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Foot Measurement Using a Smartphone App and Evaluation of Fit Satisfaction with Custom-Handmade Footwear

Jongkyu Lee · Jieun Kim · Hosun Lim†
Dept. of Clothing & Textiles, Sookmyung Women's University
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Abstract

We surveyed footwear fit satisfaction to inform the development of a custom-handmade footwear ordering system with foot measurement via augmented reality (AR) virtual fitting available to consumers on-tact (non-face-to-face) in a smartphone app. The participants included 300 Sookmyung Women's University students and female employees. The first experiment comprised foot measurement and AR virtual fitting via the app and a survey of respondents' ready-made footwear purchases and fit satisfaction evaluations. In the second experiment, 50 participants were randomly selected to wear custom handmade footwear made using the collected measurement data The study's findings revealed that the X value of the foot model accuracy for the virtual wearing function in the form of footwear was 0.0 mm, and the level of satisfaction was high. The fit of the custom handmade footwear made with the subjects' foot measurement data obtained through the foot measurement app showed a statistically significant difference of $p < .05$ compared to the ready-made footwear. The foot measurement app's accuracy was confirmed through certification within the standard tolerance $\leq \pm 1$ mm range, with a maximum average difference of 2 mm between the existing value and the 3D scanning value presented in ISO 20685-1.

***Key words*:** Non-face-to-face, Smartphone app, Foot measurement, Custom handmade footwear, Fit satisfaction

I. Introduction

In recent years, the function of footwear has expanded beyond protecting the feet from external impacts, keeping them warm, and aiding physical activity. Footwear's functional dimension now includes reducing the impact on the spine and brain and providing ergonomics based on individuals' foot shape. Accordingly, when choosing footwear, consumers demand a comfortable fit and functionality based on their foot shape rather than merely looking for footwear that fits (Kim & Kim, 2011). As the demand for personalization of consumers increases, handmade footwear manufacturers are evolving into a consumer-participatory production system tailored to the consumer's foot shape by building a 3D scanner system to identify the details of the consumer's foot types and shapes from the existing contact manual measurement method (Lee & Jeong, 2001; Kim, 2022; Rafiq et al., 2022). 3D scanners are being used in a variety of ways, from stereoscopic photography to patterns projected onto objects, laser scanning, and smartphone apps (Allan et al., 2023). Although the domestic 3D scanner market is growing as the application field expands, the domestic mobile 3D scanner technology is still insufficient to the level of purchasing and applying core parts due to the lack of technology for key element technology corresponding to the control system. Since 3D scanners are dominated by several foreign companies, it is difficult to enter the

†Corresponding author
E-mail: lhs@sm.ac.kr

market, and most of the technologies and products are used by imports, and the domestic technology level is low at 28.6% of that of developed countries (Gwangju Techno Park [GJTP], 2018). Therefore, a localization infrastructure is needed by reviewing the applicability of each product, type, and industry and establishing a foundation for customized 3D scanner support.

Recently, Prospecs (LS Networks) and a handmade footwear manufacturer in Seongsu-dong, known as “the mecca of handmade footwear,” have collaborated to implement an ordering system-based business. When a customer visits a store, they can select a design and measure their feet’s shape and dimensions using a 3D scanner; based on the results, a work order is issued to manufacture handmade footwear (Yoon, 2020). Sports brands Adidas and Lecaf have also installed 3D foot scanners in their stores to suggest customized shoes well suited to consumers’ feet based on information about their foot size and shape as captured in 3D images (Park, 2018). Thus, global brands and domestic handmade footwear companies are also developing and promoting new customized handmade footwear using the IT base of 3D scanners, some shoe manufacturers are raising problems about 3D scanners. When measuring the shape of the foot using a 3D scanner for customization, it is found that if the shape of the foot is not uniform, the accuracy of the dimensions required for footwear production is reduced, and the shaking of the body during scanning affects the image fidelity, which affects the accuracy of the foot measurement image information (Witana et al., 2006).

Telfer and Woodburn (2010) stated that the protocol used to acquire measurement data while scanning the foot under load had a significant impact on the measurement values. Therefore, it is important to develop a standardized protocol for processing scan data to ensure accuracy for customized. However, small-scale handmade footwear companies’ use of 3D scanners for measuring foot shapes is limited because of the cost burden, the time required for measurement, and the compensatory measures that must be implemented to accommodate small movements (Kim, 2022; Lee et al., 2014; Niu et al., 2021). The limitations of 3D scanner use are being increasingly digitized with data generated by quickly scanning shapes and dimensions of objects or spaces through easy-to-use iOS and Android 3D scanning apps.

In the current footwear market, since the COVID-19 pandemic, it is changing into a consumer-oriented behavior pattern in an on-tact (non-face-to-face) manner and acceptance of various high-tech technologies. Consumers prefer platforms where the interest in personalization is increasing through various mobile apps, and the demand to perform feasible augmented reality (AR) for real scenes and objects is increasing. In response to this increase in demand, footwear manufacturers are using the measurement technology and software of mobile foot measurement apps to collect 3D big data of the human body and create customized products (Niu et al., 2021). However, most apps used for foot measurement for customized footwear production lack information related to consumer foot measurement, and the current foot measurement app configuration is a way to construct a 3D foot model by measuring foot attributes and sending 3D scanned information to an internal server, so improvements are needed for applications that provide information to identify the accuracy of consumer foot measurement (Kabir et al., 2021). It is said that most foot measurement apps in the official mobile app stores, Apple app store and Google play store, do not meet the measurement standards required to measure consumers’ feet when making custom footwear. Only 23% of foot measurement apps use scanners or algorithms to reconstruct a 3D model of the foot with the user’s required measurement dimensions in customizing custom handmade footwear (Kabir et al., 2021), irregular foot shapes and sizes, apps it is said that the performance and usability of the overall measurement function is insufficient (Allan et al., 2023; Kabir et al., 2021; Rafiq et al., 2022). Therefore, it is necessary to continuously study the software that can solve the technical quality problem of the foot measurement related app.

In terms of research related to 3D foot models, Oh and Kim (2013) studied foot geometry using 3D modeling and developed a computerized handmade footwear production process that utilizes last-shape data. Further, Lee and Jeong (2001) used a 3D foot measurement system to extract foot geometry and build a footwear shape database, given custom-handmade footwear production's dependence on lasts. Oh et al. (2013) built a standardized custom foot shape database and classified the data by last and foot shape.

Kim (2022) proposed revitalizing the personalized handmade footwear industry by allowing consumers to visit a store to measure their feet with a 3D scanner, select a footwear design, place an order, and have the footwear made.

Rafiq et al. (2022) showed the accuracy of foot length (95.23%), foot width (96.54%), and foot height (89.14%), measured dimensions through the manual measurement and foot measurement smartphone application using a medical silicone foot model. The measurement of the foot circumference raised the need for a 3D scan model. In addition, the shape of the foot can change because the actual foot is not used, and it is difficult to find the measurement point, so the limitation of dimensional measurement was presented. Most studies in Korea were limited to foot shape models using 3D scanners, and research and development related to foot measurement apps using smartphone apps is minimal even overseas. Especially, with a new method of foot measurement apps. there is no software app technology development or research related to 3D scanning foot measurement and virtual footwear images in an on-tact (non-face-to-face) environment where consumers directly use their smartphones without having to visit a store.

