreover, as design technologies such as 3D scanners and 3D printers have developed rapidly, 3D systems have been actively applied in the footwear design and development (Butdee and Tangchaidee 2008) and foot-related research (Xiong et al. 2010).

According to the 2010 US Census, 5.6% of the US population is of Asian origin; a large proportion are foreign-born or recently arrived. Asians, on an average, have a relatively high socioeconomic status among both natives and immigrants (Flippen and Kim 2015). The Korean government estimated that the number of Koreans in the US would reach 2.5 million in 2016 (Ministry of Foreign Affairs Republic of Korea 2017). The total number of Koreans in the US as 2.7 million, if considering approximately 200,000 Koreans who were not included in the US government system (Kim 2017). As such, the continuous growth in the number of Asians, including Koreans, in the US and the global trend towards over-aging are providing new consumer markets in the footwear industry. There is a potential need for a new niche footwear market for elderly consumers.

Traditionally, footwear size is categorized by the length and width (or girth) of the foot. Even though people may have the same foot length and width, their foot shapes can vary, which leads to a major concern regarding the fit and comfort of shoes. Human feet vary in shape, depending on their demographic characteristics (e.g., geographical region, age, gender, ethnicity) and foot size also varies with age, weight, and other factors (e.g., job type, amount of walking, diseases such as diabetes and arthritis). Westerners' feet are thinner and longer than those of Asians (Rout et al. 2010); on the other hand, Asians have a much thicker foot shape than that of Westerners (Kim 2010). Lee and Wang (2014) study noted that the feet of Taiwanese adults were wider compared with those of Mainland Chinese and Europeans, and the foot shapes of Taiwanese and Japanese females were similar. This difference tells that one shoe shape may not fulfill each individual's needs.

The overall purpose of this study was to develop a footwear sizing system for different foot shapes, which can lead to improved mobility and fit for elderly men. The results of this study would provide fundamental data for the footwear market targeting Asian elderly men, including Koreans.

Literature review

Fit and size disparity of footwear

The type of footwear that people wear changes the way they walk and how their body weight is distributed. Ill-fitting shoes are known to cause foot deformities (Park 2012). This causal relationship between footwear fit and clinical foot problems presents the importance of wearing well-fitting shoes to promote health and well-being of wearers. Footwear fit is subjective and it is difficult to find a "right" fit because of the existence of many differing guidelines (Piller 2002). Rossi (1988) affirmed that a "perfect" fit of shoes is impossible, a "correct" fit is highly improbable, and a "compromise" fit remains the only alternative. According to previous researchers' findings (e.g., Cheng and Perng 1999; Cheskin et al. 1987; Hawes et al. 1994; Luximon et al. 2001), if a shoe is too tight, the interface pressure produces tissue compression, which makes the shoe uncomfortable for the wearer. On the other hand, if a shoe is too loose, the wearer experiences slippage between the foot and the shoe, resulting in performance degradation and injury to soft tissue due to friction (Au and Goonetilleke 2007).

In general, footwear evaluation is based on fit, function, and form (Goonetilleke 2003). In the case of bare feet, form follows function (Rossi 2001), but for footwear, fit is the most important property to govern function and form (Witana et al. 2004). Foot length has been traditionally considered as the most important or only critical measure for footwear fit (Goonetilleke 2003) and has been commonly measured using the Brannock foot-measuring device (https://brannock.com/), typically found in retail stores. However, this common method of foot length measurement often leads to poor fit, as most fitting problems concern the "width" dimension or volume (Rossi 2002).

Elderly men's foot problems

Foot pain and foot complaints are common among elderly men, regardless of the presence of underlying causative pathology. Foot pathologies are common in nearly 80% of all elderly patients (Menz and Lord 2001) and previous studies have indicated that wearing an inappropriate footwear is one of the major underlying causes (Hijmans et al. 2007; Lord et al. 2003; Win et al. 2011). It has been postulated that wearing ill-fitting shoes affects plantar pressure, thus exacerbating weak balance in the human body. Complications arising from foot pathologies, which include difficulty in maintaining balance, have increased the risk of falls that can result in fractures and other serious injuries (Ikpeze et al. 2015).

Human feet comprise a small anatomical portion compared with the rest of the body and they experience extensive impact from each footfall, adding up to tons of weight every day. Consisting of 26 bones, 33 joints, and more than 120 muscles, 100 tendons, ligaments, and nerves per foot (Biology Dictionary n.d.), an average individual takes approximately 10,000 steps per day with the feet acting as shock absorbers, while working to keep him or her upright and balanced. Standing throughout human's lifespan changes the foot, and with time, the padding in the balls and the heels of the foot are lost. The arches become flatter and less flexible, the ankle and foot joints become stiffer, and the entire foot gets wider and more elongated. These changes alone can lead to foot pain and discomfort, even if there is no risk from underlying pathology (Alpert 2016).

