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RESEARCH ARTICLE

Comfort of smartwatch wearing: A comparative study of different hand types

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ABSTRACT

This study aims to explore the relationship between wrist size and the comfort and fit of smartwatch wearability. Measurements of hand dimensions, including wrist width, palm length, finger length, and finger width, were taken from 41 participants. Based on the analysis results, participants were grouped by wrist width, and individuals from different groups were asked to subjectively rate the comfort, strap fit, and ease of operation of the smartwatch. The results revealed that wrist width significantly impacts wearing comfort, while other hand features (such as finger width) play a crucial role in the operational experience. Users with wider wrists rated strap fit and wearing pressure more favorably, whereas those with narrower wrists demonstrated superior touchscreen operation performance. Additionally, the significant effects of design factors such as strap material, dial size, and smartwatch weight on wearing experience were also validated. These findings provide valuable insights for smartwatch design, highlighting the necessity of considering variations in hand dimensions to enhance the overall user experience.

Keywords: smartwatch; wearable devices; hand dimensions; ergonomics

1. Introduction

Wearable devices refer to electronic products designed with advanced technology that can be worn directly on the user's body[1]. The origins of wearable devices can be traced back to the 1960s, when research focused on designing computing devices in a wearable form. With technological advancements, modern wearable devices have become diverse and indispensable in daily life. Among them, the smartwatch has emerged as a popular wearable device, allowing individuals to monitor their health from their wrist and improve their well-being based on feedback data[2]. Smartwatches are versatile, networked computing devices primarily serving as extensions of smartphones. They support the monitoring of physical activities and other health-related parameters such as heart rate, blood oxygen saturation, energy expenditure, and sleep quality. Through a series of sensors, smartwatches can provide timely notifications to users[3]. Additionally, modern smartwatches are often equipped with touchscreens, enabling interaction with applications[4], offering more functions than other wearable devices[5]. This convenience greatly enhances users' daily lives, making smartwatches one of the most popular products on the market.

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With the widespread adoption of wearable devices, the ergonomic aspects of their design have increasingly garnered academic attention. Shao Yuguang[6] developed an assistive design platform for head-worn products, providing designers with standardized head measurements and the relationships between head-worn products and head dimensions. This platform aids in evaluating and improving the fit and comfort of head-worn devices. Similarly, Li Xinyi et al.[7], based on anthropometric data of the head and ears, used cluster and percentile analyses to improve the comfort of headbands and ear cushions on headphones. These studies underscore the critical role of human dimensions in wearable device compatibility and design.Research by Hsiao and Chen[8], as well as Dehghani et al.[9], has explored the design aesthetics of smartwatches. Their findings confirm that dimensions, shape, and uniqueness significantly influence purchasing decisions and continued use intentions. As a device that comes into direct contact with the skin, smartwatch wearing comfort is also closely tied to its fit. Although most smartwatches come equipped with adjustable straps theoretically capable of accommodating various wrist sizes, factors such as dial size, device weight, strap tightness, and overall fit can still affect wearers' comfort. While these issues may not lead to severe conditions like tenosynovitis caused by poor design[10], they can significantly impact the frequency and duration of device use[11].

This study aims to investigate the relationship between hand dimensions and smartwatch wearing comfort. By measuring the wrist width and other hand dimensions of 41 participants, subjects were grouped based on wrist width. and incorporated a Likert scale survey to assess the wearing experiences of different participants (those who had previously worn multiple smartwatches and those who had only worn one). Through a quantitative analysis of factors such as wearing comfort, ease of operation, and stability, the study examines the effects of different hand characteristics on subjective perceptions of wearing a smartwatch. The findings not only highlight the importance of wrist width as a representative hand characteristic but also explore how hand dimensions influence smartwatch usability and comfort.

2. Methodology

2.1. Research procedure

As shown in **Figure 1**, the study began with participant recruitment and data collection. A total of 41 postgraduate students aged between 22 and 28 were selected as research subjects, including 25 females and 16 males. All participants were right-handed and wore smartwatches regularly in their daily lives. Hand dimensions were measured using standardized methods, recorded on graph paper, and supplemented by photographs to aid in statistical analysis. The collected hand data included wrist width, hand length, hand width, and the length and width of each finger for both hands, ensuring consistency in the measurement environment and tools to minimize errors.After data collection, IBM SPSS Statistics 26 software was used to perform descriptive statistics, normality tests, and correlation analyses to explore the relationship between wrist width and other hand characteristics. Based on the analysis results, hand features that were significantly correlated with wrist width were selected for grouping, aiming to investigate the potential influence of different wrist sizes on the smartwatch wearing experience.

First, the participants were divided into two groups: the first group consisted of individuals who had previously worn multiple smartwatches, while the second group included those who had only worn one smartwatch. Each group was further categorized based on wrist width, and subjective experiences of wearing smartwatches were collected using a Likert five-point scale questionnaire.The questionnaire included questions on the frequency of smartwatch use, duration of wear, strap tightness, operational sensitivity, and overall comfort. To ensure the scientific rigor of the questionnaire, reliability and validity tests were conducted, and a pilot test was performed to adjust the content as needed. After data collection, SPSS was used for descriptive statistics and significance testing to analyze differences in smartwatch wearing experiences among the groups. Based on the findings, recommendations for improving smartwatch design were proposed, offering theoretical support for personalized design and addressing market needs.

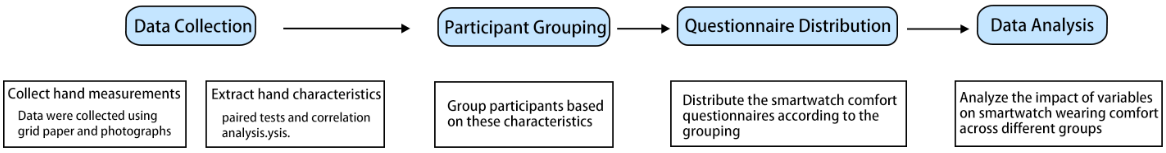

Figure 1. Research procedure flowchart.

