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Research Article

Research on the Evaluation Method of Elderly Wheelchair Comfort Based on Body Pressure Images

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With the continuous deepening of the global aging process, more and more users demand wheelchair. In the interaction between users and wheelchairs, comfort is a crucial factor. In order to provide a set of effective evaluation of wheelchair comfort, this study makes use of the back propagation neural network (BPNN) and analyzes the body pressure index by combining with the subjective evaluation in the wheelchair comfort evaluation. As shown by results, the neural network simulation values and 13 groups of wheelchair comfort levels have been obtained from the analysis of the BPNN on the wheelchair of the elderly, and the relative error of the actual comfort value is basically within 5%. At the same time, the three sets of network verification results reveal that the error between the actual value and the simulated value is 1.9%, -1.5%, and 2.5%, respectively, which basically reflects that this comfort evaluation system can quickly, conveniently, effectively, and scientifically provide wheelchair tactile comfort evaluation.

1. Introduction

On the one hand, the number of elderly people and elderly wheelchair users is increasing [1]. On the other hand, with the continuous development and rise of social and living standards, people's requirements for comfort are gradually increasing. The wheelchair user, as a very special group, is very sensitive to the comfort of wheelchairs. Apart from that, the comfort of the wheelchair will directly affect the life quality of the elderly group. Nowadays, the physical functions of the elderly are gradually declining. Compared with the young and middle-aged groups, the physical fitness of the elderly is greatly weakened [2]. Moreover, many elderly people must rely on wheelchairs to maintain their daily activities. Hence, the research on the comfort of wheelchairs is imminent. Indeed, it is not only the pursuit of manufacturing companies to produce comfortable wheelchairs suitable for the needs of the elderly but also the hope of the elderly. However, the comfort in the sitting position [3] is a very complex system. The difficulty of the research lies in that the wheelchair comfort can be affected by human physiological and psychological factors. Particularly, there are few special studies on the evaluation system for the comfort of elderly wheelchairs. Thus, this paper refers to the research on the comfort of ordinary seats and the comfort of car seats, which also involve human sitting posture and physiological characteristics. For example, the Dutch researcher Groenesteijn et al. [4] explored the factors that affect the comfort of seats through differences in sitting and posture activities during work tasks. In 2000, Fujimaki and Mitsuya [5] and Park et al. [6] studied the comfort of using a new VDT seat with a keyboard. At the same time, they used 3D imaging technology to measure the fatigue of muscles and found through the experiment that VDT seat has a high comfort. Furthermore, Shackel proposed a method of comprehensive evaluation of comfort using four seats. To be specific, the first method is using the work performance within a certain period of time as the evaluation standard of wheelchair comfort. The second is using the psychological evaluation scale as the subjective evaluation method. The third is evaluating body movements and posture records to reflect comfort. The fourth is the objective feedback of comfort based on the physiological factors of the people who are suitable for the seat [7]. In addition, Leatherwood et al. used the two indicators of vibration and noise as the input of the model and established the model of the seat comfort evaluation system [8]. In order to analyze the influencing factors of car driving discomfort, Reed et al. [9] performed a three-hour driving simulation experiment on experimental individuals. Besides, Japan's last key [10, 11] proposed a quantitative evaluation method for the comfort of car seats, analyzed the influencing factors of car seat comfort, found out the physical quantities corresponding to the influencing factors, and evaluated the comfort according to the characteristics of these physical quantities. Besides, Helander and Zhang [12] adopted two subjective evaluation scales to assess the subjective comfort of office chairs from multiple dimensions and established a subjective evaluation model of office chair comfort. At the same time, Chiba University and Hunan University cooperated to use psychometric methods and fuzzy measurement methods, adopted subjective evaluation methods to probe into the comfort of car riding, and successfully established the overall subjective comfort evaluation model of seats [13]. With the help of fuzzy mathematics theory, Hongwei et al. [14, 15] established a fuzzy relationship with factors that affect comfort and proposed a method for evaluating the comfort of car seats. Beyond that, Levrat and Voisin [16] used the multistandard fuzzy theory model to set up an evaluation model for the comfort of the seat. The model is aimed at the discomfort of different types of seats and the evaluation of the discomfort of different parts of the seat. Obviously, although the above studies on the comfort of car seats and ordinary seats related to human sitting posture and physiological characteristics have great reference value for the evaluation of wheelchair comfort, most of the above evaluation methods are based on an objective or subjective dimensional research [17–21], and the research results remain controversial.