Dunn et al. (2004) investigated the five most common foot problems among 784 elderly men. These conditions included toenail disorders (74.9%), minor debilitating toe deformities (60.0%), calluses and corns (58.2%), bunions (37.1%), and evidence of fungal infection, cracks/fissures, and/or maceration between toes (36.3%). Along with finding these foot anomalies, 30.9% of the study participants also complained for ankle or foot tenderness with palpation and 14.9% stated that their ankle joint pain was present during the study period. As such, these foot problems have changed the shape of the foot over time. Wearing footwear appropriate for their foot shape would stabilize the feet and support healthy living among the elderly.

International footwear sizing system

Many different sizing and grading systems are used in different countries or regions of the world (Luximon and Luximon 2013). There are two categories of the size specification system of footwear. One is based upon the stick length of the shoe last such as the current systems used in French, American, and British; the other is based upon the actual foot length. These systems include those used in Japan, China, as well as Mondo Point system (Cheng and Perng 1999). These systems are usually based on foot length and ball girth measures to designate sizes (Hinojo-Pérez et al. 2016). Some systems use the metric system, measuring in centimeters or millimeters, such as Mondo Point system, Chinese system, Japanese system and French system, while some use inches (British system and American system) (Luximon and Luximon 2013). Mondo Point system based on the length and width of the foot. The step size for length is 5 mm and the step size for width between length sizes is 2 mm. Within each length size, there is a width step size of 4 mm. Chinese system based on the foot length and the foot ball girth. The step size for length is 10 mm, with a half size increment of 5 mm, the step size for girth is 7 mm, both between length sizes and between girth sizes, with a half size increment of 3.5 mm. Japanese system based on the foot length and the foot ball girth. The step size for length is 10 mm, with a half size increment of 5 mm, the step size for girth is 6 mm. French system based on the shoe-last length and the shoe-last ball girth. The step size for length is 6.67 mm, while girth increases with length by 4 or 5 mm. The British system based on the shoe-last length. The step size for length is .33 inches, with a half size increment of .17 inches. Girth size based on the shoe-last ball girth increases with length size in increments of 5 or 6 mm. The American system based on shoe-last measurements. The step size for length is .33 inches, with half size increments of .17 inches (Luximon and Luximon 2013).

3D scanning technology for foot measurements

For the past two decades, three-dimensional (3D) scanning technology has been adopted to measure various human foot dimensions because these data offer detailed information on the foot contours. 3D scanning technology is considered to be the most reliable method available thus far for obtaining accurate foot measurements (Telfer and Woodburn 2010; Wu et al. 2017). However, it is not suitable to observe only the shape of the foot surface in the 3D data because of the different weight applied when the sole touches the floor during 3D scanning process (Oh and Suh 2017). Therefore, a two-dimensional (2D) scan image of the foot sole surface is required for a precise shape classification of the foot sole. In the studies of Kim and Do (2013, 2014), 12 foot shapes were obtained by combining three foot-side types (Type 1 characterized by a high forefoot and low midfoot compared to the length, instep, heel height, and gradient; Type 2 distinguished by a low forefoot and high midfoot; and Type 3 exemplified by a low forefoot and low midfoot) and four sole types (H, V, D, A), obtained from 3D and 2D scan data of elderly Korean men, respectively. Although studies on classifying foot shapes have been conducted, limited research exist on developing a footwear sizing system using the classified foot types. The current footwear sizing system does not reflect various foot shapes, which will eventually lead to hinder aging individuals' healthy living in their later life.

Methods

Using a quantitative research design, we focus on developing a footwear sizing system that considers the different foot types of elderly men, which can lead to improve the function and mobility of their daily living.

Study participants

Using a purposeful and convenience sampling method, a total of 284 elderly men were recruited from Gwangju Metropolitan area in South Korea. Participants in the study were aged 60 years and over and did not have any foot-related disease or injury. To recruit elderly male participants, we visited a few welfare centers in Gwangju during the summer of 2012. The data from the right foot of 264 elderly men, were used for the data analysis.

Instruments

In this study a 3D foot laser scanner and a 2D flat scanner were used to obtain 3D foot scan data. The 3D foot scanner (Nexcan®, K & I Technology) uses laser-triangulation, with a measurement speed of 18 s/foot, an accuracy of ± .5 mm, and a scanning area of 320 mm × 200 mm × 200 mm. The foot soles were measured using a flat scanner (HP ScanJet G2410), which has a 48-bit hardware resolution of 1200 × 1200 dpi and a speed of 21 s for a 10 × 15 cm color picture.