Therefore, the research to be covered in this study recognizes the shape of the foot through the iOS foot measurement (v1.10) app with the foot measurement app function and the virtual fitting function using a smartphone app, measuring the shape of the foot and measuring the various sizes and shapes of the foot to build a 3D foot image model through verification evaluation of the foot measurement accuracy and virtual fitting function. And evaluating foot parameters through a virtualization algorithm app based on big data augmented reality. The software used in the foot measurement app (v1.10) enables virtual fitting without separate assistive devices through augmented reality (AR) to correct virtual fitting, and can produce handmade footwear without making last (foot shape) production through big data. This has the advantage of reducing data collection costs compared to 3D foot scanners and is location-agnostic because it does not require special equipment. And when consumers scan their feet directly, the scan data enters the central server and corrects the data to fit the customer's feet through the foot dimension information big data. The expected effect of using the app can be expected to through the fusion and combination of 3D scanning, big data and augmented reality (AR) technology in the fashion (footwear) industry, a new sales platform integrated with foot size big data and handmade footwear brand can be achieved.

Therefore, this study aims to verify the accuracy and ignition of foot measurement through an iOS foot measurement (v1.10) app with a foot measurement app function and a virtual fitting function using a smartphone app, and to evaluate a virtual ignition (fit) algorithm app based on big data augmented reality by constructing a 3D foot image model. In addition, the use of smartphone foot measurement app in the existing contact manual measurement method is intended to present basic data for the development of an online order production system app that enables consumers to order handmade shoes without being restricted by the on-tact method.

II. Method

1. Research Subjects

The research subjects were 300 Sookmyung Women's University students and female employees. We conducted two rounds of experiments and surveys. The subjects of the survey were measured by contact type manual foot measurement, foot size measurement using iOS foot measurement (v1.10) application of smart phone, virtual fit verification evaluation, and questionnaire about the purchase and wearing status of footwear of consumers in general.

2. First Experiments and Surveys

1) First Survey

The survey period was from April 26 to May 4, 2023. The questionnaire administered in the first round comprised four general questions about ready-made footwear, nine questions about the purchase of ready-made footwear, 13 questions about the respondent's fit satisfaction with ready-made footwear for each part of the foot, and one question about their satisfaction with their AR virtual fitting experience (Han, 2005; Kim & Lee, 2014; Lee, 2007). <Fig. 1> shows the position of each part of the foot considered in the fit satisfaction evaluation.

To investigate differences in ready-made footwear fit satisfaction according to age, the research subjects were divided into two age groups for analysis: aged under 30 years and aged 30 years or more. The classification criteria for the age of 30 are set in the enforcement decree of the income tax act, as aged 30 years or more is a criterion for residence and household independence (economic activity), this study classified the participants based on the same age threshold (National Law Information Center [NLIC], 2023).

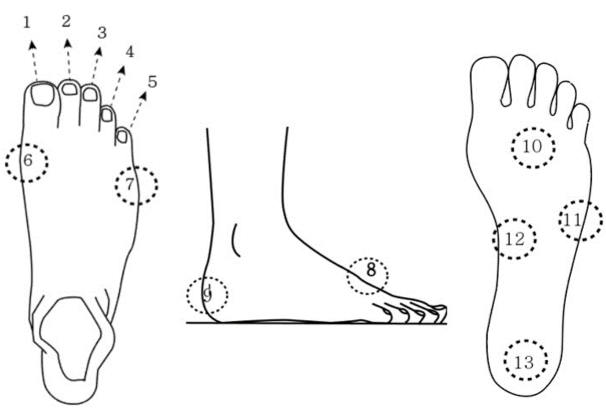
2) First Round

(1) Foot measurement app test item and method

Using the Shrub app (iOS foot measurement app v1.10) with foot size measurement and virtual ignition function, 300 survey subjects took photographed of their own feet (Fig. 2, Table 1).

As shown in <Fig. 1> to obtain the foot measurements, the size of each foot was ascertained based on the width and length as seen in photographs of the tops of the feet (Fig. 2-a, b), and the foot height was determined based on a view of the side of the foot (Fig. 2-c). Next, the foot sizes measured during the AR virtual fitting (Fig. 2-d) were compared to the subject's ready-made footwear sizes to match the consumer with a pair of shoes based on their measurements (Fig. 2-e).

The Shrub app (iOS foot measurement app v1.10), developed by MizLab software company, conducted an image recognition software evaluation on items such as foot, foot length, foot height, virtual ignition, and big data computation speed, footwear display time, footwear position recognition time, and display speed of matching information with footwear in the software test and certification laboratory of the Korea telecommunications technology association (Telecommunications Technology Association [TTA], 2023) (test report number: BT-A-23-0088). The measurement method of foot, ball length, foot height was cal-



(a) Toes (b) Foot side (c) Plantar

(a) Toes	1. Big toe
	2. Index toe
	3. Middle toe
	4. Ring toe
	5. Pinky toe
	6. Big toe bone protrusion
	7. Pinky toe bone protrusion
(b) Foot side	8. Instep
	9. Heel
(c) Plantar	10. Front part of the plantar
	11. Outside of the plantar
	12. Middle part of the plantar
	13. Plantar heel part

Fig. 1. Illustration of the parts of the foot (referenced in the questionnaire).

Fig. 2. Foot measurement and use of the AR virtual fitting app.

Table 1. Mobile terminal specifications

Rote	OS	CPU	Memory	Disk	Pre- Requisite
Mobile terminal	- Model: iPhone 13(MLPG3KH/A) - OS: iOS 16.5.1				Model app

culated in mm units of the difference from the dimension calculated by actual user foot scanning, and the scan foot height model measured the degree of coincidence with the shape of the user's foot mapped in 3D.

ISO 20685-1 (2018), an international standard, has been proposed so that the measurements obtained using 3D scanning systems can be compared with those obtained using conventional methods and used in an anthropometric database. This standard is limited to the measurement of foot length and width, and the maximum average difference between the existing value and the 3D scanning derivative value is presented as 2 mm. It was verified according to the measurement tolerance ≤±1 mm evaluation index of the accuracy of the standard certification standard of the Korea information and communication technology association (TTA, 2023). The test standards and verification method were as follows. The server architecture of the system design is as shown in <Fig. 3>.

