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Evaluation of the Suitability of Smart Health Products for Aging Based on the IIVAHP-CRITIC Model: A Case Study of Smart Health Kiosk

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Abstract: In the global situation of an aging population, the evaluation of the suitability of smart health products for aging is very important in order to achieve sustainable development goals. However, few evaluation methods have been adopted for smart health products for older individuals. An objective and comprehensive evaluation system and evaluation methods need to be established to guide the design of smart health products. In this study, a Smart Health Kiosk (SHK) was used as an example, and an index system was established for the evaluation of the suitability for aging based on the influencing factors from four dimensions. To address the problem that it is difficult to quantify the subjective and objective weights in the evaluation, this study proposes a method of evaluating suitability for aging based on the combination of the Improved Interval-Valued Analytic Hierarchy Process and the Criteria Importance Though Intercrieria Correlation (IIVAHP-CRITIC) method. The results show that the method integrates the influence of subjective and objective weights on the evaluation and avoids the limitations of a single evaluation. It takes into account the relationship between the various levels of indicators and the subjective and objective indicators. Weights calculated by the IIVAHP-CRITIC method help to better assess the objectivity and validity of the design solutions. This evaluation method can effectively reflect the related attributes of each element in the aging-suitability design stage of smart health products. The evaluation results help to improve the quality and ergonomic comfort of aging products, and can effectively reduce the occurrence of design problems.

Keywords: smart health products; aging-suitability evaluation; IIVAHP-CRITIC method; smart health kiosk

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1. Introduction

The world is facing an aging population. The number of people aged 60 years or older is expected to reach 2.1 billion by 2050 [1]. The rapid development of eHealth offers important opportunities to address the challenges associated with an aging society [2]. It promotes inclusiveness and diversity and reduces inequalities in healthcare [3]. However, eHealth also has many drawbacks, such as the lack of a standardized design evaluation and the inability to meet the needs of older adults with specific physical and cognitive limitations. In addition, it still needs to be improved in terms of a user-friendly interface for the elderly [4]. Living independently while maintaining good health is critical for many older adults, and studies have found that they prefer to age in their familiar surroundings [5]. SHK sets up in public places in the community have become a hot research topic in the medical field. They are an independent service space and contain software programs and hardware equipment to provide health check-up services to users. In 1989, a health kiosk named Healthpoint was developed in Glasgow, which was a public-access health information system with a touch-screen that made health information more accessible to the public [6]. In 2000, the first NHS Health Kiosk was installed in the UK to improve access to health information and services [7]. Some studies have begun to look at the user experience of health kiosks [8,9]. Health kiosks were a viable medium for disseminating health information to a variety of users in clinical and community settings, particularly in rural and underserved populations [10]. In the United States, most kiosks located in community or health-service settings have been designed to provide educational information, such as Wellpoint Health Kiosks, which provide users with health information including blood pressure, body fat, and body mass index measurements, as well as feedback.

The application and promotion of the SHK reflect that the interaction mode of smart health products has changed from Human-Human Interaction, Machine-Human Interaction, to Integrated Machine-Human interaction. The SHK has two system characteristics of environmental domain and design domain. It shows multidisciplinary knowledge across fields and needs to reflect both the diverse user needs and the increasingly complex functional performance of products. A systematic evaluation method can determine the feasibility and pros and cons of the conceptual design scheme. Moreover, it can provide a reference for the innovative design of other complex smart health products. In order to serve the elderly better and meet their physical and psychological needs [11], many researchers have evaluated the products from different perspectives. The usability of these products is important as it relates to the number of interfaces that older adults navigate, the length of their sessions, and the time they spend browsing [12]. The safety and comfort of transport used by older people can be assessed by developing a digital human model of older people over 65 years of age [13]. However, due to the gradual diversification of user needs and the increasing complexity of the target function and structure of intelligent product design, a set of objective and systematic evaluation methods are required to determine the feasibility and pros and cons of alternative design solutions at the current stage. In order to overcome the subjective bias in the traditional human evaluation process, researchers have proposed a series of product design evaluation methods to replace subjective human evaluation.

Commonly used evaluation methods include the Analytic Hierarchy Process method (AHP) [14], Principal Component Analysis method [15], Grey Relation Analysis method [16], Multi-objective Group Decision Making method [17], and TOPSIS method [18], etc. These evaluation methods can be used in different stages of the product design process. Xi et al. [19] used the fuzzy AHP method to evaluate product quality issues and determine the weight of evaluation criteria to reduce the subjective bias and uncertainty in evaluating product quality. Yang Cheng et al. [20] found that principal component analysis to make multi-objective decision-making for a product design scheme and used the contribution rate of principal components to reflect the influence of each principal component on the evaluation results of the design scheme. Huseyinov et al. [21] analyzed the differences between AHP and TOPSIS in product evaluation and pointed out that the TOPSIS method is more effective than the AHP method in uncertain environments. On the basis of analyzing requirements, Vinodh et al. [22] obtained a series of product innovation design schemes using quality function deployment and TRIZ. Haomin Wei et al. [23] adopted the grey correlation method to screen seven performance indicators of electronic information equipment to evaluate the performance of electronic information equipment. Zhou, Jing et al. [24] proposed an order preference technology based on multi-objective optimization based on the uncertainty of the customer’s demand for sustainable product design and obtained the optimal design scheme through the similarity with the ideal solution (TOPSIS) method.