Data collection

The right foot of each participant was measured with the 3D foot scanner to obtain a 3D foot shape and by the 2D flat scanner to acquire a 2D shape for the foot sole. The participants were required to step onto the scanner with their right foot touching the glass platform inside the scanner while the left foot remained outside, parallel with the scanner. Each participant was asked to stand in a natural position, without support, during the scan, with his body weight distributed equally on both feet. The data collection took a total of 3 min. In order to ensure the quality of the scanned image, foot and body movement during the scanning was minimized.

Foot-side and sole type classification

Identification of the key anthropometric measurements of each participant's 3D and 2D scan data was based on the chart by the 5th Size Korea (2004) and previous studies (Jung 2000; Park 2013); 75 measurements (e.g., foot length, ankle thickness, foot breadth, ball distance, heel width, ball height, instep height, ankle height, …) were used. Using SPSS software 21, descriptive statistics and other additional analyses (i.e., factor analysis, cluster analysis, ANOVA) were performed to analyze the foot shape of the elderly men.

Each participant's foot was classified followed by Kim and Do's (2013, 2014) foot classification procedure, which consists of three foot-side types and four sole types. Foot side type is divided by instep point according to height of forefoot and midfoot. Foot-side type 1 was middle instep high, and toe 1 height and ball height is high, so classified as having a high forefoot and low midfoot compared to the foot length. Foot-side type 2 was high instep high, and toe 1 height and ball height is low, so characterized by a low forefoot and high midfoot. And foot-side type 3 was low instep high, and toe 1 height and ball height is low, so differentiated by a low forefoot and low midfoot. Four different sole types were identified as H-sole type having a narrow foot width, a wide heel width, and a uniform flat shape with no protruding parts, V-sole type having a wide foot and toe widths and a narrow heel width, A-sole type having wide foot and heel widths, but a narrow toe width with protrusion to the inside, and D-sole type characterized by protrusion to the outside (Fig. 1).

Data analysis

In this study, we performed cross-tabulation with foot length and instep circumference according to the foot shapes, combining foot-side and sole types. Means of the principal components were used as center values for the middle size of foot and other sizes were arranged evenly across the range (Xia and Istook 2017). The measured foot sizes were categorized, focusing on the average instep size comprising a circumference of 255 mm and the average foot length of 250 mm.

Correlation analysis was also performed to determine the control variables, which are the body measurements used to classify size groups (Petrova 2007). These measurements best describe the body size for each individual. Control variables should be easy to measure and have little or no intercorrelation (Xia and Istook 2017). To set basic measurement items for developing a footwear sizing system for elderly men, among the 75 measurement items (i.e., 43 3D measurement items and 32 2D measurement items) related to the foot shape, we chose seven items based on the frequently used foot dimensions for making shoes (Lee et al. 2013; Lee and Wang 2014) and performed Pearson bivariate correlation analysis for each measurement item. Those seven identified items include foot length, ball distance, ball circumference, instep circumference, toe 1 height,