2.2. Preliminary data collection and analysis

2.2.1. Hand data collection

Hand data were collected by photographing the participants' hands, as illustrated in **Figure 2**. The setup for the data collection environment is as follows: A 25 × 35 cm grid paper made up of 1 × 1 mm squares was affixed at a height of 125 cm from the ground. This height was determined based on the 50th percentile of shoulder height for males and females aged 18 to 70 years, as referenced in the "Chinese Adult Body Dimensions"[12]. The camera was positioned one meter away from the grid paper, ensuring that the camera height was level with the center point of the grid to minimize angle errors. Camera parameters (such as resolution, focus mode, aperture, etc.) were preset and calibrated to ensure that the captured images were clear and the scale was accurate. During data collection, participants were instructed to stand beside the grid paper, with their upper arm and forearm forming an approximate 90° angle, allowing their hands to relax and fingers to extend naturally[13]. To ensure comprehensive data collection, both the front and back of each hand were photographed. All images were taken under consistent lighting conditions to avoid shadows or reflections that could affect the accuracy of the measurements.

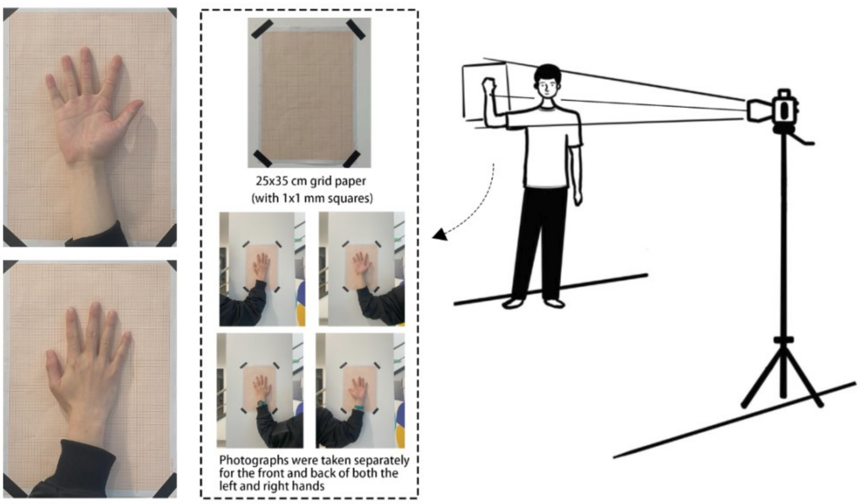

Figure 2. Hand data collection image.

After the photographs were taken, they were imported into a computer for post-processing. According to the measurement requirements outlined in the document "Classification of Hand Dimensions in Chinese Adults"[14],Computer-Aided Design (CAD) software was used to precisely annotate the hand contours, as shown in **Figure 3**. This process involved measuring various parameters of the hands, including wrist width, hand length, hand width, palm length, and the length and width of each finger for both hands.Subsequently, Adobe Photoshop was utilized for image processing and calibration to ensure the accuracy and repeatability of the data. The entire annotation process for hand data was carried out by trained technicians to guarantee precision and consistency in the markings. This method of hand data collection, through a standardized photographic procedure and accurate image processing techniques, ensured high precision and consistency of the data required for the study, providing a reliable foundation for subsequent statistical analyses[15].

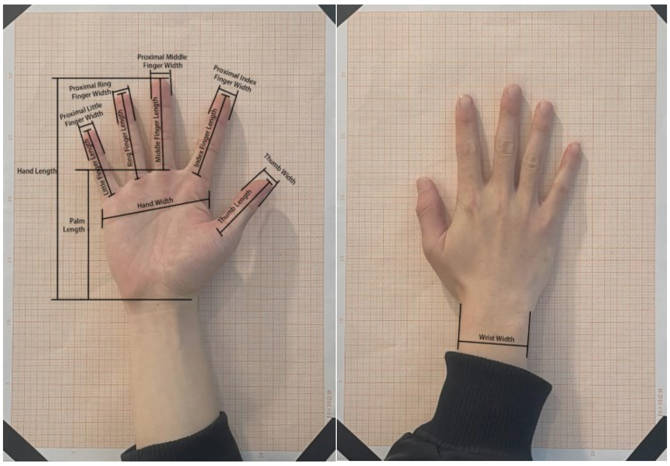

Figure 3. Annotation of hand dimension measurement items (same for left hand).

The measurements of hand dimensions for both hands were initially organized using Excel, with detailed descriptive statistical analyses presented in **Table 1**. The descriptive statistics included the mean, standard deviation, maximum value, minimum value, and median. Additionally, to further assess the distribution properties of the data, particularly to test for normality, the Shapiro-Wilk test was employed on the measurement data of both hands. The null hypothesis (H0) of the Shapiro-Wilk test posits that the data follow a normal distribution, while the alternative hypothesis (H1) posits that the data do not follow a normal distribution.

The test results are summarized in **Table 1**. For the measurements of hand length, wrist width, palm length, thumb length, index finger length, middle finger length, ring finger length, and little finger length, the p-values were all greater than 0.05, indicating that we failed to reject the null hypothesis (H0). This suggests that these variables can be considered as following a normal distribution. However, for other hand measurements, the p-values were less than 0.05, leading to the rejection of the null hypothesis (H0), indicating that these variables do not conform to the assumption of normal distribution.

Table 1. Statistical analysis of left and right hand measurements (mm).

Measurement Items	**Right or Left**	**Mean**	**SD**	**Max**	**Min**	**Mdn**	**Shapiro-Wilk Test**	
							***W* value**	***p* value**
Age (years)		24.68	1.23	28.00	22.00	25.00	0.94	0.03
Hand Length	R	174.13	11.50	211.50	151.00	174.00	0.96	0.22*
	L	173.47	11.34	210.90	150.90	174.10	0.96	0.12*
Hand Width	R	76.66	5.76	90.30	68.00	74.70	0.93	0.02
	L	76.00	5.17	87.20	68.80	74.60	0.92	0.01
Wrist Width	R	52.71	4.13	64.50	43.80	52.00	0.97	0.23*
	L	52.98	4.28	63.90	43.70	52.10	0.98	0.65*

Table 1. (*Continued*).