Although these methods can better reflect the subjective will of decision makers, they still have limitations in explaining the ambiguity and uncertainty of user perception [25]. The CRITIC method [26] is an objective weight calculation method based on the correlation of indicators. This method comprehensively considers uncertainties such as existing professional knowledge and ambiguity and is more comprehensive and reasonable than other objective weighting methods. Diakoulaki et al. [27] proposed and used the CRITIC method to evaluate the financial indicators of industrial companies, fully considering the conflict and contrast between the indicators. However, simply using this method cannot reflect the importance attached to different indicators by participating decision-makers, and there will be certain weights and degrees opposite to the actual indicators. Comprehensive application is required to make the evaluation more objective. Wang, Dong et al. [28], in order to explore the influence of various mechanical properties of ceramic tool materials on tool life, the AHP method combined with the CRITIC method was used to evaluate the indicators to optimize the mechanical properties of ceramic tool materials. Fen Wang et al. [29] adopted the subjective and objective combination weighting method based on AHP and CRITIC and used TOPSIS to rank the decision-making schemes to evaluate the cognitive APP of visually impaired users.

The improved interval AHP (IIVAHP) method [30] is based on the AHP method, using the interval number instead of the point value to construct the judgment matrix. The index weight is expressed in the form of the interval number. With the help of the interval number to reflect the subjective uncertainty of the index the improved. The IIVAHP method can avoid the arbitrariness of subjective judgment, more truly reflect the state of the index system, and make the interval-based evaluation results more convincing. Therefore, this paper attempts to propose a comprehensive evaluation method based on IIVAHP and CRITIC methods, which considers the experience span of expert scoring to a certain extent and combines experiments, questionnaires, and other methods to obtain subjective and objective index data. Try to use the data information of each indicator effectively and fully consider the conflicts and comparisons between indicators to avoid the defect of ignoring the actual relationship between indicators. We will verify the method through the evaluation case of aging-suitability evaluation of SHK, hoping to reflect the multi-dimensional and multi-level evaluation of the rationality of the design scheme.

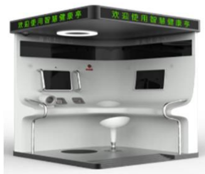
The rest of this paper is organized as follows: Section 2 introduces the design schemes of the SHK and the construction of the aging-suitability evaluation index system. Section 3 presents the evaluation process based on IIVAHP and CRITIC methods. Section 4 illustrates the validation process of the aging-suitability evaluation of the SHK. Section 5 discusses the results of the evaluation. Section 6 concludes the work and draws the future outlines.

2. Materials and Methods

2.1. SHK Design Proposals

SHK design involves interdisciplinary knowledge such as product design, interior design, interface interaction design, computer software, mechanical design, etc. These areas of expertise are integrated in order to solve practical problems and create new knowledge that transcends disciplinary boundaries [31]. Designers from different fields have worked together to facilitate the production of design solutions, but they have also posed a challenge to the evaluation of the solutions. Designers have gone through the general process of product design and ended up with a total of four sets of SHK designs, as shown in Table 1.

Table 1. Four types of design schemes of SHK.

Items	Design Scheme			
Number	1	2	3	4
Scheme				

2.2. Constructing an Aging-Suitability Evaluation System

2.2.1. Indicator Description

Design for older adults should be based on a user-centered design approach and focus on designing to meet the needs, preferences, abilities, and limitations of older users while compensating for their declining health and taking advantage of their ability [32]. The aging suitability evaluation index system of SHK is divided into the following four layers: Criterion Layer B, Criterion Layer C, and Indicator Layer D. All the indicators are shown in Figure 1.

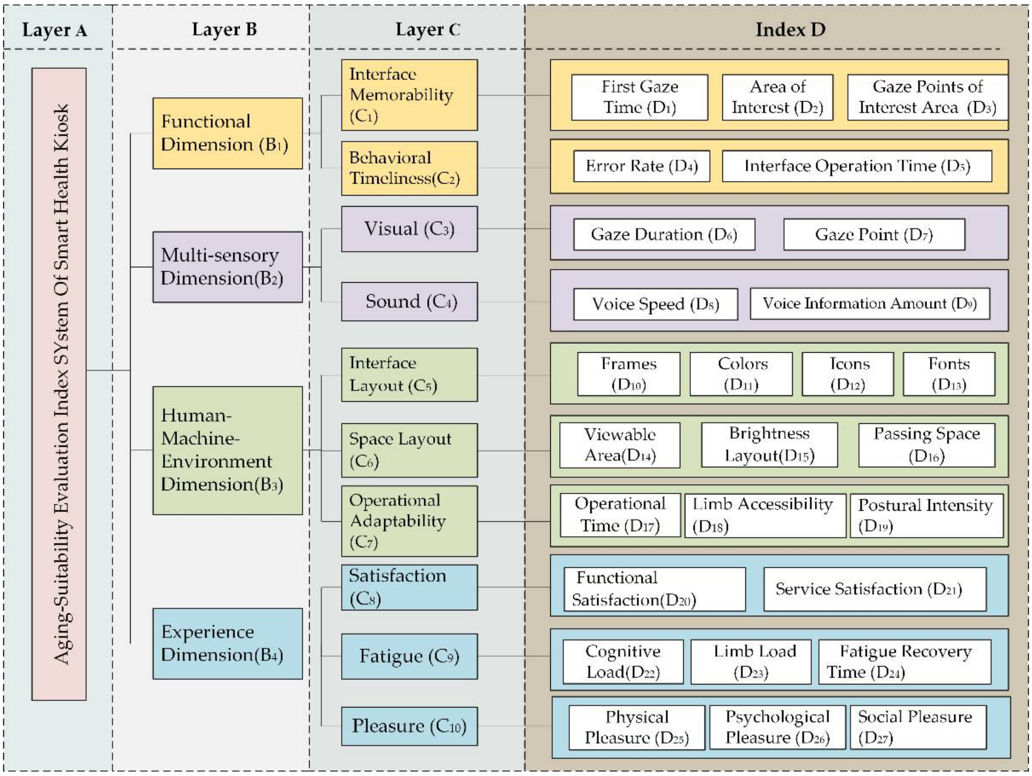


Figure 1. Aging-suitability evaluation index system of the SHK.

