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Research on treadmill design based on AHP and mass function expansion

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ABSTRACT

With the accelerated pace of life and outdoor running constrained by the environment and other factors, the consumption in treadmill is on the rise, and at the same time, the design of treadmill is more and more concerned. Starting from the customer demand, the user demand analysis method is formed by synthesizing KJ method, rough set theory, KANO theory and AHP, and combining with the prediction theory of destructive innovation technology. And the design requirements and their weights derived from the QFD model are used as the criteria for PUGH decision evaluation to select the optimal treadmill design solution. Finally, the treadmill design scheme is applied specifically. In the planned turnover analysis after the treadmill is put into operation, the turnover scale is increased from 0.73 billion yuan in 2016 to 180 million yuan in 2020. After the experimental test, both the percentile 10% of the female human body and the percentile 90% of the male human body in the treadmill to carry out some of the necessary actions are in a more comfortable state, at the same time, the various joints of the force and angle are in a reasonable range. The design program of this paper's method outputs better evaluation results, and meets the user's expectations.

Keywords: AHP, quality function development, KANO theory, treadmill design

1. Introduction

The proposal of "national fitness" has set off a fitness boom [1]. Accompanied by the material standard of living greatly improved, people will shift their attention to the construction of their own, on the shape and health of the focus gradually increased, fitness awareness is getting stronger and stronger, which makes the home fitness equipment market booming [2-3]. Economic development at the same time, the accelerated pace of people's lives, time fragmentation is serious, fitness gradually from the traditional gym fitness, outdoor sports transfer for indoor family sports, home fitness equipment market demand is increasing [4-6]. Some studies have found that there is no significant difference between the gait characteristics of running on a treadmill and road running on a flat surface at medium

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and low speeds [7-8]. When the running speed reaches a certain value, running on the treadmill will have the phenomenon of decreasing stride length and increasing stride frequency, but this change, after removing the effects of wind resistance and road conditions, has no different effect on running [9-10]. At the same time, due to its speed, slope, exercise intensity can be changed according to the demand, for more convenient and reasonable fitness provides the possibility, so the treadmill market size is still in the trend of year-on-year growth [11-13].

On the other hand, the update of technology changes people's lifestyle, the Internet upgrade of traditional products provides users with more choices, and hardware products are facing a new environment of replacement and upgrading [14-16]. Technological innovation has brought new possibilities to product design, “Internet +” product thinking to bring more product experience and services to users, home fitness equipment product design how to meet the current user needs, is a major problem faced by the home fitness equipment market [17-19]. Treadmill as one of the products with high purchase rate of home fitness equipment, but there are problems such as low usage rate, space occupation, lack of reasonable design of the mobile end of the product, and poor integration of modeling design and home environment [20-22]. Based on this, there is an urgent need to research and study the user needs of home treadmill, extract the design requirements from the needs and develop the design of home treadmill based on the human parameters of ergonomics.

The article firstly analyzed the customer demand under the framework of QFD research by using KJ method, rough set theory, AHP method and KANO theory, and constructed the customer demand analysis method based on QFD/RAHP/KANO. Then by combining Maslow's hierarchy of needs theory with user experience, the PUGH matrix judgment criteria were determined, and the application of the PUGH concept selection method in the treadmill design process was proposed. Subsequently, the requirements about treadmill design are collected by means of user interviews, and the RAHP is applied to determine the importance degree of user requirements. Meanwhile, taking into account that the user requirements attribute categories carry opinion information about user satisfaction, the FKM is utilized to divide the user requirements attribute categories, and the importance degree adjustment function is introduced to adjust the importance degree of user requirements. Then with the help of QFD, the mapping process of user requirements to design requirements is realized, which guides the completion of the program design of the treadmill. Finally, PUGH-based treadmill design scheme selection experiments are carried out, and the feasibility of the treadmill design scheme is examined through the changes in turnover and product effects.

2. User needs analysis based on QFD/RAHP/KANO

In this study, we will construct a customer demand analysis method based on QFD/RAHP/KANO under the framework of QFD research, and the analysis steps of this method are to conduct a customer demand survey by using the survey method of customer-designer bi-directional perspective, and to obtain the customer demand items. The KJ method is used to cluster the customer demand items and organize them to form a hierarchical structure of customer demand items. Calculate the basic importance of customer requirements based on RAHP. Categorize customer demand items based on KANO, and select the adjustment coefficient of basic importance of customer demand. Conduct market competitiveness analysis, calculate the original level increase rate, and adjust the level increase rate based on KANO classification. Finally, we synthesize the customer demand importance expressed in rough numbers and rough intervals based on the calculation results of RAHP customer demand basic importance and the results of market competitiveness analysis.

2.1. Hierarchical analysis of customer needs

2.1.1. Customer demand acquisition. The in-depth excavation and accurate grasp of customer needs are the basis for the success of treadmill design, and also the guarantee for the successful implementation of quality function. Therefore, only through more accurate and effective excavation of customer needs, it is possible to provide products and services that make customers satisfied. In the product design process, the first and key issue is to use the appropriate demand survey method to explore customer needs.