Measurement Items	Right or Left	Mean	SD	Max	Min	Mdn	Shapiro-Wilk Test	
							W value	*p* value
Palm Length	R	98.27	6.74	119.29	85.20	97.55	0.97	0.33*
	L	97.91	6.65	118.97	85.15	97.61	0.96	0.19*
Thumb Length	R	57.34	3.69	69.26	49.98	57.22	0.97	0.24*
	L	57.13	3.64	69.07	49.95	57.25	0.96	0.13*
Index Finger Length	R	68.79	4.12	82.73	60.07	68.66	0.95	0.10*
	L	68.52	4.07	82.49	60.03	68.09	0.95	0.08*
Middle Finger Length	R	76.19	4.85	92.56	66.11	75.87	0.96	0.11*
	L	75.89	4.79	92.28	66.07	75.69	0.95	0.08*
Ring Finger Length	R	71.90	4.59	87.22	62.43	71.80	0.96	0.13*
	L	71.62	4.53	86.97	62.38	71.63	0.95	0.09*
Little Finger Length	R	56.07	3.82	68.39	48.17	56.17	0.97	0.25*
	L	55.84	3.77	68.19	48.13	56.21	0.96	0.16*
Thumb Width	R	20.12	1.32	22.71	18.31	19.61	0.91	0.00
	L	20.03	1.27	22.33	18.43	19.51	0.89	0.00
Proximal Index Finger Width	R	18.53	1.02	20.67	17.11	18.20	0.92	0.01
	L	18.45	0.96	20.31	17.21	18.11	0.91	0.00
Proximal Middle Finger Width	R	17.95	1.02	20.10	16.50	17.66	0.93	0.01
	L	17.87	0.96	19.73	16.61	17.57	0.91	0.00
Proximal Ring Finger Width	R	16.86	1.02	19.02	15.46	16.52	0.91	0.01
	L	16.78	0.96	18.66	15.55	16.43	0.90	0.00
Proximal Little Finger Width	R	15.29	0.95	17.30	14.00	14.96	0.91	0.00
	L	15.22	0.90	16.97	14.08	14.88	0.90	0.00

* indicates normally distributed data based on the Shapiro-Wilk test

2.2.2. Hand data analysis

Due to the inclusion of different dominant hand groups and varying preferences for wearing smartwatches during the questionnaire collection, it is crucial to conduct a detailed analysis of the collected hand data to determine the hand type criteria for grouping in the questionnaire.First, paired sample t-tests and Wilcoxon signed-rank tests were employed to analyze whether there were significant differences in hand dimensions between the left and right hands. For the hand measurements that followed a normal distribution, such as hand length, wrist width, and palm length, paired sample t-tests were used for analysis. In contrast, the Wilcoxon signed-rank test was applied to data that did not meet the normal distribution assumption. As shown in **Table 2**, the results indicated significant differences in various hand dimensions between the left and right hands, except for wrist width.

This analysis reveals that although there is no significant difference in wrist width between the two hands, other hand dimensions (such as hand length and finger length) exhibit statistically significant asymmetry[16]. Given that all 41 participants in this study are right-handed, the test results (p-values and z-values) indicate that the hand dimensions for the right hand are generally larger than those for the left hand. While these differences are small, they reflect the asymmetry of the hands, which appears to be a common population characteristic.This phenomenon aligns with findings from Barut et al.[17] and Idenya et al.[18], who observed significant left-right differences in hand width, shape index, and palm length/width measurements in their studies ($p < 0.001$). Moreover, our results also demonstrated significant differences in hand width measurements, such as thumb width, index finger width, and ring finger width (p-values approaching those reported in other studies). Kumar et al.[19] similarly reported that right-handed individuals tend to have greater hand width on the dominant side compared to the non-dominant side, suggesting that the preferred hand inevitably has a strong influence on hand length, hand width, and shape index. These studies provide robust theoretical support for the analysis of hand data in this research, laying the groundwork for establishing grouping criteria and offering important references for exploring the potential relationship between hand dimensions and smartwatch wearing comfort.

Table 2. Paired sample test for each part of the left and right hands.

Item	Paired Sample *t*-test		Wilcoxon Signed-Rank Test	
	p	***t***	***p***	***z***
R & L Hand Length	0.002**	3.363		
R & L Wrist Width	0.189	−1.336		
R & L Palm Length	0.002**	3.369		
R & L Thumb Length	0.002**	3.338		
R & L Index Finger Length	0.002**	3.367		
R & L Middle Finger Length	0.002**	3.371		
R & L Ring Finger Length	0.002**	3.363		
R & L Little Finger Length	0.002**	3.405		
L & R Hand Width			0.000***	−3.787
L & R Thumb Width			0.000***	−3.740
L & R Proximal Index Finger Width			0.000***	−3.779
L & R Proximal Middle Finger Width			0.000***	−3.753
L & R Proximal Ring Finger Width			0.000***	−3.779
L & R Proximal Little Finger Width			0.000***	−3.779

**: $p < 0.01$ (highly significant); ***: $p < 0.001$ (extremely significant). Abbreviation explanations: “R” = Right, “L” = Left, “&” = and.

Since no significant statistical difference was observed between the wrist widths of the left and right hands, wrist width can be used as a grouping criterion. However, to further explore the relationship between wrist width and other hand dimensions, this study employed Pearson correlation analysis for normally distributed data and Spearman correlation analysis for non-normally distributed data. As shown in **Table 3**, the analysis results indicate that wrist width is significantly positively correlated with multiple hand dimensions, including hand length, hand width, and finger lengths for both hands. This suggests that wrist size can, to some extent, reflect the size of other hand features. This finding provides a solid theoretical basis for subsequent grouping, indicating that grouping by wrist width not only simplifies the data processing but also effectively represents the differences in overall hand size.

Table 3. Correlation analysis between wrist width and various parts of the hand.

Item	Right Wrist Width and Right Hand Parts				Left Wrist Width and Left Hand Parts			
	Pearson Correlation Analysis		Spearman Correlation Analysis		Pearson Correlation Analysis		Spearman Correlation Analysis	
	r	*p*	*ρ*	*p*	*r*	*p*	*ρ*	*p*
Hand Length	0.874	0.000***			0.816	0.000***		
Hand Width			0.815	0.000***			0.833	0.000***
Palm Length	0.873	0.000***			0.823	0.000***		
Thumb Length	0.874	0.000***			0.818	0.000***		
Index Finger Length	0.858	0.000***			0.789	0.000***		
Middle Finger Length	0.865	0.000***			0.799	0.000***		
Ring Finger Length	0.868	0.000***			0.804	0.000***		
Little Finger Length	0.872	0.000***			0.814	0.000***		
Thumb Width			0.823	0.000***			0.831	0.000***
Proximal Index Finger Width			0.824	0.000***			0.835	0.000***
Proximal Middle Finger Width			0.827	0.000***			0.838	0.000***
Proximal Ring Finger Width			0.824	0.000***			0.835	0.000***
Proximal Little Finger Width			0.825	0.000***			0.834	0.000***