1. Functional Dimension. The functional dimension reflects the overall functionality of the product and contains two sub-criteria layers: Interface Memorability (C_1) and Behavioral Timeliness (C_2). C_1 indicates that the user does not use the product for a period of time but still remembers the product. It contains three D-level indicators: First Gaze Time (D_1), Area of Interest (D_2), and Gaze Points of Interest Area (D_3). These three indicators reflect the objective responses of elderly users to different digital interface solutions in the health kiosk, and the data are derived from Eye-Movement-EEG (EME) experiments, as shown in Table 2. C_2 reflects the efficiency of users to complete the testing task using the SHK, and it contains two D-level indicators: Error Rate (D_4) and Interface Operation Time (D_5). D_4 and D_5 reflect the error situation and operation efficiency when elderly users operate the interface.

Table 2. Sources and measurement methods for SHK evaluation.

Items	Experiment	Device/Method	Process	Indicator
1	Eye-Movement-EEG experiments (EME)	Device: Biofeedback instrument produced by Weiss Company, Tobii eye tracker, Eprime1.1 software, Dell S 2340MC, 27′′ LCD monitor. Method: It can record the data changes of the user's eye movement and EEG simultaneously, obtain the physiological signals generated when the user interacts with the product, and judge the user's psychological response and preference to the design plans.	A total of 36 elderly people were invited as participants, including 18 males and 18 females aged 55 to 70, who had browsed the web at least once in the past three months. The health of these older adults had been assessed. A total of four sets of digital interface design schemes for SHK were tested. Each scheme had a total of five pages, and each page was randomly presented twice, so the participants browsed a total of 40 pages. A total of four sets of digital interface design schemes for SHK were tested. Each scheme had five pages, and each page was randomly presented twice, so the participants browsed 40 pages, and the experiment time was 480 s.	D_1, D_2, D_3, D_6, D_7, D_{22}
2	Virtual Simulation Test (VST)	Software: Simens Jack 7.1 (JACK) Method: Import a 3D model into JACK to build a simulation environment. Introduce a 3D human body model with biomechanical properties, assign tasks to the digital human, and obtain valuable information through the behavioral simulation of the digital human.	The fifth percentile, 50th percentile, and 95th percentile digital models of the elderly were established in JACK. The task was tested separately for older adults with different percentile body sizes. Data such as the visual field of the elderly facing the operating screen, the passage space of the SHK, the time to measure blood pressure, the reach of the arm, the limb load of the sitting position, and the fatigue recovery time of the entire task were tested.	D_{14}, D_{15}, D_{16}, D_{18}, D_{19}, D_{23}, D_{24}
3	Behavioral Efficiency Test (BET)	Device: Dell S 2340MC, 27′′ LCD monitor. Method: Measure the time it takes for the participants to complete the task and the error rate.	The participants sat in a comfortable position in a soundproof room with soft light and looked at the computer screen with their eyes about 1 m away from the screen. The participants were presented with four sets of design plans and asked to quickly find the "Self-Measurement" button to enter the testing program after seeing the interface. They need to respond within 10 s. If they find the "Self-Measurement" button, press the "A" button, and if they do not find it, press the "L" button.	D_4, D_5
4	Voice Test	Device: Dell S 2340MC, 27′′ LCD monitor. Method: Test participants' reaction time after voice guidance.	After listening to the voice, the participants could quickly find the "Self-Measurement" button on the interface and pressed the "A" button and recorded the time they took from staring at the interface to completing the action. After the test, the participants were asked to rate the informativeness of each utterance.	D_8, D_9
5	7-Level Liker Scale	Method: Participants rated their agreement with the test.	The following scales are used: questionnaire for the evaluation of visual elements of digital interfaces; user experience questionnaire for SHK interface under different dimensions.	D_{10}, D_{11}, D_{12}, D_{13}, D_{20}, D_{21}, D_{25}, D_{26}, D_{27}

2. Multi-sensory Dimension. This dimension reflects the multi-channel information transfer capability of the product's interaction interface and contains two sub-criteria layers: Visual (C_3) and Sound (C_4). In smart health products, an interface with the ability to integrate visuals and sound to communicate information can make older users' experience more three-dimensional and memorable. C_3 contains three D-level indicators: Gaze Duration (D_6) and Gaze Point (D_7). The D_6 and D_7 data are also derived from the EME experiments, as illustrated in Table 2. C_4 contains two D-level indicators: Voice Speed (D_8) and Voice Information Amount (D_9). D_8 refers to the operational response of the elderly to the voice prompt information in the physical examination task, and the reaction time is measured by the experimenter. D_9 refers to what the voice command contains.
3. Human–Machine–Environment Dimension. This dimension integrates the physiological and psychological factors of the elderly, the human–machine rationality of the product, and the environmental suitability factors to evaluate the product [33]. It contains three sub-criteria layers: Interface Layout (C_5), Space Layout (C_6), and Operational Adaptability (C_7). C_5 reflects the level of user awareness of digital interface elements and contains four D-level indicators: Frames (D_{10}), Colors (D_{11}), Icons (D_{12}), and Fonts (D_{13}). The index data are obtained by means of the EME experiments and a Seven-Level Likert Scale on the Visual Elements of the Digital Interface, as shown in Table 2. C_6 is the layout setting within the health kiosk environment and contains three D-level indicators: Viewable Area (D_{14}), Brightness Layout (D_{15}), and Passing Space (D_{16}). D_{14} refers to whether the position of the product's digital screen is in line with the body size of the elderly. D_{15} refers to whether the lighting values in the SHK environment are suitable for the vision of the elderly. D_{16} refers to whether the width and height of the entrances and exits of the health kiosk meet the accessibility standards. C_7 reflects whether the operational task imposes a limb load on the elderly, and it contains three D-level indicators: Operational Time (D_{17}), Limb Accessibility (D_{18}), and Postural Intensity (D_{19}). D_{17}, D_{18}, and D_{19} can be measured with the Virtual Simulation Test (VST), as shown in Table 2. A virtual simulation digital model human is constructed based on the physical data of the elderly. The force values of the limbs of the model human are measured while performing the physical examination tasks and whether there is enough time to relieve fatigue.
4. Experience Dimension. This dimension of the evaluation feedback of smart health products concerns the perspective of seniors' user experience, and it contains three sub-criteria layers: Satisfaction (C_8), Fatigue (C_9), and Pleasure (C_{10}). C8 reflects seniors' subjective experience of the product, including Functional Satisfaction (D_{20}) and Service Satisfaction (D_{21}). The index data are obtained through a seven-level Likert scale method. C_9 contains three D-level indicators: Cognitive Load(D_{22}), Limb Load (D_{23}), and Fatigue Recovery Time (D_{24}). The data for D_{22} were measured by the EME experiments, which measured brain fatigue in older adults during the detection task. VST was used to analyze the digital model of the human lower back force values when performing inspection tasks, whether there is enough time to relieve fatigue and obtain the index data of D_{23} and D24. C_{10} reflects the subjective evaluation of the health kiosk by the elderly and is assessed using the following three D-level indicators: Physical Pleasure (D_{25}), Psychological Pleasure (D_{26}), and Social Pleasure (D_{27}). The indicator data are obtained using a Seven-Level Likert Scale, as shown in Table 2.