① Foot Length, Foot Width Accuracy

The test criterion was to take a picture with a smartphone with the actual foot on top of the foot length and A4 paper for 100 podiatric images, and then compare the length of the A4 paper and the length of the foot in the taken image to calculate the relative value of the foot length and foot width and calculate the mean error between the actual foot length calculation result. Foot length and foot width accuracy were calculated using <Eq. 1> (TTA, 2023).

$$X = \sum_{i=1}^{n} \frac{|A_i - B_i|}{n} \qquad \cdots\cdots \text{Eq. 1.}$$

– A_i: Foot length of foot calculated by the product under test, foot width (mm)
– B_i: Actual foot length, foot width (mm)
– n: Number of iterations

② Instep Height Accuracy

The test standard calculated the average error of the instep height calculated as a relative value by comparing the length of the actual instep height when calculating the instep height for 100 copies of the foot photograph image. Instep height accuracy was calculated using <Eq. 2> (TTA, 2023).

$$X = \sum_{i=1}^{n} \frac{|A_i - B_i|}{n} \qquad \cdots\cdots \text{Eq. 2.}$$

– A_i: Instep height calculated by the test product (mm)
– B_i: Actual instep height (mm)
– n: Number of iterations

③ Virtual Fitting Accuracy

The test standard was calculated by calculating the average length of the foot in which the foot-wear image protrudes to the outside when the product to be tested executes the virtual fitting function app for 100 copies of the foot photograph image. The virtual fitting accuracy was calculated according to <Eq. 3> (TTA, 2023).

$$X = \sum_{i=1}^{n} \frac{A_i}{n} \qquad \cdots\cdots \text{Eq. 3.}$$

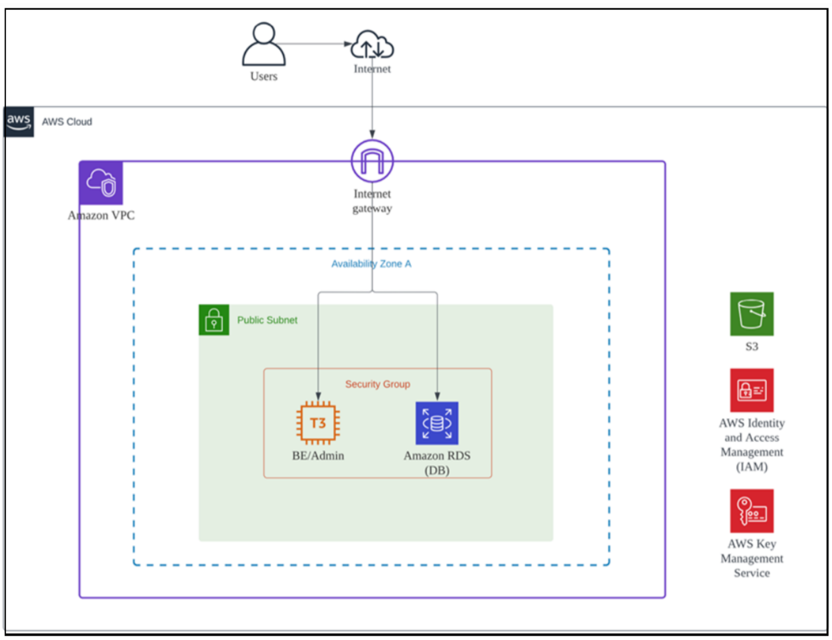


Fig. 3. Server architecture.

– A_i: Length of the foot protruding outside the footwear image (mm)
– n: Number of iterations

④ Big Data Computation Speed

Check the time required to calculate the circumference of foot circumference length by inputting a foot photo image taken by a camera for the test subject product. Big data computation speed was calculated according to <Eq. 4> (TTA, 2023).

$$X = \sum_{i=1}^{n} \frac{A_i - B_i}{n} \quad \text{...... Eq. 4.}$$

– A_i: Foot circumference length calculation completion time (seconds)
– B_i: Foot circumference length calculation start time (seconds)
– n: Number of iterations

⑤ Time Taken for Product to be Tested

The time it takes for the test subject product to recognize the foot by receiving a foot photo image taken by a camera (300 subjects). The average time required for the footwear image to adjust to a shape that fits the foot when the fitting function of the product being tested was checked using 300 subjects of the foot photo images. The time required for footwear image (expression, recognition, adjustment) was calculated according to <Eq. 5> (TTA, 2023).

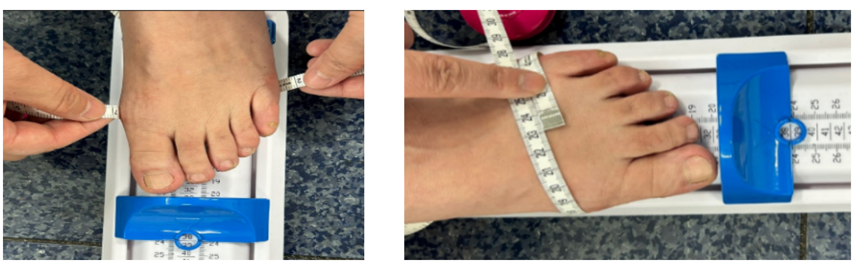
$$X = \sum_{i=1}^{n} \frac{A_i - B_i}{n} \quad \text{...... Eq. 5.}$$

– A_i: Footwear image (expression, recognition, adjustment) completion time (seconds)
– B_i: Footwear image (expression, recognition, adjustment) start time (seconds)
– n: Number of iterations

(2) Direct foot size measurement items and methods

For the direct foot size measurement, the left and right foot size of the foot length and the ball length of the foot were directly measured (Fig. 4-a, b). ISO 7250-1 (2017) suggests that when measuring foot length and width, the subject should be measured in a standing position with 50% of the body weight on each foot. This study conducted measurements based on this. As for the measurement method, the subject placed the ankle on the foot gauge in a standing posi-

(a) Foot length measurement



(b) Foot width measurement

Fig. 4. Direct foot size measurement.

tion and measured the foot length (Fig. 4-a) from the heel to the end of the longest part, and the ball length of the foot (Fig. 4-b) measured the circumference of the foot from the big toe protrusion to the little toe protrusion at the widest part of the foot width. Foot measuring instrument (Hobbit tools-12-28 cm, Etopoo: China) was used to measure foot size. The scale of 1 square was 1 mm.

3. Second Experiment and Survey

1) Second Round

The survey period was from June 12 to 13, 2023. The questionnaire comprised three questions about the purchase of custom-handmade footwear and questions about fit satisfaction for each part of the foot. The question content was identical to that of the first survey. We also analyzed differences in fit satisfaction with ready-made versus custom-made footwear. From the 300 participants, 50 subjects who responded that they footwear 2-3 times a week were randomly selected as consumer evaluators to conduct fit-tested the custom-handmade footwear. We used the results of the first survey on consumers' ready-made footwear preferences to select the custom-handmade footwear items. The survey showed that their first choice was loafers, followed by flat shoes, Mary Janes, heeled pumps, and slingbacks. Accordingly, we selected those five types of custom-handmade footwear.

(1) Footwear Design Types

In the first round of experiments, ES Shoes Company collected big data on the foot sizes of 50 selected subjects through a smartphone app (iOS foot measurement app v1.10) and produced 50 pairs of custom-handmade footwear based on the foot sizes of 50 subjects. The material used was natural leather. To evaluate the size and wearing satisfaction of five types of custom handmade footwear (loafers, flat shoes, Mary Janes, pumps, and slingbacks), footwear designs were randomly provided to 50 consumers and a verification evaluation was conducted. The five footwear designs are as shown in <Table 2>.