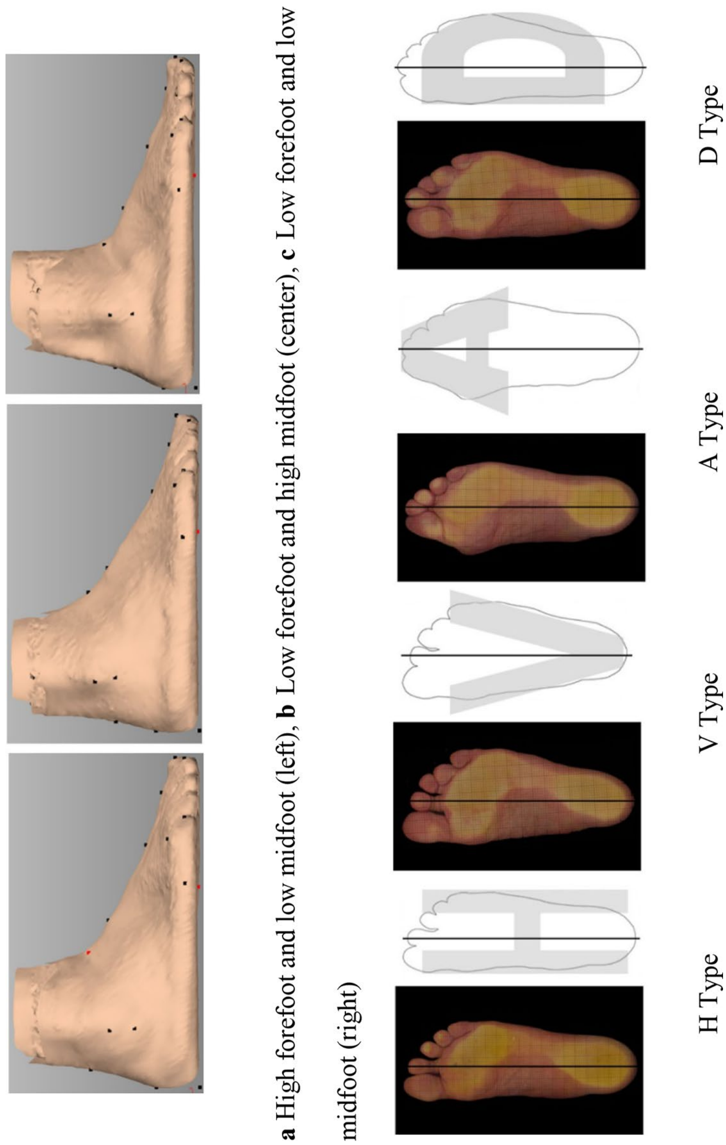

Fig. 1 Foot-side and sole types according to 3D and 2D data of the elderly men. The black dots in **a**–**c** represent the measurement foot landmarks 3D scanning

Table 1 Cross-tabulation of the elderly men according to foot-side and sole types

Foot-side type	Sole type				Total
	H	V	A	D	
1					
Frequency	33	29	12	8	82
% of total	12.50	10.98	4.55	3.03	31.06
2					
Frequency	26	27	7	4	64
% of total	9.85	10.23	2.65	1.52	24.24
3					
Frequency	43	39	21	15	118
% of total	16.29	14.77	7.95	5.68	44.70
Total					
Frequency	102	95	40	27	264
% of total	38.64	35.98	15.15	10.23	100.00

Foot-side type 1 was high forefoot and low midfoot compared to the foot length. Foot-side type 2 was low forefoot and high midfoot, and foot-side type 3 was low forefoot and low midfoot. The H-sole type has a narrow foot width, a wide heel width, and a uniform flat shape with no protruding parts, The V-sole type has foot width and toes width, wide and heel width narrow, the A-sole type has foot width and heel width, wide but toes width narrow, protruded inside, and the D-sole type has protruded outside

ball height, instep height. Then, the footwear size intervals were set referring to the KS standards (KS G 3405:2001 and KS M 6681:2007).

For the proposed footwear sizing system for elderly men, coverage and coverage efficiency were computed in a cross-tabulation by observation percentages. Size intervals and observation percentages indicating the highest coverage efficiency were recommended for the final footwear sizing charts. Focusing on a frequency of more than 5% for each foot shape, we set sections including ± 1–2 sections to continue the size range. We tried to minimize the sections as much as possible while raising the coverage rate by deleting or moving sections that did not appear within sections, while considering the economic efficiency of production.

Results and discussion

The results were presented according to each of the research objectives for the study, which were to (a) analyze the foot shape of elderly men using the foot-side and sole type classification, (b) establish basic measurement items and sizing intervals for developing a footwear sizing system, and (c) propose a footwear sizing system according to the foot shapes of elderly men.

Elderly men's foot shape analysis by combining the foot-side and sole types

Cross-tabulation with the three foot-side types and four sole types was performed (Table 1). When we examined the distribution of sole types with the foot-side types of the 264 elderly men, foot-side type 1 having high forefoot with low midfoot, showed the highest distribution in the H-sole type (40.24%), followed by V-sole type (35.37%), A-sole type (14.63%), and D-sole type (9.76%) in terms of frequency. Foot-side type 2 having low forefoot with high midfoot presented the highest distribution among V-sole type (42.19%), followed by H-sole type (40.63%). Foot-side type 3 having low forefoot

Table 2 Correlation coefficients of measurements for the elderly men

	Foot L.	Ball D.	Ball C.	Instep C.	Toe 1 H.	Ball H.	Instep H.
Foot L.	1						
Ball D.	.538***	1					
Ball C.	.497***	.917***	1				
Instep C.	.471***	.776***	.829***	1			
Toe 1 H.	.208***	.367***	.432***	.447***	1		
Ball H.	.335***	.363***	.524***	.512***	.643***	1	
Instep H.	.145*	.165**	.290***	.492***	.278***	.407***	1

L length, *D* distance, *C* circumference, *H* height

* $p < .05$, ** $p < .01$, *** $p < .001$

with low midfoot showed the highest distribution in H-sole type (36.44%), followed by V-sole type (33.05%), A-sole type (17.80%), and D-sole type (12.71%).