2.2.2. Description of Experimental Data Sources

The sources and measurement methods of the data above are shown in Table 2.

2.2.3. Raw Data for All Indicators

The raw data for the level D indicators collected using the methods described above are shown in Table 3.

Table 3. Raw data of layer D for SHK evaluation.

Index D	Unit	Scheme1	Scheme2	Scheme3	Scheme4
First Gaze Time (D_1)	ms	7.2	6.3	7.4	7
Time of Interest Area (D_2)	%	26.17	35.56	37.3	23.99
Gaze Points of Interest Area (D_3)	%	26.15	35.58	37.5	24.31
Error Rate (D_4)	%	8.6	5	6.2	11
Interface Operation Time (D_5)	S	9.74	9.08	8.4	10.12
Gaze Duration (D_6)	s	13.32	12.19	12.05	14.77
Gaze Point (D_7)	%	25.665	23.051	23.102	26.661
Voice Speed (D_8)	min	330	160	226	186
Voice Information Amount (D_9)	pcs	3.1	4.2	3.5	3.9
Frames (D_{10})	-	3.4	4	4.8	3.1
Colors (D_{11})	-	3.2	4.2	3.4	2.5
Icons (D_{12})	-	3.2	4.1	4	3
Fonts (D_{13})	-	2.5	3.9	3.6	3
Viewable Area (D_{14})	cm	480	540	680	600
Brightness Layout (D_{15})	lx	400	420	560	450
Passing Space (D_{16})	mm	900	1000	1200	1500
Operational Time (D_{17})	S	170	230	130	150
Limb Accessibility (D_{18})	mm	510	600	680	540
Postural Intensity (D_{19})	N·m	450	500	350	400
Functional Satisfaction(D_{20})	-	3.1	3.6	4.1	4.3
Service Satisfaction (D_{21})	-	3.4	3.7	3.5	3.1
Cognitive Load (D_{22})	μV	18.3993	17.3203	16.9791	18.0673
Limb Load (D_{23})	N	1600	3400	2000	2600
Fatigue Recovery Time (D_{24})	S	600	834	1100	1300
Physical Pleasure (D_{25})	-	4.2	3.2	4.1	3.6
Psychological Pleasure (D_{26})	-	3.2	3.8	3.9	2.1
Social Pleasure (D_{27})	-	2.1	2.3	2.2	1.9

3. Evaluation Process Based on IIVAHP and CRITIC Method

3.1. Subjective Weights Based on IIVAHP Method

IIVAHP is an appropriate improvement to the traditional AHP method, and the interval number is introduced to describe the pairwise comparison results as scored by experts. ℓ experts are used to discriminate and score the criterion layer B in pairs, and the scoring results are composed of symmetric matrices that are reciprocals of each other. Judgment is quantified on a scale of 1~9 to reduce the impact on scoring. $N_{ij}^t(t = 1, 2, 3 \cdots \ell; i, j = 1, 2, 3, \cdots k)$ represents the comparison between the *i*-th criterion layer B and the *j*-th criterion layer B, which triangular fuzzy numbers, according to expert *t*. The process of scoring fuzzy triangles contains the following four steps:

Step 1. Create an expert scoring fuzzy matrix, which is calculated by Equation (1).

Step 2. Calculate the initial weight interval range for the *i*-th criterion layer B; its formula is presented in Equation (2).

Step 3. Compare fuzzy weighting intervals. For the purpose of defuzzification, the concept of likelihood is introduced to compare the advantages and disadvantages of different fuzzy numbers, as shown in Equation (3).

$$N_{ij} = \frac{1}{\ell}\sum_{t=1}^{\ell} N_{ij}^t \quad (1)$$

$$D_i = \frac{\sum_{j=1}^{k} N_{ij}}{\sum_{i=1}^{k}\sum_{j=1}^{k} N_{ij}} \quad (2)$$

$$V_{D_i>D_j} = \begin{cases} 1 & n_{fav1} > n_{fav2} \\ \frac{n_{min2}-n_{max1}}{n_{max1}-n_{fav1}-n_{fav2}+n_{min2}} & n_{fav1} > n_{fav2} \text{ and } n_{max1} > n_{min2} \\ 0 & otherwise \end{cases} \quad (3)$$

For a fuzzy number greater than the other k fuzzy numbers, the degree of probability is presented in Equation (4).

$$V(N > N_1, N_2, \ldots, N_k) = \min(V_{D_i>D_{i'}})i = 1, 2, \ldots, i' \text{ and } i \neq i' \quad (4)$$

Step 4. The degree of likelihood that a fuzzy number is greater than other fuzzy numbers is used as the final weight to compare this fuzzy number with other fuzzy numbers.