2) Subjective Wearing Evaluation of Custom-Handmade Footwear

The consumer evaluators rated their fit satisfaction with the products based on the footwear performance in a comfort test comprising the following movement postures: walking freely and bent-legs crouching (Jeong, 2018; Lee & Lim, 2023). These postures were repeated three times for 30 seconds each time with 10-second intervals of rest. <Table 3> describes the movement postures comprising the comfort test.

Table 2. Footwear design types

Items	Loafers	Flat shoes	Mary Janes	Pumps	Slingbacks
Material			Natural leather		
Footwear design types					

Table 3. Movement postures assumed during the comfort wear test

	Walking freely	Bent-legs crouching
Movement posture		

4. Data Analysis

Data analysis in this study was performed using SPSS IBM 26.0 statistical program, for frequency analysis, chi square test, mean and standard deviation, and *t*-test.

In the first survey analysis, a frequency analysis was conducted on the general matters of the survey subjects and the purchase status of footwear, and a chi square test was conducted to find out the differences in the purchase status regarding the preferred footwear types, online and offline footwear purchase rates, and satisfaction with online footwear purchases between the two groups under the age of 30 and over the age of 30. Also, a *t*-test was conducted to determine the difference in satisfaction with wearing ready-made footwear.

When wearing ready-made footwear, the satisfaction level for each part of the foot and the evaluation items for the augmented reality virtual wearing (fit) were evaluated on a 5-point scale (where 1 = Very dissatisfied, 2 = Dissatisfied, 3 = Neutral, 4 = Satisfied, and 5 = Very satisfied).

For the second survey round, multiple responses to the questions about the purchase of custom-handmade footwear and the respondents' fit satisfaction around each part of the foot were allowed. The data analysis was conducted in the same way as for the first round. Additionally, we conducted an *t*-test to determine whether there was a significant difference in fit satisfaction with the ready-made versus the custom-handmade footwear.

III. Results

1. Results of the First Experiment and Survey Analysis

The first experiment and survey were conducted using 3D scanning with the developed iOS foot measurement app (v1.10), and were conducted on 300 students and faculty to verify the performance of the virtual fitting function app.

1) Subjects' General Information and Footwear Sizes

<Table 4> shows the results of the analysis of the survey that collected the research subjects' 300 people general information and footwear sizes. The participants' age distribution was as follows: aged 18–20 years (45 people, 15.0%), aged 21-29 years (193 people, 63.4%), aged 30–39 years (37 people, 0.1%) and aged 40 years (25 people, 0.1%). Regarding their height, the majority were 161–169 cm taller (162 people, 54.0%).

The distribution of footwear sizes was as follows. Most participants measured 240–245 mm (131 people, 43.7%), followed by 230–235 mm (84 people, 28.0%), 250–255 mm (50 people, 16.7%), and 210–225 mm (29 people, 9.7%). Regarding sneaker sizes, most participants measured 240–245 mm (122 people, 40.7%), followed by 230–235 mm (100 people, 33.3%), 250–255 mm (49 people, 16.3%). Therefore, the most common footwear size within the sample was 240–

Table 4. Research subjects' general information

(N=300, unit: %)

Characteristic	Value range	Frequency (%)
Age	18–20 years	45(15.0)
	21–29 years	193(64.3)
	30–39 years	37(12.3)
	40 years or more	25(8.3)
Height	140–150 cm	2(0.7)
	151–160 cm	114(38.0)
	161–169 cm	162(54.0)
	170 cm or more	22(7.3)
Footwear size	210–225 mm	29(9.7)
	230–235 mm	84(28.0)
	240–245 mm	131(43.7)
	250–255 mm	50(16.7)
	260 mm or more	6(2.0)
Sneaker size	210–225 mm	21(7.0)
	230–235 mm	100(33.3)
	240–245 mm	122(40.7)
	250–255 mm	49(16.3)
	260 mm or more	8(2.7)

245 mm, and we found that people wear a smaller size in sneakers than in others footwear.

2) Information about the Purchase of Ready-Made Footwear

(1) Consumers' Purchase Preferences by Type of Ready-Made Footwear

We conducted a chi square test to determine the types of ready-made footwear the participants' preferred, and <Table 5> shows the results. As a result of the analysis, $\chi^2 = 37.545$***, which showed a statistically significant difference. Those under the age of 30 showed the highest preference for sneakers (213 people, 71%), followed by shoes (19 people, 6.3%) and other footwear (5 people, 1.7%). Those over the age of 30 showed the highest preference for sneakers (39 people, 13%), followed by shoes (23 people, 7.7%).

In terms of ready-made footwear worn on a daily basis, as a result of the analysis $\chi^2 = 26.230$***, which showed a statistically significant difference. Those under the age of 30 most participants indicated a preference for sneakers (266 people, 76.3%), followed by shoes (4 people, 1.3%) and other footwear (7 people, 2.3%). Those over the age of 30 indicated a preference for sneakers (266 people, 76.3%), followed by footwear (4 people, 1.3%) and other footwear (7 people, 2.3%). Overall, sneakers are the most commonly wear and purchased type of ready-made footwear.

(2) Online and Offline Ready-Made Footwear Purchases

<Table 6> shows the participants' responses to the question of whether they buy ready-made footwear online or offline. As a result of comparing offline and online purchase rates by age, there were no significant differences between ages. We examined the ratio of online to offline purchases and found that 114 respondents (38.0%) bought more ready-made footwear online than offline, 81 (27.0%) bought more offline than online, 40 (13.3%) made all their ready-made footwear purchases offline, 39 (13.0%) had an equal split between their online and offline purchases, and 26 (8.7%) made all their purchases online. On the other hand, the proportion of people under the age of 30 who responded that they purchase 100% offline was 27 people (9.0%), which showed that the number of people purchasing footwear offline was higher than that of people over 30. Overall, consumers are more

Table 5. Preferred footwear type (N=300, unit: %)

	Divisions	Under 30s (n=237)	Over 30s (n=63)	Total	χ^2
Purchase	Shoes	19(6.3)	23(7.7)	42	37.545***
	Sneakers	213(71.0)	39(13.0)	252	
	etc.	5(1.7)	1(0.3)	6	
Wear	Shoes	4(1.3)	11(3.7)	15	26.230***
	Sneakers	226(75.3)	51(17.0)	277	
	etc.	7(2.3)	1(0.3)	8	

***p<.001

Table 6. Ratio of online to offline footwear purchases (N=300, unit: %)

	Divisions	Under 30s (n=237)	Over 30s (n=63)	Total	χ^2
Purchases	Online 100%	23(7.7)	3(1.0)	26	7.710
	Online > Offline	86(28.7)	28(9.3)	114	
	Online = Offline	34(11.3)	5(1.7)	39	
	Online < Offline	67(22.3)	14(4.7)	81	
	Offline 100%	27(9.0)	13(4.3)	40	

likely to shop for ready-made footwear online than offline.