Considering a general combination of 3D foot-side type and sole type among the elderly man participants, foot-side type 3 in combination with H-sole type showed the highest prevalence (16.29%), followed by foot-side type 3 combined with H-sole type (14.77%). As shown in Table 2, each combination of foot-side type 1 with H-sole type, foot-side type 1 with V-sole type, and foot-side type 2 with V-sole type comprised more than 10% of the foot shape distribution among the study participants. The A and D-sole types were much less than 10% of the foot shape distribution across the three different foot-side types.

Establishing basic foot measurement items

To set basic measurement items for developing a footwear sizing system for elderly men, we chose the following seven measurement items related to the foot shape: foot length, ball distance, ball circumference, instep circumference, toe 1 height, ball height, and instep height and performed correlation analysis between each measurement item. As shown in Table 2, the results showed significant correlations between each measurement item at $p < .05$. Correlation values higher than .7 were found among ball distance, ball circumference, instep circumference, and ball width. For ball circumference, the results showed correlation values higher than .4 for all measurement items, except instep height ($r = .290$). Ball distance also showed a low correlation with instep height ($r = .165$). Instep circumference showed correlation values higher than .4 with each selected measurement item. We found that significant relationships among ball distance, instep height, foot length, and ball height. Moreover Hinojo-Pérez et al. (2016), found girth measures (ball, waist, and instep) are largely correlated to each other and to other measures, except foot length. Therefore, these measures could be set as basic measurement items representing the other items.

Based on the results of correlations among foot measurement items of the elderly male participants, instep circumference showed high correlations with the most of foot measurement items, consistent with Seok and Park's (2007) argument, stating that instep circumference reflects the height and width of the midfoot. Among the features of the foot types, this instep circumference item was related to footwear suitability. Traditionally, the most frequently used measures to determine shoe size have been foot length and ball girth (Hinojo-Pérez et al. 2016). However, previous studies (e.g., Mochimaru et al. 2000) have demonstrated that the increase in foot length and ball girth is not proportional.

According to Kim's (2013) study on footwear worn by the elderly, sneakers and dress shoes were worn most of the time. In the case of sneakers, individuals managed the instep height with laces. Basically, the elderly put on footwear covering the instep circumference, which was one of the areas where the elderly, especially elderly males, experienced the most discomfort. This finding suggest reflecting items that measure the instep region when developing a footwear sizing system. Kim and Do (2014) also found the importance of the foot-side height by classifying 3D forms of the elderly men's feet. The standard deviation of the instep circumference showed the greatest difference compared to other items. We can conclude that their foot shape is an essential part in footwear design and development, which will support their daily function and mobility.

In this study, ball circumference, which has been confirmed as a basic item to develop a footwear sizing system, was highly correlated with instep circumference and ball distance. However, it did not reflect the middle height of the foot, as indicated by the low correlation between instep height and the middle height of the foot. Therefore, we may argue that using instep circumference rather than ball circumference seems to be more suitable for footwear design and development, which is more appropriate for foot comfort and shoe fit. Furthermore, in a previous study, Kim and Kim (2011), after interviewing managers in the footwear industry, suggested adding the two additional measurement items, instep circumference and foot length, for footwear design and development. Thus, to create a footwear sizing system for elderly men in South Korea, this study used instep circumference and foot length as the main measurement items, instead of the ball circumference item found in the KS or ISO systems according to sole type, which uses features of ball width.

Setting the sizing interval

One of the study objectives was to set a sizing interval as a basic item used to design footwear for elderly men. The footwear size interval was set by referring to the KS standards (KS G 3405:2001; KS M 6681:2007). While ball circumference is a basic measurement item in the KS shoe standard (KS M 6681 2007), it is desirable to develop a footwear sizing system appropriate for the international footwear sizing standard, without causing any confusion. Therefore, we developed a footwear sizing system using the following criteria: foot length with 5 mm interval, instep circumference with 3 mm interval, and instep circumference within the same foot length with 6 mm interval. The indicator used for the circumference was the same as the current standard, ball circumference.

