Quantitative Evaluation System of Indoor Fitness Equipment for the Elderly Based on AHP-TOPSIS

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Abstract. The paper aims to reduce the subjectivity and one-sidedness in the choice of fitness products for the elderly. The method of the Analytic Hierarchy Process (AHP) is applied to establishing the hierarchical structure of evaluation on indoor fitness equipment for the elderly, and then the quantitative index of evaluation on fitness equipment for the elderly is obtained by constructing evaluation matrix analysis, and Technique for Order Preference by Similarity to Ideal Solution (TOPSIS) is used to calculate the distance of each scheme to the ideal solution so as to obtain the best fitness products for the elderly. The result is that a more scientific evaluation system of indoor fitness products for the elderly is achieved on basis of the model integrating AHP and TOPSIS. The conclusion is that this method reduces the subjectivity of decision-makers and enhances the rationality, which can provide reference ideas for the evaluation and selection of fitness products of the same kind for the elderly.

Keyword: the elderly · indoor fitness equipment · evaluation system · AHP · TOPSIS

1 Preface

At present, there are relatively few researches on the evaluation of indoor fitness equipment for the elderly in China. Yang Aihui et al. [1] used Kansei Engineering and Quantitation Theory I to construct the correlation model between the design elements of fitness products for the elderly and the emotional needs of the elderly; Feng Weiwei et al. [2] used Kano model to conduct researches on improved design of family exercise bikes; Tang Lin et al. [3] used QFD and AHP to study the modeling design of fitness equipment for the elderly. The above-mentioned scholars has taken the different needs of the elderly as the entry point to design the products and have discussed the various design methods of fitness equipment for the elderly. However, the evaluation process of indoor fitness equipment for the elderly lacks scientific and systematic methods, and the product scheme evaluations are more subjective, which can not effectively provide objective evaluation decisions for products. Because this paper mainly solves the issue of evaluation and selection of indoor fitness equipment for the elderly, with many and complex evaluation elements and relationships involved, analytic hierarchy process (AHP) [4,

X. Yuan et al. (Eds.): ICEKIM 2023, AHCS 13, pp. 510–520, 2023.
https://doi.org/10.2991/978-94-6463-172-2_56

5] is introduced as a method to calculate the weight of each evaluation element, and targeted evaluation is carried out on the weight order of evaluation elements, which also provides emphasis for relevant designers in design. The optimal fitness products for the elderly are obtained by calculating the distances from multiple evaluation schemes to ideal solutions with TOPSIS [6, 7]. The model combining AHP and TOPSIS, used to give a quantitative evaluation method, can improve the scientificalness in the process of evaluation and selection, in order to offer a more reasonable evaluation and selection system to the conception and scheme evaluation and selection of fitness products for the elderly.

2 Extraction of the Key Points from Evaluation on Indoor Fitness Products for the Elderly Based on AHP Method

2.1 AHP Model of Evaluation on Fitness Product for the Elderly

The analytic hierarchy process model of evaluation on fitness products for the elderly is divided into three layers. Objective layer (layer A): the best scheme of fitness products for the elderly; Through literature reading [8–11], questionnaire survey and expert interview, the following elements of the model are determined. Criterion layer (layer B): it includes safety, functionality, ease of use and comfort; Scheme layer (layer C): it is divided into 14 evaluation elements. As shown in Fig. 1.

Safety. Safety is the primary consideration when choosing fitness products for the elderly. When choosing fitness products for the elderly, we should consider the safety of the elderly when using them, and the materials of the products should be safe enough. The material foundation of the product structure is materials, so we should choose functional products suitable for the elderly to avoid injuries to the elderly caused by excessive strength.