The current market demand survey methods can be divided into two categories according to the position and perspective of the survey design, the treadmill design demand survey questionnaire designed from the customer's perspective and the market survey designed from the designer's perspective. The treadmill demand survey designed from the customer's perspective is professional and meticulous, but there is the problem of low correlation between the output information of the questionnaire and the design elements, and there is the defect of generalization of the survey purpose. The questions in the market survey questionnaire designed from the designer's perspective are directly related to the design elements, but due to the designer's own lack of a comprehensive grasp of customer demand, survey question design skills, interview communication skills are relatively lacking, and the survey information is difficult to objectively reflect customer demand. Due to the complexity of customer demand, customer demand information expressed by the customer is often fragmented, superficial, unsystematic, there are many needs are customers are more difficult to realize and difficult to express [23]. Therefore, the customer needs obtained from interviewing consumers are not comprehensive and systematic enough. Comparatively speaking, designers are more systematic and professional in grasping the customer's needs, but the expression of the designer's information about the customer's needs in the interview process is often fragmented and unsystematic, and it is necessary to conduct an in-depth study of the market in order to more accurately grasp the preferences of the public consumers. Therefore, the customer demand survey is a continuous process of repetition and depth.

To improve the validity of the survey, it is necessary to improve the existing survey methods from a new perspective. In this paper, we will try to improve the existing market survey methods from the perspective of consumers and designers to improve the market output information, the relevance and effectiveness of the questionnaire survey and the operability of the survey, in order to achieve the survey of mass consumers on the design of the product under investigation. First of all, on the basis of interviews with product designers, to grasp the main points of concern of designers and their requirements for survey output information. Then, we conduct in-depth interviews with customers to understand the forms of questions that consumers can easily answer. On the basis of good communication with designers and consumers, the survey questionnaire is designed. Customer-designer two-way perspective of the survey method on the one hand, to avoid market research professionals overly refined to seek the full, a questionnaire can easily be 20, 30 pages, the output of the survey information is often tied up in the designers on the other hand, can also avoid the designers purely based on their own experience in treadmill market surveys, the questionnaire design, although simple, but is not a concern of customers' needs, market surveys can not reflect the real needs of customers. On the other hand, it can also prevent designers from conducting treadmill market survey purely based on their own experience. The customer-designer two-way perspective survey method can effectively guide designers to focus on customer needs in the conceptual design stage, integrate the professional knowledge and skills of market researchers and product designers, and greatly improve the quality of market research information.

2.1.2. Customer demand information analysis. The customer demand information obtained through the treadmill market survey is quite complicated, and there may exist a variety of different ways to express the same meaning Some customer demand information covers a wide range, and some are very narrow Some customer demand information contains other customer demand information. Therefore, it is necessary to cluster and streamline the customer demand information, using the affinity diagram method, the method of hierarchical analysis of customer demand information. It will use the method to group the needs, and the steps are Steps will be the customer needs of each item were recorded on the card Steps to avoid repetition, the expression of the meaning of the same content of the card will be discarded, the card will be lined up to be able to glance at the form Steps will be an expression of the content of the card with a similar meaning to be focused together, organized into several groups Steps and then naming the name that can represent the content of each group, recorded into the wavy card Steps and then Steps of the Wavy cards with similar content are organized into groups, then named to represent the content of each group in the step, and recorded on the diagonal cards. The name of the twill card in the step is the "sub-level" requirement, the name of the wavy card in the step is the "sub-level" requirement, and the content of the original card in the step is the "sub-level" requirement. An example of grouping for the KJ method is shown in Figure 1.

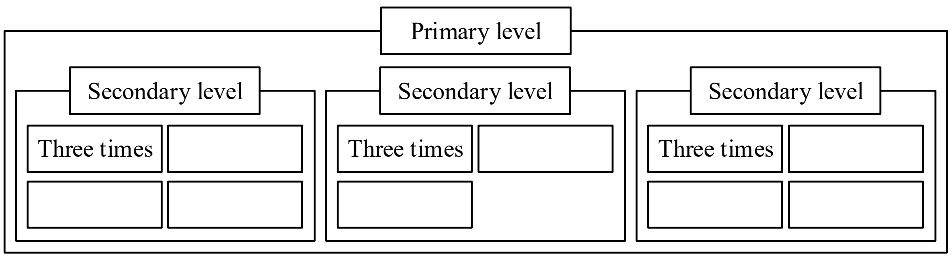

Fig. 1. The grouping example of the KJ method

2.2. RAHP-based method for determining the importance of customer needs

The AHP questionnaire was first conducted and consistency test was performed. Customers are solicited and invited to participate in the AHP questionnaire survey to obtain the AHP judgment matrix. Assuming that a customers participate in the AHP questionnaire survey, the AHP judgment matrix of these a customers can be expressed as:

$$P_k = \begin{bmatrix} 1 & P_{12}^k & \cdots & P_{1m}^k \\ P_{21}^k & 1 & \cdots & P_{2m}^k \\ \vdots & \vdots & & \vdots \\ P_{m1}^k & P_{12}^k & \cdots & P_{mm}^k \end{bmatrix} \tag{1}$$

Eq. $k = 1, 2, \ldots, a$.

Calculate the consistency ratio CR and perform consistency test on the judging matrix P_i. When $CR > 0.1$ adjusts the judgment matrix: when $CR < 0.1$, the consistency test is passed and the judgment information of the participating survey customers has consistency.