<Table 7> shows the results of the multi-response survey on people's reasons for buying ready-made footwear online. A multi-answer survey was conducted on 260 people, excluding 40 respondents who only buy 100% offline footwear out of 300 respondents. The most cited reason was 'low prices' (168 respondents, 22.1%), followed by 'varied information' (148 respondents, 19.4%)—the availability of various product information, including production descriptions and consumer reviews 'convenience of shipping anytime and anywhere' (140 respondents, 18.4%), and 'product search and comparisons' (117 respondents, 15.4%). These results suggest that consumers prefer shopping online versus offline because of the convenience of being able to shop online anytime and anywhere, various products and information accessible through the search function, and the ability to select the cheapest branded product based on price comparisons.

(3) Analysis of the Survey of Consumers' Satisfaction with Online Ready-Made Footwear Purchases

We analyzed the results of the survey on satisfaction with ready-made footwear purchased online in which respondents provided their ratings on a 5-point scale. The results are shown in <Table 8>. As a result of the analysis statistically significant differences were found in the color and design in $\chi^2 = 19.949^{**}$, material ($\chi^2 = 9.726^*$), and price ($\chi^2 = 9.874^*$).

Notably, the respondents expressed low satisfaction with the comfort and size of the ready-made footwear they purchased online. Both had a mean score below 3.50, and both qualities are directly related to the foot. However, satisfaction with price, design, and ma-

Table 7. Reasons for buying footwear online (based on the results of a multiple-response survey)

(N=260, unit: %)

	Divisions	Frequency (%)
Reason for purchase	Varied information	148(19.4)
	Product search and comparisons	117(15.4)
	Quick access to information	72(9.5)
	Various choices	66(8.7)
	Low prices	168(22.1)
	Convenience of shipping anytime and anywhere	140(18.4)
	Time saving	46(6.0)
	Other	4(0.5)
	Total	761(100.0)

Table 8. Satisfaction with footwear purchased online (N=260)

	Divisions	Under 30s (n=210)	Over 30s (n=50)	Mean (S.D.)	χ^2
		Mean (S.D.)	Mean (S.D.)		
Online footwear satisfaction	Size	3.10(.85)	3.18(.66)	3.12(.82)	6.487
	Weight and cushioning	3.06(.89)	3.00(.81)	3.05(.88)	1.938
	Color and design	4.16(.74)	3.70(.64)	4.07(.75)	19.949**
	Material	3.69(.78)	3.48(.58)	3.65(.75)	9.726*
	Quality	3.54(.82)	3.32(.74)	3.50(.81)	5.125
	Price	4.30(.71)	4.06(.77)	4.25(.72)	9.874*

$^*p<.05$, $^{**}p<.01$

terial was high. We deduced that the participants' satisfaction with the ready-made products they purchased online was low in the categories of comfort and size because when consumers purchase ready-made products, they rely solely on the footwear size information displayed on the website, which varies by brand. Conversely, when people purchase ready-made footwear offline, they visit physical stores and try the footwear on to check the fit and comfort. Hence, this factor can be identified as the main cause of consumers' dissatisfaction with their online footwear purchases. To increase consumers' wear satisfaction, footwear companies should unify and standardize ready-made footwear sizes to ensure that consumers have an accurate reference.

3) Evaluation of Ready-Made Footwear Fit Satisfaction

(1) Overall Evaluation of Ready-Made Footwear Fit Satisfaction

When the participants were asked whether they experienced discomfort while wearing ready-made footwear, the 300 subjects, most (190, 63.3%) said 'yes', and 110 people (36.7%) said 'no'. <Table 9> shows the results of the survey on satisfaction with the fit of the ready-made footwear for 190 people excluding 110 people usually wear for each part of the foot. Respondents expressed the lowest satisfaction with the fit around the pinky toe ($M = 2.88$ points) and the highest satisfaction with the fit around the middle and ring toes, which had mean scores above 4.00 points, corresponding to 'very satisfied'. The mean score for satisfaction with the fit around the index toe was 3.85 points, which corresponds to 'satisfied'. The mean scores for the fit around the big toe, the big toe bone protrusion, and the pinky toe bone protrusion were < 3.50, 3.00, and 3.08 points, respectively. On the side of the foot, the mean scores for the instep and the heel were 3.52 and 3.27 points, respectively.

Regarding satisfaction with the fit around the foot's plantar, the front part of the plantar had the lowest score, with a mean of 2.94 points, which corresponds to 'dissatisfied'.

The mean scores for the side and middle of the plantar were 3.62 and below 3.50 points, respectively.

From the results, we deduced that consumers generally experienced discomfort while wearing ready-made footwear purchased online. The parts of the foot

Table 9. Ready-made footwear fit satisfaction by foot part (N=190, unit: %)

Foot part	Divisions	Very dissatisfied	Dissatisfied	Neutral	Satisfied	Very satisfied	Mean (S.D.)
		(n=190), (%)					
Toes	Big toe	10(5.3)	52(27.4)	31(16.3)	47(24.7)	50(26.3)	3.39(1.28)
	Index toe	4(2.1)	28(14.7)	27(14.2)	64(33.7)	67(35.3)	3.85(1.12)
	Middle toe	0(0.0)	9(4.7)	33(17.4)	66(34.7)	82(43.2)	4.16(0.88)
	Ring toe	6(3.2)	9(4.7)	32(16.8)	63(33.2)	80(42.1)	4.06(1.03)
	Pinky toe	27(14.2)	68(35.8)	30(15.8)	31(16.3)	34(17.9)	2.88(1.34)
	Big toe bone protrusion	24(12.6)	67(35.3)	24(12.6)	32(16.8)	43(22.6)	3.02(1.39)
	Pinky toe bone protrusion	19(10.0)	72(37.9)	20(10.5)	32(16.8)	47(24.7)	3.08(1.39)
Side of the foot	Instep	8(4.2)	54(28.4)	19(10.0)	49(25.8)	60(31.6)	3.52(1.31)
	Heel	19(10.0)	51(26.8)	27(14.2)	46(24.2)	47(24.7)	3.27(1.36)
Plantar	Plantar front	18(9.5)	74(38.9)	33(17.4)	32(16.8)	33(17.4)	2.94(1.28)
	Plantar side	2(1.1)	39(20.5)	40(21.1)	58(30.5)	51(26.8)	3.62(1.12)
	Plantar middle	13(6.8)	41(21.6)	36(18.9)	52(27.4)	48(25.3)	3.43(1.27)
	Plantar heel	14(7.4)	39(20.5)	42(22.1)	48(25.3)	47(24.7)	3.39(1.26)

where people were uncomfortable were around the pinky toe and the big and pinky toe bone protrusions. Fit satisfaction around the front of the foot's plantar was also low. Discomfort in this part of the foot is believed to be higher due to the high pressure exerted by an individual's body weight. We recommend alleviating the discomfort by strengthening the complementary materials that distribute the pressure applied to the sole of the foot. Footwear companies should continue research to resolve the causes of discomfort in each part of the foot.