Functionality. The fitness of the elderly usually focuses on improving cardio-pulmonary function, strengthening muscle strength and improving balance ability, and the intensity should not be too high. Isokinetic muscle strength is to make muscles contract under the condition of constant velocity. Training this muscle contraction can exert maximum muscle strength training no matter what the joint angle is; Training of cardio-pulmonary function can improve the cardio-pulmonary function of the elderly

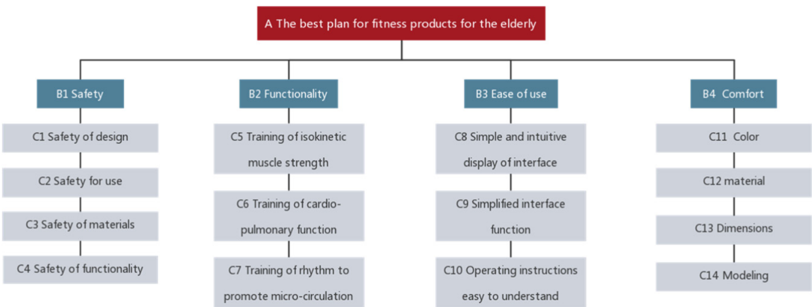

Fig. 1. Evaluation level analysis model of fitness products for the elderly

to some extent; Training of rhythm promoting micro-circulation is mainly through the equipment of whole-body vertical rhythm training, with the design concept of passive training, which can promote micro-circulation, enhance metabolism and improve common chronic diseases of the elderly.

Ease of use. Ease of use means that the elderly do not need special training and study before using fitness products, which is easier to be operated and used. The capacity of the elderly to learn new knowledge and skills is significantly reduced due to the decline of memory and adaptability. Therefore, the use and operation of products should be clear at a glance, easy to learn and understand.

Comfort. The psychological needs of the elderly are an key factor that can not be ignored. Therefore, when choosing the fitness equipment for the elderly, we should try our best to choose a neat and round instrument shape, which can bring a certain sense of intimacy to the elderly; anti-skid materials should be selected to reduce the risk during exercise; choice of neutral tone as the overall color tone and choice of reasonable size can make the elderly get warm emotional experience.

2.2 Use of AHP Method to Determine the Weight of Evaluation Elements

N items of evaluation elements are scored by relevant experts and a judgment matrix is constructed. The expert members consist of 5 postgraduate students specialized in product design, 3 rehabilitation doctors and 2 fitness instructors. Suppose, $A = \left[b_{i,j}\right]$, $b_{i,j}$ indicates the relative importance among the items in the criterion layer that make up item A, $b_{i,j} = 1, b_{j,i} = 1/b_{i,j}$. Suppose, $B_k = \left[c^k_{m,n}\right]$, $c^k_{m,n}$ indicates the relative importance among the corresponding items in the scheme layer that make up item B_k, $C^k_{m,n} = 1, C^k_{n,m} = 1/C^k_{m,n}$.

Through analysis, it is known that the importance relationship among each item in the criterion layer can be expressed by matrix A. The importance relationship among the each item in the scheme layer is given in the form of matrix B1 to B5:

$$A = \begin{bmatrix} 1 & 15/4 & 26/9 & 22/9 \\ 2/7 & 1 & 6/7 & 7/9 \\ 1/3 & 7/6 & 1 & 4/3 \\ 2/5 & 9/7 & 3/4 & 1 \end{bmatrix} B1 = \begin{bmatrix} 1 & 2/7 & 1 & 3/4 \\ 13/4 & 1 & 19/6 & 29/9 \\ 1 & 1/3 & 1 & 8/9 \\ 4/3 & 1/3 & 10/9 & 1 \end{bmatrix}$$

$$B2 = \begin{bmatrix} 1 & 3/5 & 1 \\ 12/7 & 1 & 7/4 \\ 1 & 4/7 & 1 \end{bmatrix} B3 = \begin{bmatrix} 1 & 6/5 & 1 \\ 5/6 & 1 & 8/7 \\ 1 & 7/8 & 1 \end{bmatrix}$$

$$B4 = \begin{bmatrix} 1 & 2/3 & 5/9 & 7/9 \\ 13/9 & 1 & 1 & 5/6 \\ 13/7 & 1 & 1 & 3/2 \\ 9/7 & 6/5 & 2/3 & 1 \end{bmatrix}$$