3.2. CRITIC Method for Determining Objective Weights' Figures

The CRITIC method is an objective weighting method based on the relevance of indicators. The method takes into account the variability of indicators and the conflict between indicators when determining the weights. The variability in an indicator is usually expressed as the standard deviation. The larger the standard deviation, the larger the value gap between the schemes; the correlation coefficient is used to represent the conflict between indicators. If two indicators are positively correlated, the conflict between them is low. The process consists of the following:

Step 1. Create an evaluation matrix X. Suppose there are n indicators, $x_1, \ x_2, \ldots x_n$ in m schemes, and the comparison between the two indicators is set to x_{nm}, as shown in Equation (5):

$$X = \begin{bmatrix} x_{11} & x_{12} \cdots & x_{1m} \\ \vdots & \ddots & \vdots \\ x_{n1} & \cdots & x_{nm} \end{bmatrix} \quad (5)$$

Step 2. Standardize the metrics data. There will be positive and negative indicators in the evaluation indicators, and it is necessary to convert the negative indicators into positive indicators to reduce the amount of calculation. The $maxX_i$ is the maximum value of the i index, p is the coordination coefficient, and X'_{ij} represents the matrix after the i-th index and the j-th index are forwarded, as shown in Equation (6):

$$X'_{ij} = \frac{1}{p + maxX_i + X_{ij}} \quad (6)$$

Because the meanings and units of the evaluation indicators in the matrix of X'_{ij} are different, it is dimensionlessly processed into X''_{ij}, as presented in Equation (7):

$$X''_{ij} = \frac{X'_{ij}}{\sqrt{\sum_{j=1}^{m} (X'_{ij})^2}} \quad (7)$$

Step 3. Calculate the standard deviation and correlation coefficient. X''_i is the mean of the i-th indicator, and $\text{cov}X''_i X''_{ij}$ is the covariance between the i-th row and the j-th row of the standard matrix X''. Calculate the standard deviation σ_i and the correlation coefficient p_{ij}, as shown in Equations (8) and (9), respectively:

$$\sigma_i = \sqrt{\frac{1}{m}\sum_{j=1}^{m} X''_{ij} - \overline{X''_{ij}}^2} \quad (8)$$

$$p_{ij} = \text{cov}X''_i X''_{ij} / \sigma_i \sigma_j \quad (9)$$

Step 4. Calculate the indicator conflict and the overall strength. Let C_i represent the amount of information contained in the i-th evaluation index; $\sum_{j=1}^{m}(1-p_{ij})$ is the conflicting indicator between the i-th indicator and other indicators because the amount of information C_i is proportional to the importance of the indicator, such that, the larger the C_i, the greater the relative importance of the indicator, as shown in Equation (10):

$$C_i = s_i \sum_{j=1}^{m}(1-p_{ij}) \tag{10}$$

Step 5. Calculate objective weights. The objective weight β_i of the i-th indicator is shown in Equation (11):

$$\beta_i = \frac{C_i}{\sum_{i=1}^{n} C_i} \tag{11}$$

3.3. Combined Weights

After the subjective and objective weights are calculated, the subjective weight vector a_i and the objective vector β_i of each indicator are obtained. Assuming that the comprehensive weight is w_i, in order to make the comprehensive index weight w_i closer to a_i and β_i, the least-squares method is used to optimize the obtained subjective and objective weights and then calculate the comprehensive weight; the calculation formula is shown in Equation (12).

$$\begin{gathered} \mathrm{minF}(w_i) = \sum_{i=1}^{n}\sum_{j=1}^{m}\left\{\left[(w_i-a_i)X''_{ij}\right]^2 + \left[(w_i-\beta_i)X''_{ij}\right]^2\right\} \\ \sum_{i=1}^{n} w_i = 1,\ w_i \geq 0 \end{gathered} \tag{12}$$

where $w = (w_1, w_2, \cdots, w_n)^T$ is the eigenvector of the judgment matrix.

4. Case Application

All the index data are obtained according to the construction method of the SHK aging-suitability evaluation system in Section 2 (Table 3). Then, the comprehensive evaluation method of IIVAHP in Section 3 is applied to evaluate the suitability of the SHK for aging, and the specific calculation process is as follows.

Step 1. Calculate subjective weights. Here, 12 experts in product-design-related fields were invited to score the SHK proposals. Given the minimum value, the middle value, and the maximum value for each scoring item, construct a judgment matrix to calculate the fuzzy scoring data of criterion layer B, as shown in Table 4.

Table 4. Scoring interval values for criterion layer B.

	B_1	B_2	B_3	B_4
B_1	[1, 1, 1]	[3, 4, 5] [2, 3, 4] [2, 3, 5]	[1/6, 1/5, 1/2] [1/5, 1/4, 1] [4, 5, 8]	[1/7, 1/6, 1/2] [1/4, 1/3 1] [3, 4, 5]
B_2	[1/5, 1/4, 1/3] [1/4, 1/3, 1/2] [1/5, 1/3, 1/2]	[1, 1, 1]	[6, 7, 8] [1/5, 1/4, 1] [1/8, 1/7, 1/2]	[6, 7, 8] [1/6, 1/5, 1/2] [1/4, 1/3, 1]
B_3	[2, 5, 6] [1, 4, 5] [1/8, 1/5, 1/4]	[1/8, 1/7, 1/6] [1, 4, 5] [2, 7, 8]	[1, 1, 1]	[1/8, 1/7, 1] [1/6, 1/5, 1] [6, 7, 8]
B_4	[2, 6, 7] [1, 3, 4] [1/5, 1/4, 1/3]	[1/8, 1/7, 1/6] [2, 5, 6] [1, 3, 4]	[1, 7, 8] [1, 5, 6] [1/8, 1/7, 1/6]	[1, 1, 1]

Step 2. Normalize the data. RI is the average random consistency index, and its values are shown in Table 5.