Find the rough pairwise comparison matrix. First construct the rough group decision matrix of customer demand judgment information, and find the roughness of each element in the matrix [24]. Take a AHP judgment matrix that passes the consistency test and construct the rough group decision matrix as follows:

$$P^* = \begin{bmatrix} 1 & P_{12}^* & \cdots & P_{1m}^* \\ P_{12}^* & 1 & \cdots & P_{2m}^* \\ \vdots & \vdots & & \vdots \\ P_{ml}^* & P_{m2}^* & \cdots & P_{mm}^* \end{bmatrix} \tag{2}$$

Eq. $P_{ef}^* = \{P_{ef}^1, P_{ef}^2, \ldots, P_{ef}^a\}$.

Find the roughness P_{ef}^k of each element contained in P_{ef}^*:

$$RN(P_{ef}^k) = [P_{ef}^{k-}, P_{ef}^{k+}] \tag{3}$$

Rough set P_{ef}^{*} for:

$$RN(P_{ef}^{*}) = \{[P_{ef}^{1-}, P_{ef}^{1+}], [P_{ef}^{2-}, P_{ef}^{2+}], ..., [P_{ef}^{a-}, P_{ef}^{a+}]\} \tag{4}$$

According to the algorithm of roughness number, the average roughness interval of P_{ij}^{*} is found to be:

$$RN(P_{ef}) = [P_{ef}^{-}, P_{ef}^{+}] \tag{5}$$

The rough pairwise comparison matrix is obtained:

$$P = \begin{bmatrix} [1,1] & [P_{12}^{-}, P_{12}^{+}] & \cdots & [P_{1m}^{-}, P_{1m}^{+}] \\ [P_{21}^{-}, P_{21}^{+}] & [1,1] & \cdots & [P_{2m}^{-}, P_{2m}^{+}] \\ \vdots & \vdots & & \vdots \\ [P_{m1}^{-}, P_{m1}^{+}] & [P_{m2}^{-}, P_{m2}^{+}] & \cdots & [1,1] \end{bmatrix} \tag{6}$$

In the formula, $\left[P_{ef}^{-}, P_{ef}^{+}\right]$ is a rough number, P_{ef}^{-} is its lower limit, P_{ef}^{+} is its upper limit, calculate the importance of each level of customer demand $RN(q_e)$, and finally synthesize to get the basic importance of isolated demand, multiply the importance of each level of customer demand by the importance of customer demand level, you can get the basic importance of the customer demand.

2.3. KANO modeling and customer demand weight adjustment methods

1) KANO Questionnaire and Classification Methods. For each quality attribute, two questions, forward and reverse, are asked to determine which category of demand each quality attribute belongs to according to the KANO classification table.

2) KANO classification and customer demand weight correction factor. The relationship between customer satisfaction and treadmill product performance that exists in the KANO model can be approximated quantitatively by the function $s = f(k, p)$, with s being customer satisfaction, p being product performance, and k being the adjustment coefficient for KANO classification.

Obviously, higher treadmill product performance leads to higher customer satisfaction, and the KANO model brings us much more than that.The KANO model tells us that each customer satisfaction attribute contributes different values to customer satisfaction, not only is the degree of importance of each satisfaction attribute to the customer different, but also the way in which the customer satisfaction attributes contribute to the total customer satisfaction is different. . Charismatic attributes can increase customer satisfaction more easily than course attributes, and they can increase customer satisfaction quickly as treadmill product performance improves. Therefore, corresponding to charismatic attributes, there are $\Delta s / s > \Delta p / p$, s and p for customer satisfaction and product performance levels, respectively, and Δs and Δp for incremental customer satisfaction and incremental product performance, respectively. Similarly, for one-dimensional attributes, there is $\Delta s / s = \Delta p / p$, and for course attributes, there is $\Delta s / s < \Delta p / p$.

Applying a parameter k, the above three relationships can be expressed by equation $\Delta s / s = k(\Delta p / p)$ for the charismatic property, $k > 1$. For the one-dimensional property, $k = 1$. For the course property, $0 < k < 1$. The equation can be further transformed into:

$$S = cp^{k} \tag{7}$$

In the above equation, c is a constant. Assume that s_0 and p_0 are the existing customer satisfaction and treadmill product performance levels, respectively, and s_1 and p_1 are the customer satisfaction target value and the desired treadmill product performance level, respectively. For the existing target state, there are $s_0 = cp_0^k$ and $s^1 = cp^k$, which are obtained:

$$\frac{s_1}{s_0} = \frac{cp_k^1}{cp_k^0} = \left(\frac{p_1}{p_0}\right)^k \tag{8}$$

So it can be obtained:

$$IR_{adj} = (IR_0)^{1/K} \tag{9}$$

In this equation, IR_{adj} is the adjusted level improvement rate. IR_0 is the original level improvement rate in the planning matrix in the QFD quality house. k is the KANO classification parameter. For course attributes, one-dimensional attributes and charismatic attributes, k values may be 1/2, 1, 2.