According to the data of judgment matrix, determined by the use of SPSS calculation, the maximum eigenvalue $\lambda_{\max}$ of Matrix A, showing the correlation of criterion layer, is 4.0266, and the maximum eigenvalues $\lambda_{\max 1\sim5}$ of Matrix B1-B5 showing the correlation of scheme layer are 4.0169, 3.0096, 3.0111 and 4.0297 respectively; and their corresponding weight vectors are calculated, that is,

$$\omega_1^A = \begin{bmatrix} 0.4968 \\ 0.1447 \\ 0.1859 \\ 0.1726 \end{bmatrix} \omega_1^{B1} = \begin{bmatrix} 0.1461 \\ 0.5154 \\ 0.1585 \\ 0.1800 \end{bmatrix} \omega_1^{B2} = \begin{bmatrix} 0.2711 \\ 0.4622 \\ 0.2667 \end{bmatrix}$$

$$\omega_1^{B3} = \begin{bmatrix} 0.3539 \\ 0.3276 \\ 0.3185 \end{bmatrix} \omega_1^{B4} = \begin{bmatrix} 0.1790 \\ 0.2549 \\ 0.3195 \\ 0.2466 \end{bmatrix}$$

2.3 Consistency Test

SPSS software is applied to the consistency test, and the specific results are shown in Table 1, that is,

From Table 1, it is known that the consistency test results of each judgment matrix are CR < 0.1, which meets the consistency conditions, and the obtained weight values all meet the requirements.

According to the comprehensive weight order obtained from the above evaluation indexes, it is obtained that in the process of evaluation practice, the potential safety hazards of the elderly when using fitness equipment should be considered emphatically, and more emphasis should placed on the selection of anti-skid materials, so as to reduce the possibility of injury of the elderly when using fitness equipment; reasonable exercise load should also be taken into consideration, in order to avoid injuries caused by excessive intensity to the elderly during exercise. In terms of function selection, selecting a product suitable for training the cardio-pulmonary function of the elderly is conducive to improve the problems of cardiopulmonary insufficiency and debilitating syndrome of the elderly. In terms of ease of use, as the elderly grow older, their memory and eyesight are greatly impaired. When selecting the interface, they should choose a simple interface display, easy and uncomplicated, which is convenient for the elderly to understand and operate.

Table 1. Consistency test result

Category	A	B1	B2	B3	B4
CI	0.008 9	0.005 6	0.003 3	0.005 5	0.009 3
RI	0.890 0	0.890 0	0.520 0	0.520 0	0.890 0
CR	0.009 9	0.006 3	0.006 4	0.010 7	0.010 4

Table 2. Comprehensive weight order of indexes

Index of scheme layer	Comprehensive weight	Order
Safety of design	0.072 6	4
Safety for use	0.256 1	1
Safety of materials	0.078 7	3
Safety of functionality	0.089 4	2
Training of isokinetic muscle strength	0.039 2	12
Training of cardio-pulmonary function	0.066 9	5
Training of rhythm to promote micro-circulation	0.038 6	13
Simple and intuitive display of interface	0.065 8	6
Simplified interface function	0.060 9	7
Operating instructions easy to understand	0.059 2	8
Color	0.030 9	14
Material	0.044 0	10
Dimensions	0.055 1	9
Modeling	0.042 6	11

3 Evaluation on Indoor Fitness Equipment for the Elderly Based on TOPSIS Method

3.1 Sample Determination and Emotional Thinking Orientation of Fitness Products for the Elderly

According to Table 2, it is known that the fitness of the elderly mainly focuses on cardio-pulmonary function training. Therefore, through the network platform, three cardio-pulmonary fitness equipment popular at home and abroad are collected. There are 138 types of elliptical machines, 211 types of exercise bikes and 100 types of treadmills respectively. Through questionnaire survey and cluster analysis, eight representative samples of exercise bikes are obtained, which are represented by X, and the first row of each representative sample is represented by X1, X2, X3 and X4 respectively, and the second row is represented by X5, X6, X7 and X8; Six representative samples of elliptical machines are replaced by Y; six representative samples of treadmills are replaced by Z, and so on. See Tables 3, 4, and 5 for details.