Footwear sizing system according to foot shapes

Tables 3, 4, 5 and 6 show footwear sizing system according to foot shapes of elderly men. Foot-side type 1 with H-sole type (Foot Shape H1) applied to 12.5% of the sample of elderly men. We developed sizes for this foot shape focusing on a foot length of 240–250 mm and an instep circumference of 249–267 mm, which showed a frequency of more than 5%. As a result, six different foot lengths and five circumferences were set, and 24 sections were developed, representing a total coverage of more than 72.7%. Foot-side type 2 with H-sole type (Foot Shape H2) applied to 9.85% of the feet

Table 3 Footwear sizing system of foot shape H for elderly men (unit: mm)

Foot L. \ Instep C.	C	D	E	EE	EEE	EEEE	F
235		234	240	246	252		
240	231	237	243	249	255		
245		240	246	252	258	264	
250		243	249	255	261	267	
255		246	252	258	264	270	
260		249	255	261	267	273	
265		252	258	264	270		

H1 H2 H3

Table 4 Footwear sizing system of foot shape V for elderly men (unit: mm)

Foot L. \ Instep C.	C	D	E	EE	EEE	EEEE	F
235				246	252	258	
240			243	249	255	261	
245		240	246	252	258	264	270
250		243	249	255	261	267	273
255		246	252	258	264	270	276
260		249	255	261	267	273	

V1 V2 V3

Table 5 Footwear sizing system of foot shape A for elderly men (unit: mm)

Foot L. \ Instep C.	C	D	E	EE	EEE	EEEE	F
240		237	243	249	255	261	
245	234	240	246	252	258	264	
250	237	243	249	255	261	267	
255	240	246	252	258	264		
260		249	255	261	267		
265					270	276	

A1 A2 A3

in the sample of elderly men. We developed sizes focusing on a foot length of 240–265 mm and an instep circumference of 234–270 mm, which showed a frequency of more than 5%. As a result, six foot lengths and six circumferences were set, and 22 sections were developed, showing more than 84.6% of total coverage. Foot-side type

Table 6 Footwear sizing system of foot shape D for elderly men (unit: mm)

Foot L. \ Instep C.	D	E	EE	EEE	EEEE
235				252	258
240	237	243	249	255	261
245	240	246	252	258	264
250	243	249	255	261	267
255	246	252	258	264	
260	249	255	261		

D1 D2 D3

3 with H-sole type (Foot Shape H3) applied to the feet of 16.29% of participants. This foot shape showed the greatest range. We developed sizes focusing on a foot length of 235–265 mm and an instep circumference of 234–267 mm, which showed a frequency of more than 5%. According to the results, seven foot lengths and five circumferences were set, and a total of 27 sections were developed, showing more than 74.41% of total coverage.

Foot-side type 1 with V-sole type (Foot Shape V1) applied to 10.98% of the elderly male participants. The frequency for this foot shape was more than 5% with a foot length range of 235–260 mm. For instep circumference, there was a prevalence of 6.9% at 222 mm. However, this frequency was the lowest among the measurement sections for instep circumference, indicating that it was an outlier. Therefore, we developed sizes focusing on a foot length of 246–267 mm. A total of 20 sections were developed by setting four circumferences and six foot lengths, representing 69.0% of total coverage.

Foot-side type 2 with V-sole type (Foot Shape V2) applied to 10.23% of the participants' feet. A foot length of 235–260 mm represented a frequency of more than 5% for this shape. Instep circumference represented a frequency of more than 5% for all the sections. Therefore, sizes were developed focusing on a foot length of 243–270 mm, excluding 285 mm, which was considered as an outlier. As a result, six foot lengths and six circumferences were set and a total of 27 sections were developed, for a high coverage of 88.9%. Foot-side type 3 with V-sole type (Foot Shape V3) applied to 14.77% of the feet in our sample. A frequency of more than 5% was found for foot lengths between 235–260 mm and instep circumferences of 243–270 mm. Therefore, we developed the size focusing on these parameters. Subsequently, six circumferences and six foot lengths were set and 26 sections were formed, resulting in a total coverage of 87.2%.

Foot-side type 1 with A-sole type (Foot Shape A1) applied to only 4.55% of the total number of elderly male participants, indicating a very low frequency. In every section, it appeared more than 5%. Therefore, we developed sizes focusing on a foot length of 245–265 mm and an instep circumference of 249–273 mm, excluding an instep circumference of 231 mm, which was considered as an outlier. After deleting or moving

Table 7 Coverage according to the elderly men's foot shape

	Foot shape											
	H1	**H2**	**H3**	**V1**	**V2**	**V3**	**A1**	**A2**	**A3**	**D1**	**D2**	**D3**
Number of sizes	24	22	27	20	27	26	19	13	20	22	5	18
Coverage (%)	72.7	84.6	74.4	69.0	88.9	87.2	83.3	57.1	76.2	75.0	75.0	73.3
Coverage efficiency rates	3.03	3.84	2.75	3.45	3.29	3.35	4.38	4.39	3.81	3.40	15.0	4.07

A foot shape represents a combination of sole type (H, V, A, D) and foot-side type (1, 2, 3). Coverage means the coverage rate of selected specific size intervals for total users' size distribution. Coverage efficiency rates is coverage/the number of the observed intervals

some parts of sections that were not supported in the data, five circumferences and five lengths were set and 19 sections were formed, resulting in a total coverage of 83.3%.