(2) Ready-made Footwear Fit Satisfaction by Age Group

To determine whether fit satisfaction with ready-made footwear varied by age group, we divided the participants into two groups: aged under 30 years and aged 30 years or more. The results of the analysis using these two age groups are shown in <Table 10>.

We performed an independent sample *t*-test to comparatively analyze the age-segmented participants' fit satisfaction for each part of the foot. Significant between-group differences were found for all toes except the pinky toe, as well as for the front part of the plantar. The mean fit satisfaction score for the big toe was 3.55 points among participants who were aged under 30 years at the time of the survey and 2.83 points for those aged 30 years or more ($t = 3.305^{**}$). The mean fit satisfaction score for the index toe was 3.99 points for participants aged under 30 years and 3.36 points for those aged 30 years or more ($t = 3.057^{**}$). The mean fit satisfaction score for the middle toe was 4.28 points for those aged under 30 years and 3.74 points for those aged 30 years or more ($t = 3.667^{***}$). The mean fit satisfaction score for the ring toe was 4.20 points for those aged under 30 years and 3.57 points for those aged 30 years or more ($t = 3.609^{***}$). The mean fit satisfaction score for the front part of the plantar was 3.09 points for those aged under 30 years and 2.38 points for those aged 30 years or more ($t = 3.272^{**}$).

From these results, we deduced that consumers' fit satisfaction was low for the areas around the pinky toe, the big toe bone protrusion, and the front of the plantar. Generally, people aged 30 years or more tended to experience more discomfort than those aged under 30 years. However, footwear fit satisfaction was low in all categories, probably because of factors known to make people feel uncomfortable while wearing foot-

Table 10. Age-based comparison of ready-made footwear fit satisfaction (N=190)

Foot part	Divisions	Under 30s (n=148)	Over 30s (n=42)	*t*-value
		Mean (S.D.)	Mean (S.D.)	
Toes	Big toe	3.55(1.27)	2.83(1.17)	3.305**
	Index toe	3.99(1.05)	3.36(1.23)	3.057**
	Middle toe	4.28(0.83)	3.74(0.91)	3.667***
	Ring toe	4.20(0.95)	3.57(1.15)	3.609***
	Pinky toe	2.89(1.37)	2.86(1.24)	0.119
	Big toe bone protrusion	3.08(1.40)	2.79(1.35)	1.214
	Pinky toe bone protrusion	3.13(1.38)	2.93(1.44)	0.820
Side of the foot	Instep	3.61(1.32)	3.19(1.23)	1.868
	Heel	3.30(1.40)	3.17(1.21)	0.550
Plantar	Plantar front	3.09(1.25)	2.38(1.23)	3.272**
	Plantar side	3.59(1.16)	3.69(0.98)	-0.538
	Plantar middle	3.39(1.30)	3.55(1.13)	-0.761
	Plantar heel	3.49(1.27)	3.07(1.20)	1.893

$^{**}p<.01$, $^{***}p<.001$

wear, such as the following: age-related weight gain, frequently wearing footwear for prolonged periods due to work attire requirements, the shape of the front of the footwear, and heel height, which can cause foot deformity and fatigue.

4) Evaluation of AR Virtual Fit Satisfaction

The AR virtual fitting satisfaction survey results presented in <Table 11>. As a result of conducting a chi square test on the feeling of wearing virtual footwear (fit) for each age group, no statistically significant difference was found with $\chi^2 = 0.272$. Three hundred consumers rated the survey items on AR virtual fit satisfaction by foot type on a 5-point Likert scale (where 1 = Very dissatisfied, 2 = Dissatisfied, 3 = Neutral, 4 = Satisfied, 5 = Very satisfied). Of the 300 respondents, 143 (47.7%) were 'satisfied', 94 (31.3%) were 'very satisfied', 39 (13.0%) were 'neutral', 20 (6.7%) were 'dissatisfied', and 4 (1.3%) were 'very dissatisfied'.

For those under 30, 113 people (37.7%) were 'satisfied', 75 people (25%) were 'very satisfied', 31 people (10.3%) were 'average', and 15 people were 'not satisfied' (5.0%). %), followed by 3 people (1.0%) who were 'very dissatisfied'. For those aged 30 or older, 30 people (10.0%) responded 'satisfied', 19 people (6.3%) responded 'very satisfied', and 8 people (2.7%) responded 'average'. Indicating that most respondents were satisfied with the outcome of their AR-based virtual fitting.

5) Foot Measurement App (v1.10) Measurement Test Results

In ISO 20685-1 (2018), the standard for the accuracy between the actual value and the 3D scanning value, the measurement of the foot length and width of the measured value obtained by using the 3D scanning system for each test item met the maximum average allowable difference of 2 mm. In addition, it met the tolerance ≤ ±1 mm range of the accuracy of the standard certification standards of the Korea information and communication technology association (TTA, 2023). As a result of the software test certification of the iOS foot measurement app (v1.10) by the Korea information and communication technology association (TTA, 2023), the accuracy of the foot measurement for the app measurement value and the actual foot measurement value was foot length 0.12 mm, and the foot width was X = 0.07 mm, indicating an error range of ≤ ±1 mm in the evaluation standard index of handmade shoe companies, and the instep height was X = 0.01 mm. Additionally, as a result of executing the virtual fitting function in the form of wearing footwear on the foot image, the X value was found to be 0.0 mm. Therefore, the reliability of the accuracy of the consumer's foot measurement was verified for the software foot measurement app used in this study. The Korea telecommunication technology association (TTA, 2023) test evaluation result table is shown in <Table 12>.

The big data calculation speed of the foot circumference length is X = 0.044928 seconds, and the time required to track the foot position is X = 0.00158 seconds. As a result of measuring the time required to adjust the shoe image 300 times during the virtual fitting function execution process, the time required to display the matching information with the shoe was X = 0.0011 seconds, these results showed that the time required was faster than the comparison level (standard) ≤ ±2 seconds (TTA, 2023).

And the results of the virtual fitting test of 300 photo images of the test target product showed that the average time taken to display the shoe image when executing the function was X = 0.00385 seconds, which was faster than the comparative level (standard) ≤ ±5 seconds (TTA, 2023).

Table 11. Satisfaction with virtual footwear using augmented reality (N=300)

Division	Age	Very dissatisfied	Dissatisfied	Neutral	Satisfied	Very satisfied	χ^2
		n (%)					
Virtual footwear with AR	Under 30s (n=237)	3(1.0)	15(5.0)	31(10.3)	113(37.7)	75(25.0)	0.272
	Over 30s (n=63)	1(0.3)	5(1.7)	8(2.7)	30(10.0)	19(6.3)	

Table 12. Foot size sample measurement results (N=100, unit: mm)

TC	Sample measurements value		Error value
	App value	Actual measured value	
	Mean (S.D.)	Mean (S.D.)	
TC1 (Foot length)	235.45(10.37)	235.57(10.40)	0.12
TC2 (Instep height)	65.72(3.91)	65.73(3.91)	0.01
TC3 (Foot width)	93.49(5.65)	93.42(5.70)	0.07

The average number of days to produce handmade footwear before software Shrub app (iOS foot measurement app v1.10), development was 8 days, and when the number of days shortened was measured and compared based on the average number of days, the production period was shortened by about 3 days. Shortening the time for making handmade footwear is a very important part of product competitiveness (reducing management costs and improving productivity).