Five groups of intentional word pairs are obtained by extracting the focus of design evaluation elements sorted out through AHP analysis and combining with the needs of the elderly at three layers. By the use of SD questionnaire, a seven-order semantic scale is established, that is, the score from -3 to 3. Questionnaires are distributed to 61 elderly people, and 60 valid questionnaires are received. Among them, there are 37 males and 23 females, with the age above 55 to 65. According to statistics, the average value of perceptual evaluation data of representative samples are obtained by SPSS, as shown in Tables 6, 7, and 8.

Table 3. Samples of various exercise bikes

Name	Picture			
	X1	X2	X3	X4
Exercise bikes X				
				

Table 4. Samples of each elliptical machine

Name	Picture			
	Y1	Y2	Y3	Y4
Elliptical machine Y				
				

From Tables 6, 7, and 8, it is known that the highest average values belong to exercise bike sample X8, elliptical machine sample Y6 and treadmill sample Z2.

3.2 Construction of the Weighting Matrix According to the Weight of Each Evaluation Element

Suppose that there are M schemes to be evaluated, which can constitute a scheme set $D = \{X_1, Y_2, \cdots, Z_M\}$; suppose that there are N evaluation elements, which can constitute a element set $C = \{C_1, C_2, \cdots, C_N\}$, then the initial evaluation matrix is

$$A = \left(a_{ij}\right)m \cdot n(i = 1, 2, \cdots, m; j = 1, 2, \cdots, n) \tag{1}$$

Table 5. Samples of treadmills

Name	Picture			
	Z1	Z2	Z3	Z4
Tread-mills Z				
				

Table 6. The average perceptual evaluation of the elderly to fitness vehicles

Sample	Aesthetic	Safe	Easy-to-use	Comfortable	Intimate	Mean value
X1	1.2	1.52	1.03	1.3	1.22	1.25
X2	0.55	0.75	0.45	0.52	0.18	0.49
X3	−0.22	−0.73	0.15	−0.45	−0.47	−0.34
X4	1.08	1.23	0.67	0.87	0.67	0.9
X5	1.23	1.02	1.03	1.08	0.77	1.03
X6	0.58	−0.08	0.43	0.1	0	0.21
X7	−0.13	−0.23	0	0.17	−0.12	−0.06
X8	1.72	1.72	1.73	1.83	1.72	1.74

Table 7. The average perceptual evaluation of the elderly to elliptical machines

Sample	Aesthetic	Safe	Easy-to-use	Comfortable	Intimate	Mean value
Y1	−0.1	−0.27	−0.1	−0.03	−0.22	−0.14
Y2	1.12	0.47	0.9	0.4	0.42	0.66
Y3	1.02	0.6	0.33	0.4	0.38	0.55
Y4	0.77	0.73	0.23	0.28	0.03	0.41
Y5	−0.72	−0.45	−0.1	−0.38	−0.18	−0.37
Y6	1.88	1.78	1.38	1.65	1.58	1.66

Table 8. The average perceptual evaluation of the elderly to treadmills

Sample	Aesthetic	Safe	Easy-to-use	Comfortable	Intimate	Mean value
Z1	0.68	−0.13	0.3	0.27	−0.05	0.21
Z2	0.82	1.13	1.33	0.97	0.65	0.98
Z3	0.88	1.08	1.2	0.77	0.68	0.92
Z4	1.08	0.23	−0.15	0.15	0.18	0.3
Z5	0.47	1	0.7	0.8	0.43	0.68
Z6	0.42	−0.38	−0.18	0.2	0.05	0

Seven postgraduate students majoring in product design, five physical therapists, three designers and two fitness instructors are selected to score 11 evaluation elements of the above three cardio-pulmonary function fitness products, and the scoring range is between 0 and 10 points ($0 <$ poor ≤ 3, $3 <$ below the average ≤ 5, $5 <$ general ≤ 6, $6 <$ better ≤ 8, $8 <$ excellent ≤ 10). SPSS is used to take the mean value as the final score of each evaluation element, as shown in Table 9.