***: $p < 0.001$ (extremely significant).

2.3. Questionnaire design

With the continuous expansion of the smartwatch market, major brands are demonstrating increasingly diverse design trends. Based on the representativeness and influence within the smartwatch market, this study selected four brands—Apple, HUAWEI, Samsung (Galaxy), and Xiaomi—as the subjects of investigation. As shown in **Table 4**, the design of smartwatch screens has evolved from a single-size approach to offering multiple sizes and shapes (square and round screens). In related research, Kim[20] pointed out that compared to square screens, round screens are more effective in enhancing device pleasantness, further promoting user acceptance and usage of smartwatches. This trend indicates that smartwatch manufacturers are placing greater emphasis on meeting users' personalized needs. Moreover, the weight of smartwatches across various brands has also been continuously optimized. Notably, the latest Apple Watch Series 10 and HUAWEI Watch Series 4 are lighter than their predecessors, despite featuring larger screen sizes. The materials used for smartwatch bands include nylon, silicone, titanium alloy, leather, fluoroelastomer, and carbon fiber. This variety of material choices reflects adaptability to different application scenarios, such as sports, business, and daily use.

The questionnaire in this study was designed to focus on participants' comfort, fit, and usability when wearing smartwatches, aiming to explore the potential impact of hand dimensions on wearing experience. The survey required users to provide feedback solely based on their wearing experience (e.g., weight, stability, tactile sensation) without evaluating the watch's appearance or design style. Furthermore, no images of smartwatches were included in the questionnaire to prevent participants' assessments of comfort from being influenced by factors such as style, color, or appearance.

Table 4. Survey on basic information of different smartwatch brands.

	Apple Watch Series	**HUAWEI Watch Series**	**Galaxy Watch**	**Xiaomi Watch Series**
Dial Shape	Square Screen	Round Screen	Round Screen	Round Screen
Dial Size	1: 38 mm and 42 mm 2 and 3: 38 mm and 42 mm 4–6: 40 mm and 44 mm 7–9: 41 mm and 45 mm 10: 42 mm and 46 mm	1: 42 mm 2: 45 mm 3: 46 mm 4: 46.2 mm	1: 41.7 mm 2: 46 mm 3: 41 mm and 45 mm 4 and 5: 40 mm and 44 mm 6: 44 mm 7: 40 mm and 44 mm	1: 46.5 mm 2: 42 mm and 46 mm 3: 46.5 mm 4: 47.3 mm
Watch Weight	1: 25 g and 30g 2: 28.2 g and 52.4 g 3: 26.7 g and 52.8 g 4: 30.1 g and 47.9 g 5: 30.8 g and 46.7 g 6: 30.5 g and 47.1 g 7: 32 g and 51.5 g 8 and 9:31.9 g and 51.5 g 10:34.2 g and 41.7g	1: 46 g 2: 57 g 3: 54 g 4: 48 g	1:49 g 2: 63 g 3: 43 g and 53.8 g 4: 25.9 g and 30.3 g 5: 28.7 g and 33.5g 6: 33.3 g 7: 28.8 g and 33.8 g	1: 36.3 g 2: 39.9 g and 46.5 g 3: 44 g 4: 44.5 g
Strap Material	Nylon Material, Silicone, Titanium	Titanium Material, Genuine leather, Nylon, Fluoroelastomer	Genuine leather, Nylon, Leather, Carbon Fiber	Fluoroelastomer

The questionnaire comprised four modules with a total of 24 questions. The first module collected participants' demographic information, including gender, age, occupation, dominant hand, and the hand used for wearing the smartwatch. Participants were also required to measure their wrist width (either wrist was acceptable) to determine their group assignment. Based on the median and mean wrist widths from prior studies, wrist widths less than 5.3 cm were classified as Group A, while those greater than or equal to 5.3 cm were classified as Group B. The second module focused on wearing habits, with questions designed to investigate the frequency of daily smartwatch use, duration of each wearing session, and the brand and model of the smartwatch worn by the participants[21]. Referring to the relevant data in **Table 4**, the study selected sample models with similar screen sizes and weights for analysis, specifically: Apple Watch Series 8 (45 mm/51.5 g), HUAWEI Watch Series 3 (46 mm/54 g), Galaxy Watch 3 (45 mm/53.8 g), and Xiaomi Watch Series 2 (46 mm/46.5 g). All selected models used fluoroelastomer straps. The third module emphasized wearing comfort and fit, employing a five-point Likert scale for quantitative evaluation. Questions addressed factors such as wrist pressure, strap tightness, the impact of sweating on smartwatch stability, and how the materials and weight of the smartwatch influenced the wearing experience. These questions aimed to capture participants' subjective perceptions in various wearing scenarios[22]. The fourth module examined the usability of smartwatches, focusing on participants' experiences with the functional operations of the devices. This included ease of touchscreen interaction, user-friendliness of the interface, and feedback from health monitoring features.

To ensure the scientific validity and effectiveness of the questionnaire, the research team initially conducted a small-scale pilot test. Using preliminary data, Cronbach's Alpha coefficient was employed to assess the internal consistency of the questionnaire, ensuring that the scale design had high reliability. Based on the pilot test results, the wording and response options for some questions were revised to enhance the readability and relevance of the final questionnaire. The final version was designed to incorporate user feedback from various dimensions, covering the three main aspects of comfort, fit, and usability, thus ensuring the reliability of subsequent statistical analyses and the representativeness of the data.

3. Results

The subjects of this survey were smartwatch users aged 18–35 years (mean age: 25.8 years), encompassing individuals of different genders, ages, occupations, and dominant hands. The demographic information of all participants is summarized in **Table 5**. Based on the survey data, participants were divided into two groups: the first group (control group) consisted of individuals who had previously used multiple smartwatches, while the second group included those who had only used one smartwatch. A total of 182 valid questionnaires were collected (95 from the first group and 87 from the second group). Additionally, participants in each group were further categorized based on wrist width to analyze differences in wearing comfort across groups and wrist width categories.

Table 5. Basic information for smartwatch wearing comfort questionnaire survey.