3. Construction of PUGH matrix for program evaluation

In the early stages of the design process, the right decisions for a treadmill product have a great deal to do with the success of the project. During the treadmill product design process, treadmill products require multiple reviews and decisions by team members from the sketching program to the final program. During the conceptual sketch stage, the design team generally conducts an internal evaluation of the many sketch solutions according to the project requirements and determines 3~4 creative directions. Then the design team supervisor, customer representatives, structural engineering designers, industrial designers, users, etc. form an evaluation group to select and weigh the 3~4 groups of design solutions according to the PUGH matrix judging criteria, and determine the advantages and disadvantages of the selected solutions. Finally, the design solution with the best user experience is determined through ranking, which lays the foundation for the development of treadmill products. In the prototype testing stage, the user experience of the treadmill product can be determined according to the user experience testing of the prototype by different testers.

3.1. Constructing PUGH Matrix Judgment Criteria

Maslow's hierarchy of needs theory proposes that human needs are like a ladder, divided into 5 types of needs from low to high according to the hierarchy: physiological needs, safety needs, social needs, respect needs and self-actualization needs. Mapping Maslow's Hierarchy of Needs Theory to the 3 types of experiences proposed by Norman, namely sensory experience, behavioral experience and emotional experience, the user research areas and directions in the product design process are specifically divided, and the criteria for judging the PUGH matrix in product design are determined according to the treadmill product design method as well as the research areas.

3.2. Product design based on user need hierarchy and user experience

Sensory experience, mainly focusing on the user's sensory needs, that is, the visual and tactile experience of treadmill products, mainly focusing on the aesthetics of product modeling and material comfort. Behavioral experience, mainly focusing on the interaction needs of the product, is a continuation of sensory experience, mainly including the reliability of the product use, the perfection of the function, the operability of the treadmill product, and the reasonableness of the product function layout and other aspects of the experience.

Emotional experience, the highest level of user experience, focuses on the user's emotional needs, social needs and self-needs, and refers to a continuation of the user's experience after using the product, including the image and impression of the treadmill product, the formation of brand loyalty, being able to communicate well with people, being friendly to people, and reflecting the user's personality and other aspects of the experience.

3.3. Selection of the PUGH matrix in product design programs

The PUGH matrix is divided into three main steps in the selection and weighing of treadmill product design options. In the first step, a benchmark option is identified by the assessment team based on key factors related to product design, combined with judgmental guidelines for option selection. In the second step, the evaluation team compares the optional solution with the benchmark solution and uses "+", "S" and "-" to rank the optional solutions, and when the optional solution is better than the benchmark solution When the option is better than the baseline option, "+" is used, and vice versa, when the option is worse than the baseline option, "-" is used, and for the same, "S" is used. In the third step, after completing the solution ranking, the ranking symbols of the optional solutions are counted, and the overall ranking of the optional solutions is calculated, resulting in the optimal solution. In the weighing process, in addition to determining the optimal program, the good aspects of other programs will be found, and the optimal program can be improved at a later stage by combining the good aspects of other programs [25].

4. Analysis of treadmill user requirements

4.1. Obtaining user requirements

In the research of determining the user needs of treadmill, semi-structured in-depth interviews were mainly used to obtain first-hand information. First of all, we screened the target users through online consultation and neighborhood visits, and the selection criteria were users who used treadmill products for more than half a year. 26 target users were finally identified as the target of this interview, among which 16 were female, aged 26-39. 10 were male, aged 25-42. After determining the interview subjects and making an appointment with them through online communication, the interviews were conducted with a prepared interview outline to collect first-hand information. After the interviews, the collected information was analyzed by means of group discussion, and 15 user requirements about treadmills were finally identified, and the KJ method was used to model the hierarchical division of the 15 user requirements for subsequent research.

4.2. Determining the importance of user needs

First of all, the target users are invited to compare the requirements of each level two by two based on the 1 to 9 degree scale method, and the user data are transformed into RAHP judgment matrix according to the formula, and the consistency test is performed on the judgment matrix according to the formula. From the consistency test results, it can be seen that the CR values are all in the range of 0 to 0.1, which leads to the conclusion that the judgment matrix constructed in the paper is more reasonable and passes the consistency test. According to the formula to further construct the rough pairwise comparison matrix F. After obtaining the rough pairwise comparison matrix F, according to the formula, we can get the importance degree of the morphology demand B1~B4. Similarly, we can get the importance degree of other user requirements at each level, and the weights of treadmill user requirements are shown in Table 1.

Table 1. The treadmill user demand weight

Target layer	Index layer	Subindex	Importance
Treadmill design(H)	Aesthetic design(B1)	Modelling (C1)contracted affinity	0.079
		Color collocation(C2)	0.036
		Strong safety(C3)	0.059

		In size(C4)	0.04
	Functional design(B2)	Core motion system design(C5)	0.098
		Ergonomics protection system(C6)	0.137
		Intelligent interaction matrix(C7)	0.047
		Spatial efficiency system(C8)	0.137
	Visual design(B3)	Visual interface hierarchy design(C9)	0.01
		Behavior guidance design(C10)	0.037
		Affective design(C11)	0.041
	Humanistic design(B4)	Ergonomic adaptation system(C12)	0.04
		Safety protection matrix(C13)	0.083
		Intelligent assisted ecology(C14)	0.055
		Scenario care design(C15)	0.101

4.3. Delineate user requirement category attributes

When dividing the user requirements of treadmill, the questionnaire was first made and completed based on the fuzzy Kano model. Then the user demand category attributes are divided according to the specific steps of the fuzzy Kano model for dividing user demand, and the results of the division of user demand of treadmill are shown in Table 2.