Table 9 is standardized to establish a standardized evaluation matrix, as shown in Table 10.

The weighted standardization matrix is obtained by multiplying the weights of 11 design evaluation elements determined in Table 2, as shown in Table 11.

Table 9. Initial evaluation matrix

Evaluation element	Scheme score		
	Scheme X	Scheme Y	Scheme Z
C1	8.71	7.94	7.65
C2	7.82	7.82	7.53
C3	8.53	7.71	7.41
C4	7.88	7.88	7.65
C8	7.59	7.94	7.59
C9	7.88	7.94	7.88
C10	7.65	7.65	7.94
C11	8.65	8	6.94
C12	8.18	8	7.18
C13	8.18	7.76	7.18
C14	8.76	8.47	6.76

Table 10. Standardized evaluation matrix

Evaluation element	Scheme score		
	Scheme X	Scheme Y	Scheme Z
C1	0.619 9	0.565 1	0.544 4
C2	0.584 5	0.584 5	0.562 8
C3	0.623 6	0.563 6	0.541 7
C4	0.583 0	0.583 0	0.566 0
C8	0.568 5	0.594 7	0.568 5
C9	0.575 9	0.580 3	0.575 9
C10	0.570 1	0.570 1	0.591 7
C11	0.632 6	0.585 0	0.507 5
C12	0.605 6	0.592 2	0.531 5
C13	0.611 9	0.580 5	0.537 1
C14	0.628 6	0.607 8	0.485 1

Table 11. Weighted normalization evaluation matrix

Evaluation element	Scheme score		
	Scheme X	Scheme Y	Scheme Z
C1	0.045 0	0.041 0	0.039 5
C2	0.149 7	0.149 7	0.144 1
C3	0.049 1	0.044 4	0.042 6
C4	0.052 1	0.052 1	0.050 6
C8	0.037 4	0.039 1	0.037 4
C9	0.035 1	0.035 3	0.035 1
C10	0.033 7	0.033 7	0.035 0
C11	0.019 5	0.018 1	0.015 7
C12	0.026 6	0.026 1	0.023 4
C13	0.033 7	0.032 0	0.029 6
C14	0.026 8	0.025 9	0.020 7

Table 12. Euclidean distance and relative closeness

Scheme	S_i^+	S_i^-	Ci	Order
X	0.001 7	0.014 3	0.893 4	1
Y	0.006 7	0.011 4	0.630 7	2
Z	0.013 8	0.004 2	0.232 7	3

3.3 The Calculation of Euclidean Distance and Relative Closeness Degree of the Three Schemes

Positive ideal solution F^+ and negative ideal solution F^- are obtained according to Table 11, which are

$$F^+ = \begin{pmatrix} 0.0450, 0.1497, 0.0491, 0.0521, 0.0391, 0.0353, \\ 0.0337, 0.0195, 0.0266, 0.0337, 0.0268 \end{pmatrix} \quad (2)$$

$$F^- = \begin{pmatrix} 0.0417, 0.1409, 0.0431, 0.0510, 0.0374, 0.0351, \\ 0.0337, 0.0157, 0.0235, 0.0294, 0.0207 \end{pmatrix} \quad (3)$$

The Euclidean distance and relative closeness degree C_i of the three fitness product schemes are calculated, as shown in Table 12.

The greater the value of C_i is, the closer the fitness product is to the optimal solution, and the better the scheme is. It can be found from Table 12 that the scheme X is obviously superior to the other two schemes.

4 Conclusion

By the use of AHP-TOPSIS, quantitative evaluation system of fitness equipment for the elderly overcomes the more subjective factors in the evaluation result depending on subjective impression, large deviation and the selected fitness equipment at variance with the characteristics of the elderly, which can objectively evaluate and select fitness equipment for the elderly. At the same time, it is easy to operate AHP-TOPSIS evaluation system, which is reasonable and scientific. With the continuous perfection of the quantitative evaluation system, the evaluation selection of fitness equipment for the elderly will be more reasonable and better serve the elderly and related designers.

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