	Sample Category	Sample Size	Percentage
Gender	Male	86	47.25%
	Female	96	52.75%
	Other	0	0
Occupation	Students	53	29.12%
	Educational Professionals (e.g., professors, teachers of various grades, lecturers)	16	8.79%
	Medical Professionals (e.g., doctors, nurses, caregivers)	12	6.59%
	Service Industry Workers (e.g., restaurant servers, delivery personnel)	13	7.14%
	Office/Administrative Workers (e.g., white-collar employees, executives)	18	9.89%
	Technical/Engineering Professionals (e.g., repair technicians, programmers)	10	5.49%
	Manufacturing Workers	16	8.79%
	Sports Professionals (e.g., athletes, fitness coaches)	14	7.69%
	Freelancers	14	7.69%
	Unemployed	16	8.79%
Dominant Hand	Left Hand	65	35.71%
	Right Hand	117	64.29%
Hand Usually Wearing the Smartwatch	Left Wrist	71	39.01%
	Right Wrist	111	60.99%
Wrist Width Range	Less than 5.3 cm	112	61.54%
	Greater than or equal to 5.3 cm	70	38.46%
Brand and Model of the Watch Usually Worn	Apple Watch Series 8 (Square Dial)	56	30.77%
	HUAWEI Watch Series 3 (Round Dial)	32	17.58%
	Galaxy Watch 3 (Round Dial)	37	20.33%
	Xiaomi Watch Series 2 (Round Dial)	57	31.32%
How long have you been wearing this watch	Less than 1 month	26	14.29%
	1 to 3 months (excluding 3 months)	38	20.88%
	3 to 6 months (excluding 6 months)	60	32.97%
	6 to 12 months (excluding 12 months)	37	20.33%
	More than 1 year	21	11.54%

Table 5. (*Continued*).

	Sample Category	Sample Size	Percentage
Average Daily Wearing Duration	Less than 1 h	20	10.99%
	1 to 3 h (excluding 3 h)	28	15.38%
	3 to 6 h (excluding 6 h)	58	31.87%
	6 to 9 h (excluding 9 h)	53	29.12%
	More than 9 h	23	12.64%

Among individuals who had previously used multiple smartwatches, as shown in **Table 6**, wrist width was found to significantly affect certain indicators of smartwatch wearing comfort. Regarding the sensation of wearing pressure over prolonged use, Group A, with smaller wrist widths, reported significantly higher scores than Group B (Group A mean = 2.98, Group B mean = 2.36, p = 0.021), indicating a stronger perception of pressure. This suggests that for users with smaller wrists, smartwatch designs may not adequately address the distribution of wearing pressure, resulting in a diminished wearing experience.

Similarly, in terms of the impact of watch face size and smartwatch weight on wearing comfort, Group A also scored significantly higher than Group B. Smaller wrist widths may limit users' acceptance of larger watch faces and heavier watches, further influencing their overall evaluation of smartwatches. Additionally, there was a significant difference in strap material comfort (Group A mean = 2.93, Group B mean = 2.41, p = 0.027), with Group B expressing greater dissatisfaction, highlighting deficiencies in physical wearing comfort for users with larger wrist widths.

Notably, the differences in wearing stability were particularly significant. Whether in normal wearing conditions (Group A mean = 2.38, Group B mean = 3.10, p = 0.001) or after sweating (Group A mean = 2.32, Group B mean = 3.08, p = 0.001), Group A scored significantly lower than Group B. This indicates that users with smaller wrists generally found the smartwatch less secure to wear. For smartwatch design, improving wearing stability to accommodate a wider range of wrist sizes is a pressing challenge. Furthermore, Group B's lower ratings in touchscreen responsiveness (Group A mean = 3.00, Group B mean = 2.49, p = 0.015) also reflect the potential influence of wrist width, and consequently finger size, on interaction and operational experience.

Table 6. Analysis of Group A and Group B data for the first set of subjects.

Question	Group	Mean	SD	Wilcoxon Signed-Rank Test	
				p	***z***
Personal Subjective Comfort Level(1 = Very Uncomfortable, 5 = Very Comfortable)	A	2.93	1.08	0.635	−0.475
	B	2.90	0.94		
Personal Subjective Expectation Value(1 = No Expectation, 5 = Very High Expectation)	A	2.84	0.95	0.925	−0.094
	B	2.82	1.10		
Sense of Pressure During Long-Term Wear (1=None, 5=Very Uncomfortable)	A	2.98	1.00	0.021*	−2.315
	B	2.36	1.06		
Impact of Watch Weight (1 = No Impact, 5 = Very Impactful)	A	3.04	1.03	0.027*	−2.210
	B	2.31	1.00		
Impact of Dial Size (1 = No Impact, 5 = Very Impactful)	A	3.07	1.13	0.015*	−2.441
	B	2.41	0.94		

Table 6. (*Continued*).

Question	Group	Mean	SD	Wilcoxon Signed-Rank Test	
				p	*z*
Strap Fit (1 = Very Inappropriate, 5 = Very Appropriate)	A	3.00	0.87	0.057	−1.904
	B	2.69	0.95		
The Comfort of Strap Material(1 = Very Uncomfortable, 5 = Very Comfortable)	A	2.93	0.95	0.027*	−2.208
	B	2.41	0.88		
Stability of the Watch When Worn (1 = Very Unstable, 5 = Very Stable)	A	2.38	0.91	0.001**	−3.324
	B	3.10	0.99		
Stability of the Watch When Worn After Sweating (1 = Very Unstable, 5 = Very Stable)	A	2.32	0.79	0.001**	−3.332
	B	3.08	0.96		
Touchscreen Sensitivity (1 = Very Insensitive, 5 = Very Sensitive)	A	3.00	1.01	0.015*	−2.438
	B	2.49	0.94		
Fit of Buttons and Touchscreen Operations with Finger Width (1 = Very Inappropriate, 5 = Very Appropriate)	A	2.98	1.10	0.085	−1.723
	B	2.51	0.91		
Fit of Touchscreen Icons (1 = Very Inappropriate, 5 = Very Appropriate)	A	2.89	1.07	0.074	−1.787
	B	2.33	1.11		
Accuracy of Function Detection (1 = Very Inaccurate, 5 = Very Accurate)	A	2.93	1.08	0.889	−0.140
	B	2.90	0.82		
Overall Satisfaction (1 = Very Dissatisfied, 5 = Very Satisfied)	A	2.71	0.89	0.109	−1.604
	B	3.08	0.98		

*: $p < 0.05$(significant); **: $p < 0.01$ (highly significant). A: Individuals with a wrist width less than 5.3 cm, B: Individuals with a wrist width greater than or equal to 5.3 cm.