Table 2. User requirements for runners

User demand	Category frequency					Category attribute
	M	O	A	I	R	
C1	48	20	11	6	0	M
C2	57	21	0	4	0	M
C3	43	34	17	0	0	A
C4	54	23	1	2	0	M
C5	15	28	33	0	0	M
C6	26	41	14	0	0	M
C7	33	36	10	6	0	A
C8	72	10	2	0	0	M
C9	41	35	8	4	0	O
C10	18	25	34	0	0	O
C11	32	38	6	0	0	M
C12	41	24	11	4	0	M
C13	33	49	17	5	0	M
C14	43	23	4	5	0	A
C15	64	21	1	0	0	M

4.4. *Adjusting the importance of user requirements*

The importance is adjusted according to the formula to get the final importance of treadmill user demand, and the final importance of treadmill user demand is shown in Table 3.

Table 3. The maintenance of the treadmill user needs ultimately important

User demand	Initial importance	Requirements category	Adjustment factor	Ultimate importance
C1	0.079	M	0.5	0.02
C2	0.036	M	0.5	0.031
C3	0.036	A	0.5	0.028
C4	0.04	M	0.5	0.019
C5	0.098	M	1	0.156
C6	0.137	M	2	0.186
C7	0.047	A	2	0.007
C8	0.137	M	0.5	0.107
C9	0.01	O	0.5	0.035
C10	0.037	O	0.5	0.126
C11	0.041	M	1	0.04
C12	0.04	M	2	0.003
C13	0.083	M	0.5	0.095
C14	0.055	A	0.5	0.05
C15	0.101	M	1	0.097

4.5. *Transforming user needs*

In the process of the transformation from user needs to design requirements, through interviews with relevant technical personnel of the enterprise, collecting information related to the technical characteristics of the treadmill, and forming describable design requirements through further integration, the design requirements of the treadmill are shown in Table 4. The matrix of the relationship between user requirements and design requirements is shown in Table 5 (●, ○, △, and "blank" indicate that there is a strong correlation, medium correlation, weak correlation, and no correlation between user requirements and design requirements, and the values are 5, 3, 1, and 0, respectively). Finally, the importance of each design requirement is calculated to obtain the key design requirements to guide the completion of the design and development of the treadmill.

From the table, it can be seen that through a more in-depth analysis of user requirements and transforming them into specific design requirements, the weight of the treadmill shock absorbing device, noise module, intelligent detection module, cleaning module, and reaction device design adds up to more than 70%, which occupies a large proportion. Therefore, when designing the treadmill program, designers should focus on these important design requirements, such as treadmill reaction device, intelligent detection module, shock absorption module, cleaning module, and noise module design, so as to design a treadmill that meets the practical needs of users and has high user satisfaction.

Table 4. Design requirements of the treadmill

H_1	H_2	H_3	H_4	H_5	H_6	H_7	H_8	H_9	H_{10}
Form design	Shock absorber module	Noise module	Intelligent detection module	Removable structural design	Cleaning module	Information display module	Interaction design	Mobile module	Entertainment module

Table 5. The relationship matrix between user requirements and design requirements

User demand	Design requirement									
	H_1	H_2	H_3	H_4	H_5	H_6	H_7	H_8	H_9	H_{10}
C_1	●				●	△		△	△	
C_2	△					○		△		
C_3	○							△		
C_4	○									○
C_5		○	●	△						○
C_6		●	△	○		○				○
C_7				△						△
C_8				△						
C_9	△			●						
C_{10}	△						●	○		
C_{11}	△						●	○		
C_{12}	△			●			●	○		
C_{13}				○				○	●	
C_{14}	△				○					
C_{15}					●		○	○	○	
Importance	0.023	0.118	0.093	0.128	0.061	0.145	0.044	0.072	0.022	0.294
Sort	9	4	5	3	7	2	8	6	10	1

5. Selection and evaluation of PUGH-based treadmill design options

5.1. *Design Options Selection and Preliminary Evaluation*

In order to ensure that the evaluation has a certain reference value and the objectivity of the evaluation results, 8 designers and 4 technical engineers in the fitness machine R&D project in the enterprise are invited to form a decision-making group of 12 experts, and 8 treadmills with consistent modeling styles and market positioning are selected as the programs to be evaluated under the background of the same design demand, and the 12 expert panel members complete the preliminary evaluation of the program after discussion, comparison and comprehensive analysis. Preliminary evaluation of the program, treadmill interface design program coarse screening PUGH decision matrix shown in Table 6 (better than "+". Same as "S". Inferior to "-"). 12 members of the expert group voting results selected program B as the benchmark program, the other programs and program B for comparative evaluation, resulting in a comprehensive net score of each program and ranked from high to low. The last four options in the ranking were screened out, and the final options A, C, E and F entered the comprehensive conceptual scoring stage for detailed quantitative evaluation.

Program A shape simple and strong sense of design, the overall style of coordination and unity, can be folded, covers an area of small, goodbye to the past to give people a strong mechanized, cold feeling of the treadmill design, intelligent, fashionable sense of stronger can be more compatible with the home environment. The operation is simple, no matter any age group is very easy to get started; fewer buttons, easy to clean. The treadmill has a large display to watch videos, and the angle of the screen can be rotated as needed. The treadmill comes with an APP that can provide fitness tutorials and help users arrange reasonable fitness planning.