Table 5. Average Stochastic Consistency Index RI.

n	1	2	3	4	5	6	7	8	9
RI	0	0	0.58	0.96	1.12	1.24	1.32	1.41	1.45

Calculate the maximum eigenvalue λ_{max} of the discriminant matrix A, the consistency index CI, and the consistency ratio CR. The calculation formulas are shown in Equations (13)–(15), respectively:

$$\lambda_{max} = \sum_{i=1}^{n} \frac{(Aw)_i}{nw_i} \quad (13)$$

$$CI = \frac{\lambda_{max} - n}{n - 1} \quad (14)$$

$$R = \frac{CI}{RI} \quad (15)$$

$\lambda_{max} = 4.1391,\ CI = 0.0464,\ CR = 0.0483.$

From $CR = 0.0483 < 0.1$, it is clear that the discriminant matrix A passes the consistency test. Similarly, the eigenvectors and maximum eigenvalues λ_{max} of each factor in the other discriminant matrices can be calculated, and finally, all indicators are calculated to pass the consistency test.

Step 3. Calculate the subjective weight w_{AHP} by calculating the eigenvectors and the maximum eigenvalue λ_{max} of each factor in the other discriminant matrices. The subjective weights of criterion layers B and C are shown in Table 6, and the subjective weights of index layer D are shown in Table 7.

Table 6. Subjective weights of criterion layer B and criterion layer C.

Layer B	w_{AHP}	Layer C	w_{AHP}
B_1	0.1207	C_1	0.7500
		C_2	0.2500
B_2	0.0641	C_3	0.7500
		C_4	0.2500
B_3	0.5777	C_5	0.1429
		C_6	0.4286
		C_7	0.4286
B_4	0.2375	C_8	0.2583
		C_9	0.6370
		C_{10}	0.1047

Table 7. The feature vector w, subjective weight w_{AHP}, mean $\overline{X}$, standard deviation σ_i, overall strength C_j, and objective weight value w_{CRITIC} of the index D.

Index D	w	w_{AHP}	$\overline{X}$	σ_i	C_j	w_{CRITIC}
D_1	0.0719	0.0065	94.26	5.60	138.9352	0.0215
D_2	0.2790	0.0253	82.45	15.44	200.5149	0.0310
D_3	0.6491	0.0588	82.36	15.29	197.7315	0.0306
D_4	0.8333	0.0251	71.06	20.93	343.4324	0.0532
D_5	0.1667	0.0050	90.44	6.49	79.2296	0.0123
D_6	0.7500	0.0361	92.73	7.41	102.5044	0.0159
D_7	0.2500	0.0120	94.01	6.00	82.0168	0.0127
D_8	0.1667	0.0027	76.33	19.11	485.5044	0.0752
D_9	0.8333	0.0134	85.47	9.91	277.6481	0.0430
D_{10}	0.4995	0.0412	79.69	13.53	165.0359	0.0256
D_{11}	0.0655	0.0054	79.17	14.42	270.0285	0.0418
D_{12}	0.1465	0.0121	87.20	11.74	165.2866	0.0256
D_{13}	0.2884	0.0238	83.33	13.87	229.8383	0.0356
D_{14}	0.4806	0.1190	84.56	10.88	191.7667	0.0297
D_{15}	0.1140	0.0282	81.70	11.04	171.5032	0.0266
D_{16}	0.4054	0.1004	76.67	15.28	454.3062	0.0703
D_{17}	0.1047	0.0259	79.91	15.88	361.1817	0.0559
D_{18}	0.6370	0.1577	85.66	9.55	122.4814	0.0190
D_{19}	0.2583	0.0640	83.82	11.21	227.1599	0.0352
D_{20}	0.7500	0.0460	87.79	10.83	262.4082	0.0406
D_{21}	0.2500	0.0153	92.57	5.85	101.6320	0.0157
D_{22}	0.7306	0.1105	96.07	3.08	40.9307	0.0063
D_{23}	0.1884	0.0285	72.15	19.87	551.9521	0.0855
D_{24}	0.0810	0.0123	68.16	20.60	623.5856	0.0965
D_{25}	0.4545	0.0113	89.88	9.58	241.0123	0.0373
D_{26}	0.4545	0.0113	83.33	18.36	266.4111	0.0412
D_{27}	0.0909	0.0023	92.39	6.43	105.1560	0.0163

Step 4. Calculate the standard deviation and correlation coefficient of the indicator. The mean $\overline{X}$, standard deviation σ_i, and correlation coefficient p_{ij} of the evaluation index data are calculated as shown in Equations (16)–(18), respectively:

$$\overline{X} = \sum_{i=1}^{N} x_i \tag{16}$$

$$\sigma_i = \sqrt{\frac{\sum_{i=1}^{N} \left(x_i - \overline{X}\right)^2}{N}} \tag{17}$$

$$p_{ij} = \frac{n \sum_{i=1}^{n} x_i y_j - \sum_{i=1}^{n} x_i \sum_{j=1}^{n} y_j}{\sqrt{n \sum_{i=1}^{n} x_i^2 - \left(\sum_{i=1}^{n} x_i\right)^2} \times \sqrt{n \sum_{j=1}^{n} y_j^2 - \left(\sum_{j=1}^{n} y_j\right)^2}} \tag{18}$$

Step 5. Determine the conflict and overall strength of indicators. In order to reflect the conflict between each evaluation index relative to other indicators, the overall strength C_j of each evaluation index is calculated, and the formula is shown in Equation (19):

$$C_j = \sigma_j \sum_{i=1}^{n} \left(1 - p_{ij}\right) \tag{19}$$

Step 6. Calculate the objective weight w_{CRITIC} of each evaluation index, as shown in the Equation (20):

$$w_{CRITIC} = \frac{C_j}{\sum_{j=1}^{n} C_j} \tag{20}$$

The feature vector w, subjective weight w_{AHP}, mean $\overline{X}$, standard deviation σ_i, overall strength C_j, and objective weight value w_{CRITIC} of the indicator D, as shown in Table 7.