As shown in **Table 7**, among individuals who had only used one smartwatch, the impact of wrist width on wearing comfort was further validated. Regarding the influence of watch face size, Group A scored significantly higher than Group B (Group A mean = 3.21, Group B mean = 2.35, $p = 0.001$). This difference reinforces the observation that larger watch faces may cause more pronounced discomfort for users with smaller wrists. Similarly, the effect of smartwatch weight on comfort aligned with the findings from the first group.Furthermore, Group B again exhibited significant dissatisfaction with the comfort of strap materials (Group A mean = 3.04, Group B mean = 2.29, $p = 0.015$), suggesting that this issue is widespread. In terms of wearing stability, although the difference in normal wearing conditions was only marginally significant ($p = 0.066$), Group A's stability rating (mean = 2.82) was still lower than that of Group B (mean = 3.26).

Additionally, significant differences in touchscreen responsiveness (Group A mean = 2.98, Group B mean = 2.26, $p = 0.021$) and touchscreen icon compatibility (Group A mean = 3.05, Group B mean = 2.29, $p = 0.021$) indicate that users with smaller wrists tend to have higher satisfaction with touchscreen interaction. This may be attributed to better operational accessibility of the touchscreen area and a more harmonious proportion between finger size and the screen.

Table 7. Analysis of Group A and Group B data for the second set of subjects.

Question	Group	Mean	SD	Wilcoxon Signed-Rank Test	
				p	***z***
Personal Subjective Comfort Level(1 = Very Uncomfortable, 5 = Very Comfortable)	A	3.59	1.44	0.928	−0.090
	B	3.58	1.12		
Personal Subjective Expectation Value(1 = No Expectation, 5 = Very High Expectation)	A	2.95	1.23	0.709	−0.373
	B	2.97	1.11		
Sense of Pressure During Long-Term Wear (1=None, 5=Very Uncomfortable)	A	2.96	1.08	0.084	−1.727
	B	2.39	1.25		
Impact of Watch Weight (1 = No Impact, 5 = Very Impactful)	A	3.13	1.06	0.029*	−2.178
	B	2.35	1.08		
Impact of Dial Size (1 = No Impact, 5 = Very Impactful)	A	3.21	1.00	0.001**	−3.447
	B	2.35	0.84		
Strap Fit (1 = Very Inappropriate, 5 = Very Appropriate)	A	2.63	1.04	0.018*	−2.369
	B	3.13	0.85		
The Comfort of Strap Material(1 = Very Uncomfortable, 5 = Very Comfortable)	A	3.04	1.11	0.015*	−2.435
	B	2.29	0.94		
Stability of the Watch When Worn (1 = Very Unstable, 5 = Very Stable)	A	2.82	1.01	0.066	−1.840
	B	3.26	1.15		
Stability of the Watch When Worn After Sweating (1 = Very Unstable, 5 = Very Stable)	A	2.93	0.97	0.732	−0.343
	B	3.10	1.01		
Touchscreen Sensitivity (1 = Very Insensitive, 5 = Very Sensitive)	A	2.98	1.09	0.021*	−2.308
	B	2.26	0.96		
Fit of Buttons and Touchscreen Operations with Finger Width (1 = Very Inappropriate, 5 = Very Appropriate)	A	3.04	1.09	0.019*	−2.355
	B	2.19	1.14		
Fit of Touchscreen Icons (1 = Very Inappropriate, 5 = Very Appropriate)	A	3.05	1.05	0.021*	−2.312
	B	2.29	1.04		
Accuracy of Function Detection (1 = Very Inaccurate, 5 = Very Accurate)	A	3.09	1.03	0.065	−1.842
	B	2.55	0.99		
Overall Satisfaction (1 = Very Dissatisfied, 5 = Very Satisfied)	A	2.96	0.97	0.674	−0.420
	B	3.19	0.91		

*: $p < 0.05$(significant); **: $p < 0.01$ (highly significant). A: Individuals with a wrist width less than 5.3 cm, B: Individuals with a wrist width greater than or equal to 5.3 cm.

A comparison of the two groups' data reveals that wrist width significantly and consistently affects both the physical comfort and interactive compatibility of smartwatches. Group A, with smaller wrists, scored significantly higher than Group B on multiple indicators, particularly in wearing pressure sensation, the impact of watch face size, smartwatch weight, and wearing stability.

As shown in **Figure 4** (left), the median scores for watch weight in both groups were significantly higher for Group A than for Group B, with Group A displaying a broader score distribution that included more high scores. This indicates that users with smaller wrists are more sensitive to the negative impact of smartwatch weight on wearing comfort. Similarly, for watch face size, **Figure 4** (middle) shows that the median scores in Group A were also higher than those in Group B. This suggests that users with smaller wrists are more likely to perceive watch face size as having a substantial impact on wearing comfort. In contrast, Group B exhibited lower median scores and a more concentrated distribution, reflecting a weaker perception of this factor's influence among users with larger wrists. These findings indicate that current smartwatch designs are more suitable for users with larger wrists, while those with smaller wrists may experience significant discomfort during use.

In addition, Group A's notable advantage in touchscreen responsiveness and touchscreen icon compatibility highlights that users with smaller wrists also report higher satisfaction with the interactive experience. As shown in **Figure 4** (right), the median scores for Group A in both categories were higher than those for Group B, with Group A's score range being broader and including more high scores. This suggests that users with smaller wrists tend to perceive smartwatch touchscreen operations as more responsive. On the other hand, Group B exhibited a more concentrated score distribution with a smaller interquartile range, indicating a more consistent subjective perception of touchscreen responsiveness among users with larger wrists.

Overall, these findings emphasize the importance of wrist width as a critical variable in smartwatch design. Future designs should focus on optimizing watch face size, strap material, and wearing stability for users with larger wrists, while also improving the adaptability of touchscreen operations. These improvements could ensure broader user coverage and enhanced wearing comfort.