Option C has a strong sense of modeling, but also gives a sense of art, giving the product a language, so that it is not only a fitness product, but also a work of art, can be more integrated into the home environment, to enhance the attractiveness of the product itself. The overall design is simple and harmonized in all parts, and it can be folded with a small footprint. Say goodbye to the previous strong mechanized, cold feeling treadmill design, intelligent, fashionable sense of strong to meet the current aesthetic needs of users. And the operation is simple, no matter any age group is very easy to get started. Fewer buttons, easy to clean. The treadmill is designed with wheels underneath.

Program E has a strong sense of shape, gives a sense of art, can be more integrated into the home environment, but also be able to carry out two folding, one of the folding is the whole support bar counterclockwise turn down, the other folding is the upper part of the support bar folded down clockwise, and into the lower half of the armrests inside the folding, after two folding, so that the floor space is smaller. The operation is simple and easy to use for people of any age. There are fewer buttons for easy cleaning. The treadmill is designed with wheels underneath, making it easy to move and change the position of the treadmill. One of the desired type of demand also includes an emergency stop button design, the treadmill has a larger display screen to be able to watch videos, and the angle of the screen is also able to be rotated as needed. The treadmill also comes with an APP that provides fitness tutorials to help users organize reasonable fitness planning.

Solution F breaks through the previous cumbersome and mechanized treadmill design. The design plan is goodbye to the previous treadmill design that gives people a strong mechanized and cold feeling, and can be more integrated into the home environment. In addition to the support bar that can be folded on the running board, the handrail design can also be folded inside the support bar, making the footprint smaller. The operation is simple and easy to use for people of any age. There are fewer buttons for easy cleaning. The treadmill is designed with wheels underneath, making it easy to move and change the position of the treadmill.

Table 6. The running machine interface design side case sieve PUGH decision matrix

	The treadmill of the treadmill							
Parameter	A	B	C	D	E	F	G	H
Aesthetic design	+	+	S	-	+	S	+	-
Functional design	+	S	+	+	-	-	S	+
Visual design	+	S	S	+	-	-	-	+
Humanistic design	S	S	S	-	-	+	-	-
“+” total	0	4	-3	-1	0	0	3	1
“S” total	1	2	3	-1	-2	3	2	0
“-” total	2	0	-1	4	3	4	-1	5
Net fraction	3	6	-1	2	1	7	4	6
Sort	4	2	7	5	6	1	3	2
Abandon/continue	Continue	Abandon	Continue	Abandon	Continue	Continue	Abandon	Abandon

5.2. *Comprehensive evaluation of design options*

The questionnaire information is collated, analyzed and summarized, and the evaluation data of the 4 interface design schemes initially screened are counted in 4 aspects, namely, functional requirements, key characteristics, display characteristics and overall layout. Taking scheme B as the evaluation standard scheme (the evaluation scores of B are all 3), rating scheme A, D and F according to the 5-level evaluation standard, constructing the conceptual scoring PUGH decision matrix, combining the corresponding weighting values of each index, calculating the corresponding weighted scores of each scheme index according to Eqs. (6) and (7), and the comprehensive scores of the treadmill interface design schemes are shown in Table 7. According to the results of the data in the table, the treadmill design solutions are ranked as follows: Scheme E>Scheme A>Scheme C>Scheme F, i.e., Scheme E is the optimal design solution. In order to further optimize the design scheme to improve the operation efficiency of the treadmill interface and the satisfaction of user needs, Scheme E is improved and designed. As can be seen through the table, Scheme E scores low in the 2 design indexes of core exercise system design and scenario care design, which are 0.073 and 0.076, respectively, so further scheme optimization and detailed design are carried out for Scheme F in response to the relevant design requirements.

Table 7. Comprehensive scoring of the design of the treadmill interface

Design evaluation index		Weighting	Solution A		Solution C		Solution E		Solution F	
			Grade	Score	Grade	Score	Grade	Score	Grade	Score
B_1	C_1	0.02	4	0.347	3	0.237	5	0.427	2	0.161
	C_2	0.031	3	0.222	3	0.444	3	0.454	2	0.408
	C_3	0.028	3	0.476	3	0.36	5	0.356	2	0.325
	C_4	0.019	2	0.467	3	0.69	2	0.633	2	0.887
B_2	C_5	0.156	3	0.13	3	0.077	2	0.073	2	0.074
	C_6	0.186	4	0.474	3	0.449	2	0.496	2	0.468
	C_7	0.007	4	0.503	3	0.401	3	0.27	2	0.374
	C_8	0.107	3	0.087	3	0.093	5	0.142	2	0.082
B_3	C_9	0.035	3	0.058	3	0.047	4	0.041	2	0.089
	C_{10}	0.126	4	0.253	3	0.248	3	0.238	2	0.163
	C_{11}	0.04	3	0.415	3	0.231	3	0.44	2	0.162
B_4	C_{12}	0.003	3	0.206	3	0.451	4	0.476	3	0.395
	C_{13}	0.095	3	0.475	3	0.326	3	0.41	3	0.339
	C_{14}	0.05	2	0.472	3	0.634	3	0.629	2	0.89
	C_{15}	0.097	4	0.153	3	0.027	3	0.076	2	0.064
Comprehensive score			3.005		3.001		3.052		2.963	