Step 7. Comprehensive weight and score. Calculate the comprehensive weight w_i^* of the indicator, as shown in Equation (21):

$$w_i^* = \frac{w_{AHPi} w_{CRITICi}}{\sum_{i=1}^{n} w_{AHPi} w_{CRITICi}} \tag{21}$$

According to the comprehensive weight value, calculate the age-appropriate evaluation score H_j of the SHK. The calculation formula is shown in Equation (22).

$$H_j = \sum_{i=1}^{27} w_i^* X_{ij} (j = 1, 2, 3, 4) \tag{22}$$

Finally, the comprehensive index weight w_i^* and the evaluation score H_j of the four schemes of the SHK based on the IIVAHP-CRITIC method are shown in Table 8.

Table 8. The comprehensive index weight w_i^* and the evaluation score H_j of the four schemes of the SHK.

Layer B	Layer C	Index D	w_i^*	H_1	H_2	H_3	H_4
B_1	C_1	D_1	0.0042	97.30	85.14	100.00	94.59
		D_2	0.0234	70.16	95.34	100.00	64.32
		D_3	0.0538	69.73	94.88	100.00	64.83
	C_2	D_4	0.0399	58.14	100.00	80.65	45.45
		D_5	0.0018	86.24	92.51	100.00	83.00
B_2	C_3	D_6	0.0172	90.47	98.85	100.00	81.58
		D_7	0.0046	89.81	100.00	99.78	86.46
	C_4	D_8	0.0061	48.48	100.00	70.80	86.02
		D_9	0.0172	100.00	73.81	88.57	79.49
B_3	C_5	D_{10}	0.0315	70.83	83.33	100.00	64.58
		D_{11}	0.0067	76.19	100.00	80.95	59.52
		D_{12}	0.0093	78.05	100.00	97.56	73.17
		D_{13}	0.0253	64.10	100.00	92.31	76.92
	C_6	D_{14}	0.1056	70.59	79.41	100.00	88.24
		D_{15}	0.0224	71.43	75.00	100.00	80.36
		D_{16}	0.2110	60.00	66.67	80.00	100.00
	C_7	D_{17}	0.0433	76.47	56.52	100.00	86.67
		D_{18}	0.0896	75.00	88.24	100.00	79.41
		D_{19}	0.0673	77.78	70.00	100.00	87.50
B_4	C_8	D_{20}	0.0558	72.09	83.72	95.35	100.00
		D_{21}	0.0072	91.89	100.00	94.59	83.78
	C_9	D_{22}	0.0208	92.28	98.03	100.00	93.98
		D_{23}	0.0728	100.00	47.06	80.00	61.54
		D_{24}	0.0355	100.00	71.94	54.55	46.15
	C_{10}	D_{25}	0.0126	100.00	76.19	97.62	85.71
		D_{26}	0.0139	82.05	97.44	100.00	53.85
		D_{27}	0.0011	91.30	100.00	95.65	82.61
		H_j		11.6723	11.9472	30.1197	26.4608

5. Results and Discussion

5.1. Results

Based on the above comprehensive evaluation results of all indicators of the four dimensions of the SHK, we can obtain the following results.

1. As seen in Table 8, based on the comprehensive IIVAHP-CRITIC evaluation of the design scheme of SHK for aging, the index weight scores of the four schemes are [11.6723, 11.9472, 30.1197, 26.4608], respectively. Scheme 3 has the highest score, followed by Scheme 4. Scheme 1 has the lowest scores. Scheme 1 and 2 have similar scores. If we adopt the traditional evaluation method, it is difficult to distinguish the pros and cons of the scheme. In the comprehensive evaluation of impact indicators, the Passing Space, Viewable Area, Limb Accessibility, Limb Load, and Postural Intensity of the SHK have a greater impact on the decision-making of age-suitability design plan and are the key attributes of the evaluation plan.
2. Combined with the indicator weights in Tables 6 and 8, the four dimensions of the impact assessment scheme are ranked as follows: Human–Machine–Environment Dimension > Experience Dimension > Functional Dimension > Multi-Sensory Dimension. For the Human–Machine–Environment Dimension, the Space Layout has the greatest impact on it, which is related to whether the passing space, the brightness of the environment, and the visual field of the digital interface can meet the physiological needs of the elderly. The second is work adaptability. The reachable area and postural strength of the limbs are related to the ergonomic comfort of the equipment. Meanwhile, the physical load was found to have the greatest impact on the Experience dimension. When an elderly person feels very tired, their user experience will be worse. Among these four dimensions, the Multi-Sensory Dimension has the lowest weight, indicating that with the maturity of technology, products are making continuous progress in the interaction of visual and voice information.
3. Based on the histogram shown in Figure 2, we can compare the weights of the indicator layers. The top five groups of indicators representing the most important influencing factors are Passing Space, Viewable Area, Limb Accessibility, Limb Load, and Postural Intensity. Four of these indicators are related to the Human–Machine–Environment Dimension, and the Limb Load belongs to the Experience Dimension. The last place in the index weight ranking is Social Pleasure, indicating that the need to pay attention to the social needs of the elderly did not receive sufficient attention in the design of the SHK.