According to the ES Shoes company survey, companies that make handmade footwear through the foot measurement technology by smartphones are still insignificant in domestic and overseas markets, so if the iOS foot measurement app (v1.10) is released, it is expected that the preoccupation and ripple effect of the handmade shoe market will be high.

2. Results of the Second Experiment and Survey Analysis

The second survey was based on data measured through the iOS foot measurement app (v1.10), creating customized handmade footwear and evaluating the feeling of wearing for 50 subjects.

1) Purchase of Custom-Handmade Footwear

<Table 13> shows the results of the multi-response survey on the advantages and disadvantages of custom-handmade footwear. We administered the survey to ascertain the reasons for which 50 people who

Table 13. Advantages and disadvantages of custom-handmade footwear (based on the results of a multi-response survey) (N=50, unit : %)

	Divisions	Frequency (%)
Advantages	Material (natural leather)	23(19.0)
	Customization	36(29.8)
	Custom sizing	26(21.5)
	Quality	20(16.5)
	Design	6(5.0)
	Customer service	9(7.4)
	Other	1(0.8)
	Total	121(100.0)
Disadvantages	Long production time	88(12.1)
	High price	19(28.8)
	Size incorrectly reflected	15(22.7)
	Uncomfortable fit	14(21.2)
	Design	9(13.6)
	Other	1(1.5)
	Total	146(100.0)

measured their foot size using a smartphone app (iOS foot measurement app v1.10) buy custom-handmade footwear. According to the results, the perceived advantages of custom-handmade footwear include the following: 'customization' (custom manufacturing service; 29.8%); 'custom sizing' (i.e., shoes made based on the customer's foot size; 21.5%); 'material (natural leather)' (19.0%); 'product quality' (16.5%). Disadvantages were 'high price' (i.e., more expensive than ready-made footwear; 28.8%), 'size incorrectly reflected' (22.7%), and 'uncomfortable fit' (21.2%).

2) Satisfaction Evaluation of Customized Handmade Footwear Size

As a result of satisfaction with the size of handmade custom footwear, the satisfaction with 'foot width and foot circumference' was answered as 'satisfied' with an average score of 3.84, and 'foot length' was answered as 'satisfied' with an average score of 3.82. The 'sole cushioning' of the shoes also had a high percentage of 'satisfied' responses with an average score of 3.86 (Table 14).

3) Evaluation of Custom-Handmade Footwear Fit Satisfaction by Foot Part

Wearing satisfaction of customized handmade footwear was conducted based on data measured through the smartphone foot measurement app. We surveyed 50 consumer evaluators and asked them to rate their fit satisfaction with the custom-handmade footwear provided to them based on their measurement data for each part of the foot. The results presented in <Table

Table 14. Custom-handmade footwear size satisfaction

Divisions	Very dissatisfied	Dissatisfied	Neutral	Satisfied	Very satisfied	Mean (S.D.)
	(n=50, %)					
Width and circumference of foot	0	2(4.0)	15(30.0)	22(44.0)	11(22.0)	3.84(0.82)
Length of foot	0	3(6.0)	13(26.0)	24(48.0)	10(20.0)	3.82(0.83)
Cushioning of sole	0	2(4.0)	13(26.0)	25(50.0)	10(20.0)	3.86(0.78)

Table 15. Custom-handmade footwear fit satisfaction by foot part

Foot part	Divisions	Very dissatisfied	Dissatisfied	Neutral	Satisfied	Very satisfied	Mean (S.D.)
		(n=50, %)					
Toes	Big toe	0	5(10.0)	11(22.0)	18(36.0)	16(32.0)	3.90(0.97)
	Index toe	0	0	8(16.0)	25(50.0)	17(34.0)	4.18(0.69)
	Middle toe	0	1(2.0)	4(8.0)	29(58.0)	16(32.0)	4.20(0.67)
	Ring toe	1(2.0)	1(2.0)	10(20.0)	24(48.0)	14(28.0)	3.98(0.87)
	Pinky toe	1(2.0)	4(8.0)	13(26.0)	18(36.0)	14(28.0)	3.80(1.01)
	Big toe bone protrusion	1(2.0)	6(12.0)	14(28.0)	16(32.0)	13(26.0)	3.68(1.06)
	Pinky toe bone protrusion	1(2.0)	1(2.0)	12(24.0)	20(40.0)	16(32.0)	3.98(0.91)
Side of the foot	Instep	0	8(16.0)	11(22.0)	14(28.0)	17(34.0)	3.80(1.09)
	Heel	0	2(4.0)	8(16.0)	19(38.0)	21(42.0)	4.18(0.85)
Plantar	Plantar front	0	2(4.0)	9(18.0)	20(40.0)	19(38.0)	4.12(0.85)
	Plantar side	0	3(6.0)	3(6.0)	27(54.0)	17(34.0)	4.16(0.79)
	Plantar middle	0	0	14(28.0)	19(38.0)	17(34.0)	4.06(0.79)
	Plantar heel	0	2(4.0)	8(16.0)	23(46.0)	17(34.0)	4.10(0.81)

15> show high fit satisfaction for every part of the foot, with a mean score above 3.68 points. First, the mean fit satisfaction scores for the index and middle toes were 4.18 and 4.20 points, respectively—both scores above 4.00—confirming the participants' high satisfaction level. The mean scores for the big, ring, and pinky toes were 3.90, 3.98, and 3.80 points, respectively, indicative of a high satisfaction level. Participants also reported high satisfaction with the fit around the big and pink toe bone protrusions, which had mean scores of 3.68 and 3.98 points, respectively. On the side of the foot, the mean scores for the instep and heel were 3.80 and 4.18 points, respectively, with the latter indicating that wearers were 'very satisfied'.

Regarding the various parts of the foot's plantar, the mean scores were above 4.00, indicating that wearers were "satisfied" with the fit around the front of the plantar (M = 4.12 points), the side of the plantar (M = 4.16 points), the middle of the plantar (M = 4.06 points), and the plantar heel (M = 4.10 points). Overall, participants showed high satisfaction with the fit around all parts of the foot while wearing custom-handmade footwear manufactured based on the foot size data captured using the smartphone app.

4) *Comparative Evaluation of Ready-Made versus Custom-Handmade Footwear Fit Satisfaction*

We conducted a t-test 190 subjects who wore ready-made footwear and 50 subjects who wore custom handmade footwear to determine whether there was a significant difference in fit satisfaction with the ready-made versus the custom-handmade footwear for each part of the foot. <Table 16> shows the results. Significant differences in fit satisfaction at the statistical level of p < .05 were found between the ready-made and custom-handmade footwear for all parts of the foot except the middle and ring toes. The fit satisfaction for the index toe was with a significant difference in fit satisfaction by age group (t = -2.575*), the big toe (t = -3.042**), the pinky toe (t = -5.328***), the big toe bone protrusion (t = -3.678***), and the pinky toe bone protrusion (t = -5.458***).