6. Analysis of the inputs to the treadmill design program

6.1. Customer satisfaction and after-sales quality improvement

After applying QFD technology in treadmill design, the whole development process of the product is directly driven by customer demand, emphasizing the cost reduction planning in the conceptual design stage, and reducing the cost of subsequent engineering changes by increasing the start-up cost of customer research and communication. As a result, customer satisfaction with treadmill products has been greatly improved. Claims for treadmill after commissioning are shown in Figure 2.The after-sales claims ratio decreased significantly after the new product was put into production in 2021, from the highest 13.56% claims rate in 2019 to 4.32%.The after-sales quality improvement translates into quantifiable economic benefits is that the amount of claims can be reduced by more than 3 million per year under the circumstance of unchanged turnover.

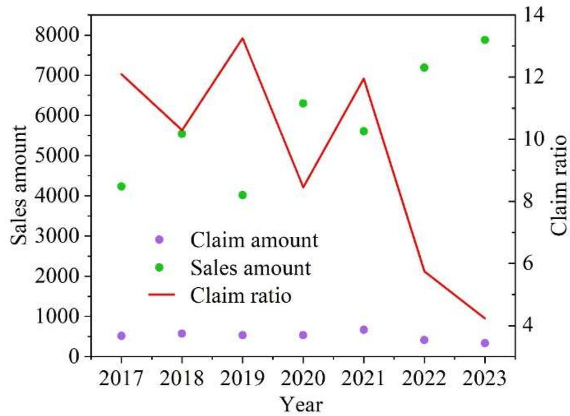

Fig. 2. The claim ratio of the running machine after production

6.2. New project acquisition and turnover increase

The planned turnover of the treadmill after commissioning is shown in Figure 3.After the new product was commissioned in 2018, the average growth rate of turnover was more than 16%, and it is expected that the total amount of supporting orders and orders in hand as well as potential orders will reach a sales scale of 180 million by 2023.The turnover of the treadmill segment, which was developed under the guidance of the QFD methodology, was raised from 73 million yuan in 2016 to 180 million yuan in 2020 billion dollars turnover scale.

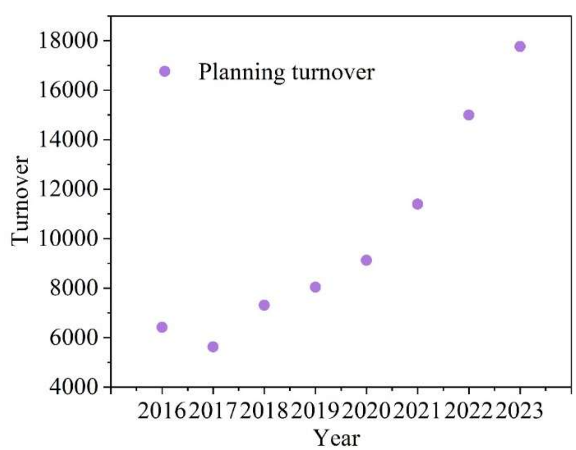

Fig. 3. The planning turnover after the running machine is put into operation

6.3. Product Effectiveness Analysis

6.3.1. Visualization analysis. In order to better verify the rationality of the treadmill design, two extreme human body parameters were selected for the visibility simulation during the visibility analysis, i.e., the female human body model with a percentile of 10% and the male human body model with a percentile of 90%. It can be seen that both the female human body with the percentile of 10% and the male human body with the percentile of 90% can easily and comfortably see the treadmill screen from any position on the treadmill, and the treadmill screen is within the field of vision and sight distance. This shows that the design of the treadmill in terms of visibility meets the ergonomic parameters.

6.3.2. Comfort analysis. The relative complexity of the factors and conditions affecting comfort results in comfort analysis being a difficult concept to quantify. In this software, comfort is judged based on analyzing the angles of the joints. When changing the body posture, whether the angle of each joint of the body is within a reasonable range. Based on the ergonomic data, a simple and quick comparative analysis is carried out to give the results of the comfort evaluation of the current posture.

Comfort analysis is also possible in ergonomics mode with the human body model selected. Select Comfort Analysis in the Comfort Analysis toolbar. For the accessibility analysis, two limiting anthropometric parameters were still selected for the comfort simulation, i.e., a female mannequin with a percentile of 10% and a male mannequin with a percentile of 90%. These virtual mannequins were allowed to perform virtual actions such as clicking on the screen, grasping the treadmill armrests, and running on the treadmill to determine the comfort level of the treadmill in terms of comfort. Both the 10th percentile female and 90th percentile male mannequins were in a more comfortable state when they performed the necessary actions on the treadmill, and the forces and angles of the joints were within reasonable ranges, and there is a small window on the left side to report the results of the comfort analysis. The maximum percentile male comfort level is shown in Table 8 to Table 10. The minimum percentile female comfort levels are shown in Table 11 to Table 13. Therefore, the design of the treadmill in terms of comfort is in accordance with the ergonomic parameters.