Foot-side type 2 with A-sole type (Foot Shape A2) applied to 2.65% of the sample. This shape showed a low distribution among the foot shapes of elderly men. In every section, it showed frequency of more than 5%. Moreover, this foot shape was largely distributed across sections. The sizes were developed focusing on a foot length of 240–255 mm and an instep circumference of 240–264 mm, excluding the lowest and highest values. Subsequently, five circumferences and four foot lengths were set and 13 sections were formed, with a total coverage of 57.1%. Foot-side type 3 with A-sole type (Foot Shape A3) applied to 7.95% of elderly men. The frequency of this shape was more than 5%. The sizes were developed focusing on a foot length of 240–260 mm and an instep circumference of 243–261 mm. Five circumferences and five foot lengths were set and 20 sections were formed, with a total coverage of 76.2%.

Foot-side type 1 with D-sole type (Foot Shape D1) applied to only 3.03% of the elderly men in this study. This shape showed very low frequency, accounting for more than 5% in every section. Therefore, the sizes for this foot shape were developed focusing on a foot length of 235–265 mm and an instep circumference of 243–264 mm, excluding an instep circumference of 234 mm and a foot length of 235–265 mm, resulting in five circumferences, six foot lengths, and 22 sections with a total coverage of 75.0%.

Foot-side type 2 with D-sole type (Foot Shape D2) applied to 1.52% of the total sample of elderly men and had the lowest range among the elderly men's foot shapes. It ranged across more than 5% in every section. Therefore, the sizes for this foot shape were developed focusing on a foot length of 240–250 mm and an instep circumference of 252–261 mm, which were relatively close to the average size. As a result, three circumferences and two foot lengths were set and five sections were formed with a total coverage of 75.0%. Foot-side type 3 with D-sole type (Foot Shape D3) applied to 5.68% of the total sample, with a low frequency (more than 5%) in every section. In the development of this size, four circumferences and six foot lengths were set and 18 sections were formed with a total coverage of 3.3%.

The number of sections, coverage rate, and coverage efficiency for the footwear sizing system according to the foot shapes of elderly men are shown in Table 7. Size development based on a frequency of more than 5% for each section resulted in a coverage of 70% for all foot shapes, except for foot shapes of V1 and A2. For the foot shape Vl, the range for the instep circumference was too large and did not reach a coverage of 70%. The foot shape A2 showed a low coverage rate because there was a wide distribution range across sections and the frequency was also low. Foot shape D2 showed a coverage of 75.0% in 5 sections, with a coverage efficiency of 15.0%. The frequency of this foot shape was the lowest. Its distribution was close to the other shapes and its range was small; however, it did demonstrate the highest coverage efficiency. Thus, to set a footwear sizing system related to low-frequency shapes such as A and D-sole types, further analysis using frequency should be conducted in the future.

When we compare differences in the sizing system after combining sizes and shapes for the feet of elderly men, H-sole type conformed to most foot length sections by using seven ranges for foot lengths of 235–265 mm. A-sole type conformed to six ranges for foot lengths of 240–265 mm. V and D-sole types encompassed six of the same ranges for foot lengths of 235–260 mm. For instep circumference, H and A-sole types conformed to shoe widths of C–EEEE in seven sections covering C-F widths. V-sole type conformed to six ranges of shoe widths D-F. D-sole type conformed to five ranges of shoe widths D–EEEE. While H and A-sole types included a small range for instep circumference, V-sole type included a large range for instep circumference, and D-sole type featured a large circumference range. Therefore, these findings reflect differences between foot shapes.