Admittedly, a lot of comfort assessment methods have various advantages and disadvantages, but the establishment of a more scientific evaluation system is indeed of great significance for the evaluation of wheelchair comfort. Some studies began to use BPNN for similar assessment and prediction. For example, Han et al. constructed a hybrid GA-BP model to effectively evaluate and screen out scientific design options [22]. What is more, Hsu et al. adopted the nonlinear ANN model approach to provide a better representation of the rainfall-runoff relationship of the medium-sized Leaf River basin near Collins, Mississippi [23]. In this paper, the seat surface pressure experiment in the body pressure distribution is combined with subjective evaluation, so as to explore the relationship between subjective comfort assessment and pressure distribution indicators and provide a theoretical basis and data support for BPNN simulation prediction. Furthermore, based on the BPNN that has self-learning capabilities and can accurately describe the nonlinear relationship between data, this paper establishes a wheelchair comfort evaluation model, uses the obtained parameters and the basic information of the subjects as input data, and inputs it into the BPNN prediction model. Besides, the overall wheelchair comfort evaluation score is used as the output data of the network. Finally, a better evaluation model of generalization and fault tolerance is established to achieve quick and efficient prediction of wheelchair tactile comfort.

2. Methods

2.1. BP Neural Network. The BPNN [24, 25] described by McCelland and Rumenlhart in 1968 is a multilayer feedforward network trained by the error back propagation algorithm. Meanwhile, it can imitate the manufacturing and analysis of the human brain in the process of identifying things. In fact, the learning state of things is one of the most commonly used and most popular neural networks (see the algorithm flow in Figure 1). The BP artificial neural network consists of three levels: input, output, and hiding. Each level consists of a certain number of neurons. Each of these neurons has a threshold, and each level is connected by weight. The relationship between the two levels of input and output can be regarded as a mapping relationship; namely, each set of input corresponds to a set of output, and the relationship is represented by the weight (or threshold), and then, the problem is processed. In terms of fault tolerance, it has a relatively good BPNN, which can be studied using the nonlinear fitting ability of the nonlinear relationship between variables and targets.

Firstly, the sample data should be obtained as an indicator of neural network training. Second, the BPNN needs to be trained. Third, the data parameters of the corresponding problem need to be input into the neural network. The final step is to get the corresponding problem through the neural network algorithm. It is noteworthy that this algorithm has the disadvantages of slow convergence and insufficient local extremum, but it can still be improved by various methods to overcome the local extremum phenomenon. The algorithm is simple, easy to operate, does not require too much calculation, and has strong parallelism. This study builds a wheelchair haptic comfort evaluation model based on the neural network algorithm, mainly because the artificial neural network not only has better nonlinear approximation ability but also can more accurately depict the nonlinear relationship between various body pressure distribution experimental indicators and wheelchair comfort. With better learning ability, this network can overcome the local extreme value through the learning of a large number of samples, thus eliminating the errors caused by subjective factors of individual samples.

2.2. Sitting Posture Body Pressure Distribution Test and Subjective Comfort Evaluation

2.2.1. Research Object. In order to make the experimental data have obvious differences, in the experiment, 18 products of different types from 9 popular brands of different wheelchairs of different manufacturers and different materials had been selected. Then, the overall appearance and details of the 18 wheelchairs were processed. Apart from that, coverage materials and cognitive value were analyzed in many aspects, and the wheelchair types with greater similarity were integrated. Finally, 5 representative wheelchairs of different types were obtained [23], which were, respectively, denoted

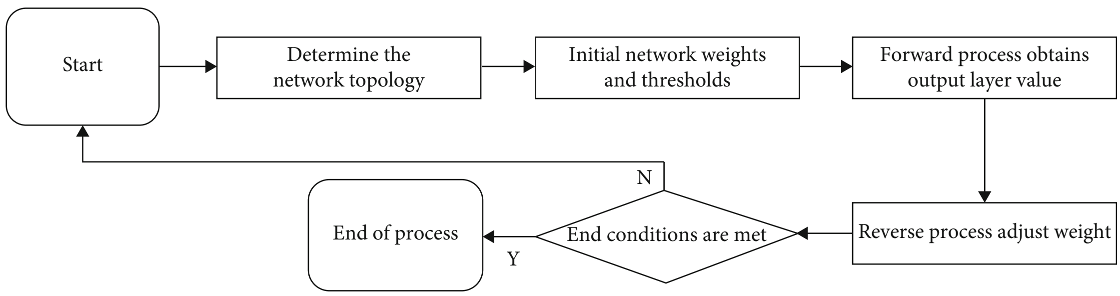

Figure 1: Algorithm flow of BPNN.