Table 8. The maximum percentage of men's hands are analyzed by the comfort level

Body part	Angle	Recommendation Angle	Score
Upper arm	14.04(Z)	-20-20	1
Right arm	23.08(Z)	-20-20	1
Left forearm	58.67(Z)	60-100	2
Right front arm	58.31(Z)	60-100	2
Left wrist	17.76(Z)	0-0	3
Right wrist	9.93(Z)	0-0	4
Left wrist twist	-8.11(X)	-90-60	1
Right wrist twist	13.41(X)	-90-60	1
Left leg	0(N)	0-0	1
Right leg	0.02(N)	0-0	2
Cervical vertebra	-0.68(Z)	-5-10	3
Lumbar	4.4(Z)	-10-0	1
Whole body	-	-	3

Table 9. The maximum percentage of male running comfort analysis

Body part	Angle	Recommendation Angle	Score
Upper arm	-14.07(Z)	-20-20	1
Right arm	9.42(Z)	-20-20	1
Left forearm	74.48(Z)	60-100	1
Right front arm	96.64(Z)	60-100	1
Left wrist	15.65(Z)	0-0	2
Right wrist	-5.74(Z)	0-0	3
Left wrist twist	-28.66(X)	-90-60	1
Right wrist twist	2.3(X)	-90-60	1
Left leg	0(N)	0-0	1
Right leg	0(N)	0-0	1
Cervical vertebra	-3.81(Z)	-5-10	2
Lumbar	2(Z)	-10-0	1
Whole body	-	-	3

Table 10. Analysis of the comfort level of the maximum male touch screen

Body part	Angle	Recommendation Angle	Score
Upper arm	1.08(Z)	-20-20	1
Right arm	40.8(Z)	-20-20	1
Left forearm	4.16(Z)	60-100	2
Right front arm	26.66(Z)	60-100	2
Left wrist	3.22(Z)	0-0	2
Right wrist	-13.47(Z)	0-0	2
Left wrist twist	-6.84(X)	-90-60	1
Right wrist twist	2.35(X)	-90-60	1
Left leg	0(N)	0-0	1
Right leg	0(N)	0-0	2
Cervical vertebra	-0.92(Z)	-5-10	2
Lumbar	6.38(Z)	-10-0	1
Whole body	-	-	3

Table 11. Analysis of the comfort level of touch screen of the minimum percentile female

Body part	Angle	Recommendation Angle	Score
Upper arm	-6.37(Z)	-20-20	1
Right arm	7.31(Z)	-20-20	1
Left forearm	11.11(Z)	60-100	2
Right front arm	88.96(Z)	60-100	1
Left wrist	-1.1(Z)	0-0	1
Right wrist	-16.64(Z)	0-0	1
Left wrist twist	-7.89(X)	-90-60	1
Right wrist twist	7.21(X)	-90-60	3
Left leg	0(N)	0-0	1
Right leg	0(N)	0-0	2
Cervical vertebra	1.62(Z)	-5-10	1
lumbar	6.62(Z)	-10-0	2
Whole body	-	-	3

Table 12. The minimum percentage of women running

Body part	Angle	Recommendation Angle	Score
Upper arm	-30.65(Z)	-20-20	2
Right arm	6.93(Z)	-20-20	1
Left forearm	87.27(Z)	60-100	1
Right front arm	97.45(Z)	60-100	1
Left wrist	-21.46(Z)	0-0	1
Right wrist	5.6(Z)	0-0	1
Left wrist twist	-18.67(X)	-90-60	1
Right wrist twist	9.24(X)	-90-60	2
Left leg	0(N)	0-0	1
Right leg	0(N)	0-0	2
Cervical vertebra	-2.54(Z)	-5-10	1
Lumbar	1.89(Z)	-10-0	1
Whole body	-	-	3

Table 13. Analysis of the comfort level of touch screen of the minimum percentile female

Body part	Angle	Recommendation Angle	Score
Upper arm	16.86(Z)	-20-20	1
Right arm	23.64(Z)	-20-20	1
Left forearm	60.7(Z)	60-100	2
Right front arm	71.28(Z)	60-100	1
Left wrist	13.55(Z)	0-0	1
Right wrist	15.82(Z)	0-0	1
Left wrist twist	-18.2(X)	-90-60	3
Right wrist twist	21.77(X)	-90-60	1
Left leg	0(N)	0-0	1
Right leg	0(N)	0-0	1
Cervical vertebra	5.13(Z)	-5-10	2
Lumbar	6.22(Z)	-10-0	1
Whole body	-	-	3

7. Conclusion

At this stage, people's demand for fitness is gradually deepening, the fitness equipment market is unprecedentedly hotter than ever, and the service consciousness of product design should also be upgraded. This article from the source of the design of the demand side of the acquisition of the user's intention and product design knowledge closely combined, after continuous modification and screening to arrive at the design of the treadmill, and the final design of the program was evaluated in order to ensure that the user's use of the comfort of the user to the greatest extent possible to enhance the user's satisfaction. The article draws the following conclusions:

1) After putting the treadmill solution on the market, it was found that the claim ratio of the treadmill decreased significantly after the commissioning of the treadmill in 2021, from the highest claim ratio of 13.56% in 2019 to 4.32%. And the turnover increases from 0.73 billion dollars in 2016 to 180 million dollars in 2020.

2) After the experience using the treadmill designed in this paper, the 10th percentile female human body and the 90th percentile male human body feel that exercising on the treadmill is in a more comfortable state, and that the forces and angles of the joints are within a reasonable range.

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