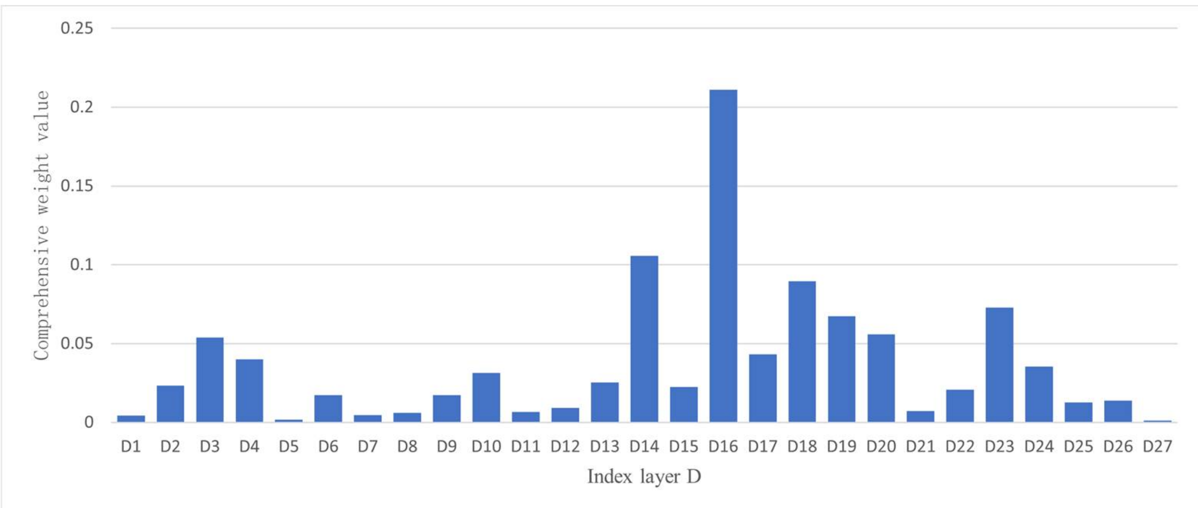


Figure 2. The comprehensive weight of the evaluation index layer D.

4. As can be seen from the scheme scores in Table 8, Scheme 3 has the best overall score in the evaluation of functions, Multi-Sensory Information interaction, and Human–Machine-Environment indicators, and Scheme 4 has the lowest scores in the Function and Multi-sensory Information dimensions. Scheme 1 has the lowest score in the Human–Machine–Environment indicators. The interface memorability of Scheme 3 obtained a high score, indicating that the design of the digital interface conforms to the aesthetic needs and cognitive habits of the elderly, but further optimization is needed in terms of fatigue and sound.

5.2. Discussion

From the results, it is found that it is impossible to determine whether the product can meet the diversified needs of users only from the appearance design of the four schemes. In the problem-solving-oriented design process, designers need to go through the following steps: requirements investigation, problem definition, thinking divergence, prototyping, model iteration, and solution release. However, the knowledge and experience of designers are often reflected in the design innovation of the entire product. The lack of unified standards will bring difficulties in evaluating the scheme.

The integrated scores are now a widely used method for evaluating multiple indicators in product design, and the establishment of weighting factors has been a vital issue to be resolved. At present, the more commonly used method is still the expert assignment method. In the case of the four design solutions of this paper, we use the traditional AHP method [34] to assign a weighting resulting in [18.7561, 20.3530, 28.5912, 30.2843]. This method is more subjective, less stable, and easy to ignore the information of the actual sample data. Furthermore, we use the combined AHP-CRITIC method [35] resulting in [12.3856, 12.9127, 29.2973, 29.3155], this method reflects the objective information while giving importance to the actual weight relationship between indicators, however, it can easily result in poor differentiation of the sample. This is because it is difficult to estimate the difference between Scheme 3 and Scheme 4. The results [11.6723, 11.9472, 30.1197, 26.4608] obtained by the IIVAHP-CRITIC proposed in this paper, on the contrary, address this problem in a better way.

6. Conclusions

This study expounds on the aging-suitability evaluation of intelligent health product design, proposes the evaluation method of IIVAHP-CRITIC method, and validates it through the evaluation process of SHK. The following conclusions are drawn:

1. This paper establishes a product evaluation index system with four dimensions and three levels, and to a certain extent, the experience span of expert scoring is considered. In addition, the combination of experiments, questionnaires, and other methods to obtain subjective and objective data results in complementary effects.
2. A comprehensive evaluation method of IIVAHP-CRITIC is proposed that considers the uncertainty of decision-making factors and the difficulty of quantifying various subjective and objective weights in the evaluation process of this type of product design scheme. This method comprehensively considers the influence of subjective and objective weights on the design scheme and avoids the limitations of a single point of view. In addition, it avoids the defect of ignoring the actual relationship between indicators. It effectively uses the data information of each indicator. Overall, it makes evaluation results more objective and reasonable.
3. It avoids traditional design methods' complex and repetitive modeling process and provides a reference for the appropriate design of intelligent health products. It also helps improve the product's ergonomic comfort and the satisfaction of older users.

Sustainable design requires the harmonious development of people and the environment. Designers explore various practices within the framework of sustainable development; green, ecological, and social innovation; design for the elderly; inclusive design; etc. The creative and design stage is the key to a sustainable product, and designers can improve existing product designs based on user usage issues, design evaluations, and standards. This research demonstrates multidisciplinary knowledge across domains and needs, reflecting diverse user needs and increasingly complex product functional performance. An objective and systematic evaluation method can determine a conceptual design scheme's feasibility and pros and cons.

However, this study also has limitations. Intelligent health product design is a process that requires comprehensive consideration of multi-field and multi-disciplinary design knowledge. The innovative design not only needs to meet upstream design requirements but also needs to meet downstream performance requirements. The measurement of original indicators requires more scientific methods. At the same time, because the calculation process of evaluation is relatively complicated, and designers are often limited to professional knowledge in this field, it is difficult to break through and promote the design evaluation method. In the future, on the one hand, we can consider adopting more intelligent technologies and methods to explore the influencing factors of products and make the established indicator system more representative; on the other hand, we can develop a set of cross-domain visualization software based on the IIVAHP-CRITIC model for better application and promotion.

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