Considering the range of sizes among the 3D shapes, H-sole type was included in the size range for the C–D shoe width sections. The instep circumference for foot-side types 1 and 2 were smaller than for foot-side types 3. Therefore, the measurement chart could reflect the size category for H-sole type, with a narrow width and high height. The sizes were divided according to the 3D type in the section that was lower than 240 mm in foot length. V-sole type appeared to have the same size range for all three shapes, up to an instep circumference in the D–EEE range, excluding 260 mm. The size categories for foot-side types 2 and type 3 were distributed in the section for F shoe width, which reflects large foot widths and high foot-side height. Shoe sizes for A-sole type differed among the 3D shapes. Foot-side type 2 was characterized by a small circumference. Therefore, a foot with a small width and high height was classified as A-sole type. The size categories for foot-side type 1 and 3 were distributed according to a large circumference. Therefore, foot-side type 3 with the largest width in A-sole type does not have a long foot length, whereas foot-side type 1 has a large width and long foot length. The sizing for D-sole type differed among the three foot-side types. However, foot-side type 1 included all of the sizes. Therefore, it is possible to apply the footwear sizing system for foot-side type 1.

Based on these results, the footwear sizing system was composed in accordance with the foot shapes of elderly men. The final footwear sizing system created for elderly men in this study is shown in Table 8.

Conclusions

Foot shape and size information are very important for footwear design and production (Lee and Wang 2014). Footwear sizing systems based on the distribution of foot shapes is essential for the production of well-fitting footwear for consumers. Footwear sizing must be appropriate for the foot characteristics of a country or region in order to achieve best fit (Luximon and Luximon 2013). There exist intrinsic foot shape differences between people in different countries as well as generations, hence different

Table 8 New sizing system for the elderly men's footwear (unit: mm)

Foot length	Sole type	Instep circumference						
		C	D	E	EE	EEE	EEEE	F
235	H		234	240	246	252		
240		231	237	243	249	255		
245			240	246	252	258	264	
250			243	249	255	261	267	
255			246	252	258	264	270	
260			249	255	261	267	273	
265			252	258	264	270		
235	V				246	252	258	
240				243	249	255	261	
245			240	246	252	258	264	270
250			243	249	255	261	267	273
255			246	252	258	264	270	276
260			249	255	261	267		
240	A		237	243	249	255	261	
245		234	240	246	252	258	264	
250		237	243	249	255	261	267	
255		240	246	252	258	264		
260			249	255	261	267		
265						270	276	
235	D					252	258	
240				243	249	255	261	
245			240	246	252	258	264	
250			243	249	255	261	267	
255			246	252	258	264		
260				255	261			

Length sizes start from 235 to 265 mm. There are seven instep circumference-sizes from C to F, which have step sizes of 6 mm

nations should investigate their own characteristics of foot shape and to develop shoe sizing system (Lee et al. 2013).

Hill (2005) study showed that there was no significant change in the foot width ratio (heel width to joint width) with increasing age, but the forefoot part became broader relative to the foot length with increasing age. Also, he reported that both the height of the instep and the joint girth became significantly larger relative to the foot length, with increasing age. According to KS M 6681 (2001), the control dimensions for footwear sizing were foot length, foot circumference, and foot width. The men size of this system is wide ranging from 200 to 300 mm in foot length, 189–303 mm in foot circumference and 79–122 mm in foot width for men over 12 years old. The step size for length is 5 mm and the step size for width between length sizes is 2 mm. Within each length size, there is a width step size of 1–2 mm. In the previous study (Kim 2013), height measurement of the side was found to be important feature in the elderly men's foot shape classification, instep circumference showed larger deviation than other measurements. In this study, the footwear sizing system was proposed based on the foot length and instep circumference according to the elderly men foot shape.

Footwear sizing system according to foot shapes of the elderly men suggested in this study can improve shoe-fitness of the elderly men. In addition, the range of size for choosing is much larger for the elderly men. Therefore, their satisfaction is expected to be high. Although the 3D technology has been developed these days, the 3D scanner has a high initial cost, so it is limited to be used in research and small-sized handmade companies.

The international footwear sizing system offers a sizing system based on foot length and foot width. As the age increases, the shape of the foot changes. Some foot sizing system use different sizing systems for different types of shoes (e.g. men's, women's, children's, sport, and safety shoes), but there is no footwear sizing system that reflects the foot shape. This study is to classify the elderly men's foot shape by the combination of the side type and the sole of the elderly men foot, and to establish the footwear sizing system according to each foot shape.

The footwear sizing system presented in this study can help to develop a new production plan for each foot shape based on foot shape classification. The manufacturers can produce footwear according to different foot shape characteristics and the proportion of each foot shape to facilitate the matching and wearing fit of the elderly men. They can first identify the corresponding foot shape and then select footwear with the right size to assure better footwear fit. This study provides designers grading information that is helpful for shoe last design.

Abbreviations

L: length; D: distance; C: circumference; H: height.

Authors' contributions

Both authors read and approved the final manuscript.

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Competing interests

The authors declare that they have no competing interests.

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