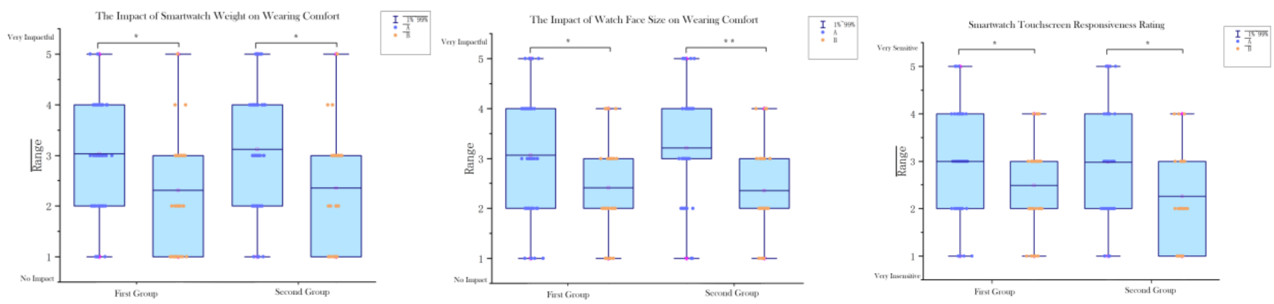

Figure 4. Comparison of Data Between Group 1 and Group 2.

4. Discussion

This study focuses on the issue of smartwatch wearing comfort by conducting a comparative analysis of subjective experience data between two groups: individuals who have used multiple smartwatches (Group 1) and those who have only used one smartwatch (Group 2). Each group was further divided based on wrist width into smaller-wrist users (Group A, wrist width < 5.3 cm) and larger-wrist users (Group B, wrist width ⩾ 5.3 cm). The analysis explored the impact of physical design features of smartwatches (e.g., weight, watch face size, strap design) on wearing comfort, with a detailed discussion on subjective comfort levels and personal expectations.The results indicated no significant differences in subjective comfort and personal expectation levels between the two groups. This suggests that users with different wrist widths perceive overall comfort and personal expectations similarly when using smartwatches. These findings indicate that the physical characteristics of smartwatches, rather than subjective psychological factors, primarily determine users' comfort perception, and these perceptions do not interfere with the conclusions of the study.

Design aesthetics should serve as a guiding principle in smartwatch development. According to Choi and Kim[23], smartwatches are perceived as fashion products, and companies and developers should emphasize design attributes such as shape, size, and weight[24]. In terms of specific design dimensions, this study identified significant impacts of smartwatch weight and watch face size on wearing comfort. Users with smaller wrists were found to be more sensitive to watch weight, likely due to its more pronounced effects on wrist muscle strain and fatigue. Similarly, the impact of watch face size showed notable differences, with smaller-wrist users perceiving large watch faces as inconvenient for wear. These findings highlight the importance of lightweight design and adaptability optimization for smaller-wrist users while indicating that users with larger wrists are better able to accommodate larger watch faces and weights. This may result from more even weight distribution across their wrists, reducing discomfort[25]. Notably, factors related to watch straps, such as fit and material comfort, also exhibited significant differences between the groups. Smaller-wrist users expressed dissatisfaction with strap fit, potentially due to concentrated pressure and inadequate fixation[25], whereas larger-wrist users rated strap material comfort lower. As comfort is a critical factor influencing the adoption of wearable devices[26], strap design should prioritize more flexible adjustment mechanisms and softer materials to enhance both comfort and stability. Moreover, stability and sweat resistance during wear significantly affect overall satisfaction. Data analysis revealed that users with larger wrists perceived the watch as more stable during wear, including under sweaty conditions. This finding underscores the need for optimized wrist-to-watch contact shapes in smartwatch design. Integrating anatomical features of the wrist and ergonomic principles[27] can ensure better wrist conformity. Additionally, innovations in sweat-resistant materials can further improve comfort and adaptability, enhancing the overall user experience.

The current design trends in smartwatches indicate that lightweight construction, diversification, and functional integration are becoming pivotal directions for industry development[28]. These trends align with the findings of this study, which highlight users' high sensitivity to weight and watch face size. With advancements in chip, sensor, and battery technologies, lightweight design has become a central approach to enhancing wearing comfort, particularly for users with smaller wrists, as increased weight can significantly diminish their wearing experience. Meanwhile, diversified watch face designs can cater to a broader range of wrist sizes, especially in segments with a higher proportion of female users. Furthermore, the study reveals that operational responsiveness is a crucial factor affecting smartwatch wearing comfort. Users with larger wrists have higher expectations for touchscreen usability, which correlates with the market's focus on functional integration and convenience. As smartwatches evolve into multifunctional devices encompassing health monitoring, mobile payments, and communication, a design that offers clear information display, intuitive interfaces, and user-friendly operation is essential for achieving higher user satisfaction[29]. Consequently, optimizing operating system interfaces and improving touchscreen technology are critical for enhancing the overall user experience.

User satisfaction has been proven to have a significant impact on the intention to continue using smartwatches[30], further underscoring the critical importance of aligning design with user needs to enhance product competitiveness. Simultaneously, trends in smartwatch design reflect a deep integration with user requirements. From a market perspective, the drive for lightweight design is not only fueled by technological advancements but also by a focus on the comfort of long-term wearers. Additionally, diverse material and aesthetic designs demonstrate manufacturers' understanding of personalized preferences and market segmentation. These trends not only highlight the market's responsiveness to user demands but also provide concrete directions for product optimization. The findings of this study align with these trends. For instance, user feedback on strap material and breathability emphasizes the pivotal role of material selection in ensuring wearing comfort. Furthermore, it illustrates how design details can influence the overall user experience, supporting the continuous improvement of smartwatches in both functionality and comfort.

Finally, it is important to note that this study primarily sampled young adults aged 18–35, which may limit the generalizability of the findings. Additionally, the annual design updates, market trends, and technological advancements in smartwatches may pose potential challenges to the applicability of the conclusions. Future research could focus on the comprehensive impact of diverse user groups and novel design factors on wearing comfort. By aligning with industry trends, such studies could explore new directions for optimizing smartwatch design. This would provide more comprehensive theoretical support for enhancing user satisfaction and product competitiveness.

5. Conclusion

This study examines the relationship between wrist dimensions and the comfort and adaptability of smartwatch wear, integrating biometric measurements and survey analyses to focus on users' subjective wearing experiences. By grouping participants based on wrist width and analyzing their perceived comfort with smartwatches, the findings offer valuable insights into the impact of wrist size on the usability of wearable devices. However, this study has certain limitations. First, the sample primarily consists of young adults, which restricts the generalizability of the results to a broader population. Additionally, the influence of other factors, such as operating systems and design updates, warrants further exploration. Although hand measurements were conducted using standardized procedures, potential measurement errors may have arisen due to human or equipment limitations. Future research could adopt more precise tools and methodologies, such as 3D scanning technologies, to improve the accuracy of hand dimension data. Expanding the participant pool to include a broader range of ages and wrist sizes, along with conducting longitudinal analyses, could help capture changes in user adaptation and experience over time. In conclusion, this study provides empirical support for the field of wearable technology, emphasizing the importance of accounting for biometric variations and subjective expectations when designing next-generation wearable devices. The findings offer important references for improving the comfort and user satisfaction of smartwatches.