Regarding the side of the foot, the mean fit satisfaction score for the heel was 3.27 points among the participants aged under 30 years and 4.18 points among

Table 16. Comparison of ready-made and custom handmade footwear fit satisfaction by degree of comfort around each part of the foot

Foot part	Divisions	Ready-made (n=190)	Handmade (n=50)	t-value
		Mean (S.D.)	Mean (S.D.)	
Toes	Big toe	3.39(1.28)	3.90(0.97)	-3.042**
	Index toe	3.85(1.12)	4.18(0.69)	-2.575*
	Middle toe	4.16(0.88)	4.20(0.67)	-0.323
	Ring toe	4.06(1.03)	3.98(0.87)	0.523
	Pinky toe	2.88(1.34)	3.80(1.01)	-5.328***
	Big toe bone protrusion	3.02(1.39)	3.68(1.06)	-3.678***
	Pinky toe bone protrusion	3.08(1.39)	3.98(0.91)	-5.458***
Foot side	Instep	3.52(1.31)	3.80(1.09)	-1.543
	Heel	3.27(1.36)	4.18(0.85)	-5.870***
Plantar	Front part of the plantar	2.94(1.28)	4.12(0.85)	-7.800***
	Outside of the plantar	3.62(1.12)	4.16(0.79)	-3.934***
	Middle part of the plantar	3.43(1.27)	4.06(0.79)	-4.373***
	Plantar heel part	3.39(1.26)	4.10(0.81)	-4.792***

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

those aged 30 years or more, with a significant difference between the age groups (t = -5.870***).

Regarding the plantar area of the foot, fit satisfaction with the ready-made versus custom-handmade footwear showed significant differences at the statistical level of $p < .001$. Specifically, significant fit satisfaction differences were found for the front of the plantar (t = -7.800***), the side of the plantar (t = -3.934***), the middle of the plantar (t = -4.373***), and the heel (t = -4.792***). As the results show, the research subjects' overall fit satisfaction with the customized handmade footwear was higher than that with the ready-made footwear, and their satisfaction with the former was particularly high regarding the fit around the front, outside, middle, and heel of the plantar.

IV. Conclusion

In this study, foot sizes, including foot length, ball foot length and instep height were measured through a smartphone foot measurement app (v1.10), and consumer wearing tests and evaluations were conducted on the virtual ignition (fit) function of augmented reality. In addition, a general survey on the purchase and wearing of ready-made footwear, and a consumer verification evaluation on the wearing feel of customized handmade footwear produced through a smartphone foot measurement app were conducted. The research results are as follows.

First, most respondents reported experiencing discomfort while wearing ready-made footwear, especially around the pinky toe and the big and pinky toe bone protrusions. Fit satisfaction was low for the front of the plantar, likely because the wearer's body weight exerts more pressure on the forefoot than on other areas of the foot. To minimize this, people are advised to wear comfortable footwear with reinforced cushioning to distribute the pressure evenly. Generally, we found that the degree of discomfort people experienced around each part of the foot increased with age.

Second, in the execution of virtual ignition function applications through augmented reality (AR) in the form of wearing footwear on foot images, the scan foot model accuracy X value was highly evaluated as 0.0 mm. This finding reflects the understanding that AR technology can increase productivity and efficiency through simulated interactions between the real and virtual worlds based on real-world information

Third, the participants' fit satisfaction with the custom-handmade footwear manufactured for them based on the foot measurement data the iOS foot measurement app (v1.10) captured was higher than their satisfaction with the fit of the ready-made footwear. Participants expressed high custom-handmade footwear fit satisfaction for the areas around the pinky toe and the big and pinky toe bone protrusions—areas where their ready-made footwear fit satisfaction was low. A comparison of the ready-made and custom-handmade footwear revealed a significant difference in fit satisfaction at the statistical level of $p < .05$.

This study presents an approach to deriving a consumer's foot size by taking pictures from the top and side of the foot using a smartphone equipped with a camera, allowing consumers to use the ordering system function of the smartphone app without having to visit the shoemaker in person. It is significant in that it allows consumers to directly order customized handmade footwear in real time. In addition, the measured value of the iOS foot measurement app (v1.10) and the actual measured value were 0.12 mm in the foot length, 0.07 mm in the foot width, and 0.01 mm in instep height. This met both the 2 mm tolerance standard suggested by ISO 20685-1 (2018) and the ≤±1 mm tolerance standard suggested by the Korea information and communication technology association. The speed of big data on foot circumference and length, the time required for foot recognition, and the average time required for the footwear image to be adjusted to fit the foot were found to be faster than the standard of ≤ ±2 seconds the foot measurement app standard test results. In addition, it was confirmed that the average time required to display footwear images during virtual fitting was faster than the basic standard of ≤±5 seconds.

Therefore, if the on-tact ordering system app (iOS foot measurement v1.10) technology is commercialized, it is expected that handmade footwear companies will be able to establish a strategy for quick delivery and commercialization by customizing foot shape and size confirmation by costs savings due to the elimination of the reducing last (foot types) production through fit correction, shortening the process through an online order production system, and reducing footwear production time.

This study's findings are considerably significant for all stakeholders in the footwear industry. Our research has established that consumers can order custom-handmade footwear directly in real-time using an AR-based smartphone app without having to visit a shoemaker in person. The commercialization of this on-tact(non-face-to-face) custom-handmade footwear ordering app technology will create a new sales platform for custom-handmade footwear companies, secure the domestic and international custom-handmade footwear markets, and produce a strongly synergistic effect. Furthermore, this technology will allow even consumers with foot diseased, peculiar foot shape characteristics to place non-face- to-face (i.e., online) orders for custom footwear. The limitation of this study is that most of the subjects surveyed were young people, thus generalize and apply the results of this study, verification should be done by subdividing the subjects by age group. To further the development of on-tact custom-handmade footwear ordering apps, future studies should verify our findings across more age groups and people with variations foot, and it is various foot measurement app technologies should be conducted continuously.

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2. Ethics and consent

Not applicable.

3. Availability of data and materials

Not applicable.

4. Conflicting interests

Not applicable

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6. Authors' contributions

JL was responsible for research design, data collection, data analysis, and manuscript writing. JK was responsible for research design, data collection, data analysis. HL was responsible for and involved in the overall management of the study. All authors discussed the results and contributed to the final manuscript.

7. Authors' information

Jongkyu Lee

Dept. of Clothing & Textiles, Sookmyung Women's University, Lecturer

Jieun Kim

Dept. of Clothing & Textiles, Sookmyung Women's University, Graduate Student

Hosun Lim

Dept. of Clothing & Textiles, Sookmyung Women's University, Professor

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