Author contributions

Conceptualization, HZ and MZ; methodology, HZ and MZ; software, BW; validation, HZ, MZ and BW; formal analysis, HZ; investigation, BW; resources, MZ; data curation, HZ and BW; writing—original draft preparation, HZ; writing—review and editing, HZ and MZ; visualization, HZ; supervision, MZ; project administration, BW; funding acquisition, MZ. All authors have read and agreed to the published version of the manuscript.

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Conflict of interest

The authors declare no conflict of interest.

References

1. Haghi M, Thurow K, Stoll R. Wearable devices in medical internet of things:scientific research and commercially available devices. Healthcare Informatics Research. 2017; 23(1): 4–15.
2. Reeder B, David A. Health at hand: A systematic review of smart watch uses for health and wellness. Journal of Biomedical Informatics. 2016; 63: 269–276.
3. King CE; Majid S. A Survey of Smartwatches in Remote Health Monitoring. Journal of Healthcare Informatics Research. 2018; 2: 1–24.
4. Dai R, Lu C, Yun L, et al. Comparing stress prediction models using smartwatch physiological signals and participant selfreports. Computer Methods and Programs in Biomedicine. 2021; 208: 106207.
5. Boillat T, Siebert JN, Alduaij N, et al. GOFlow: Smartwatch app to deliver laboratory results in emergency departments–A feasibility study. International Journal of Medical Informatics. 2019; 134:104034.

6. Shao Y. Research on an Auxiliary Design Platform for Head-mounted Products Based on Three-dimensional Head Shapes and Acupuncture Point Distribution. South China University of Technology; 2020.
7. Li X, He R, Wang H. Method for Improvement and Verification of Headphones Based on Human Data. Design. 2021; 34(19): 8–10.
8. Hsiao KL, Chen CC. What drives smartwatch purchase intention? Perspectives from hardware, software, design, and value. Telematics and Informatics. 2018; 35(1): 103–113.
9. Dehghani M, Kim KJ, Dangelico RM. Will smartwatches last? Factors contributing to intention to keep using smart wearable technology. Telematics and Informatics. 2018; 35(2): 480–490.
10. Kong Y, Jang H, Freivalds AJHF, et al. Wrist and tendon dynamics as contributory risk factors in work-related musculoskeletal disorders. Human Factors and Ergonomics in Manufacturing & Service Industries. 2006; 16(1): 83–105.
11. Zhang D. Fitbit is More Comfortable to Wear, While Huawei is More Practical. Consumer Reports. 2015; 08: 52–53.
12. National Technical Committee on Ergonomics Standardization. Body Dimensions of Chinese Adults. National Administration for Market Regulation. GB/T 10000-2023. SAC/TC7. National Standardization Administration; 2023.
13. National Technical Committee on Ergonomics Standardization. Fundamental Body Measurement Items for Technical Design. National Administration for Market Regulation. GB/T 5703-2023. SAC/TC7. National Standardization Administration; 2023.
14. National Technical Committee on Ergonomics Standardization. Classification of Adult Hand Dimensions. National Administration for Market Regulation. GB/T 16252-2023. SAC/TC7. National Standardization Administration; 2023.
15. Ma L, Tsao L, Yu C, et al. A Quick Method to Extract Earphone-Related Ear Dimensions Using Two-Dimensional (2D) Image. International Conference on Applied Human Factors and Ergonomics. 2017.
16. Buffa R, Marini E, Cabras S, et al. Patterns of Hand Variation-New Data on a Sardinian Sample. Collegium Antropologicum. 2007; 31(1): 315–319.
17. Barut C, Sevinc O, Sumbuloglu V. Evaluation of hand asymmetry in relation to hand preference. Collegium Antropologicum. 2011; 35(4): 1119–1124.
18. Idenya PM, Gichangi P, Ogeng'o J. Directional asymmetry in handedness and hand efficiency. Anatomy Journal of Africa. 2020; 9(2): 1848–1856.
19. Kumar T, Vishram S. A preliminary report on hand preference with hand length, hand breadth and shape indices and its role in sexual dimorphism. Medicine. 2015; 10–16.
20. Kim KJ. Round or Square? How Screen Shape Affects Utilitarian and Hedonic Motivations for Smartwatch Adoption. Cyberpsychology, Behavior, and Social Networking. 2016; 19(12): 733–739.
21. Chen Q. Design of a Human Factor Comfort Assessment Device for Wrist-Worn Products Based on Wrist Measurement. Hunan University; 2022.
22. Li H, Xu B, Sun Z, et al. The role of comfort, personality, and intention in smartwatch usage during sleep. Humanities and Social Sciences Communications. 2024; 11(1): 1–11.
23. Choi J, Kim S. Is the smartwatch an IT product or a fashion product? A study on factors affecting the intention to use smartwatches. Computers in Human Behavior. 2016; 63: 777–786.
24. Dehghani M. Exploring the motivational factors on continuous usage intention of smartwatches among actual users. Behaviour & Information Technology. 2018; 37(2): 145–158.
25. Knight JF, Chris B. A tool to assess the comfort of wearable computers. Human Factors: The Journal of Human Factors and Ergonomics Society. 2005; 47(1): 77–91.
26. Spagnolli A, Guardigli E, Orso V, et al. Measuring User Acceptance of Wearable Symbiotic Devices: Validation Study Across Application Scenarios. International Workshop on Symbiotic Interaction. 2014; 87–98 .
27. Delva ML, Lajoie K, Khoshnam M, et al. Wrist-worn wearables based on force myography: on the significance of user anthropometry. BioMedical Engineering OnLine. 2020; 19(1): 1–18.
28. Yang X, Guo Y. Research on the Development Trends of Wearable Sports Devices. Fujian Sports Science and Technology. 2018; 37(03): 17–19.
29. Park KS, Lim CH. A structured methodology for comparative evaluation of user interface designs using usability criteria and measures. International Journal of Industrial Ergonomics. 1999; 23(5–6): 379–389.
30. Rabaa'i A, Al-Lozi E, Al-Hammouri Q, et al. Continuance intention to use smartwatches:An empirical study. International Journal of Data and Network Science. 2022; 1643–1658.