Table 1: Basic information of the subjects (partial data).

Number	Sex	Date of birth	Height (cm)	Weight (kg)
X1	Men	1951.7	170	50
X2	Women	1947.6	159	49
X3	Men	1944.3	173	69
...	...	...	...	...
X16	Men	1953.1	172	65

as C1–C5. In addition, 16 applicable subjects were selected as the subjects of the experiment, denoted as X1–X16, including 10 males and 6 females. At the same time, their height and weight were measured (see the data of the experimenters in Table 1). During the experimental test, the subjects were asked to dress loosely and comfortably so as to avoid subjective feelings and body pressure distribution due to uncomfortable clothing. During the whole experiment, the subjects should actively cooperate with the experimenters to complete the experiment according to the requirements. Apart from that, the experimenters can read books, play music, and watch TV. However, if there is an obvious discomfort within a short period of time, it is necessary to inform the experimenter timely.

2.2.2. Sitting Posture Pressure Distribution Test. The pressure distribution of the sitting position, which refers to the pressure distribution of the weight of the human body to the seat surface in the sitting position, can be used as the main index factor for evaluating the comfort of the seat. The pressure exerted by the weight of the upper body of the human body on the seat surface of the office chair is not evenly distributed. As shown by practice, the pressure distribution of the seat surface in a good sitting posture is as follows: the maximum pressure is the nodule of the ischium. From the inside to the outside, the pressure presented to the surroundings has a law of decreasing distribution, and the contact point between the front edge of the seat and the thigh reaches the lowest value (see the reasonable pressure distribution of the human body sitting on the seat in Figure 2).

The American Tekscan body pressure distribution system was used for body pressure distribution test [26]. Its advantage lies in that its grid-shaped flexible film structure has the better flexibility. Beyond that, the thickness of the flexible film structure is less than 0.1 mm, which is convenient for measuring various contact pressure between surfaces. With the aid of computer-aided software, it can not only intuitively display two-dimensional and three-dimensional color images as well as pressure distribution values of various data points but also perform corresponding data index analysis. In this experiment, 16 subjects were free to adjust the wheelchair posture during the sitting pressure distribution test until they achieved a comfortable sitting posture. Then, this study read the contact area and pressure characteristic data representing the sum of the sensor area of all the pressure units of the seat surface and backrest, including the average pressure (PV): the arithmetic average value of the pressure of all the pressure unit sensors; maximum pressure (PM): the maximum value of all measuring points on the seat surface sensor; total pressure: mainly reflects the overall effect of pressure stimulation on the human body. Through the above data, this study could get the correlation between the heights of the comfort of the 5 wheelchairs under the pressure of the sitting position.

As shown in four graphs (a)–(d) in Figure 3, the ordinate in graph (a) represents the value of the average pressure, while the abscissa represents five different types of wheelchairs. In terms of the average pressure, the most direct factor affecting the average pressure is the rigidity of the seat surface and is greatly affected by the shape of the seat surface. This study read the average pressure value of seat C2 < C3 < C1 < C4 < C5, indicating that seat C2 is the softest and C5 is the hardest. As shown in (b), in terms of the maximum pressure, C2 < C3 < C4 < C1 < C5. The total pressure reflects the overall effect of pressure. As displayed in (c), the total pressure value of each seat under the pressure of the sitting position is not much different. The order of the contact area is C2 > C3 > C4 > C1 > C5. Among them, the contact area of the C2 wheelchair is significantly larger, and there is no significant difference between the other four wheelchairs. It can be observed from the stress test that the comfort of the four wheelchairs is ranked from high to low as C2 > C3 > C4 > C1 > C5. At the same time, wheelchair C2 has the highest comfort, while C5 has the lowest comfort.

2.2.3. Subjective Comfort Evaluation. In the sitting pressure distribution test, the subjects were asked to sit in a wheelchair to evaluate the comfort [27]. Then, they were evaluated using a seven-level evaluation scale, and specific scores were given. The higher the comfort level, the higher the score, and the lower the comfort level, the lower the score. The scoring

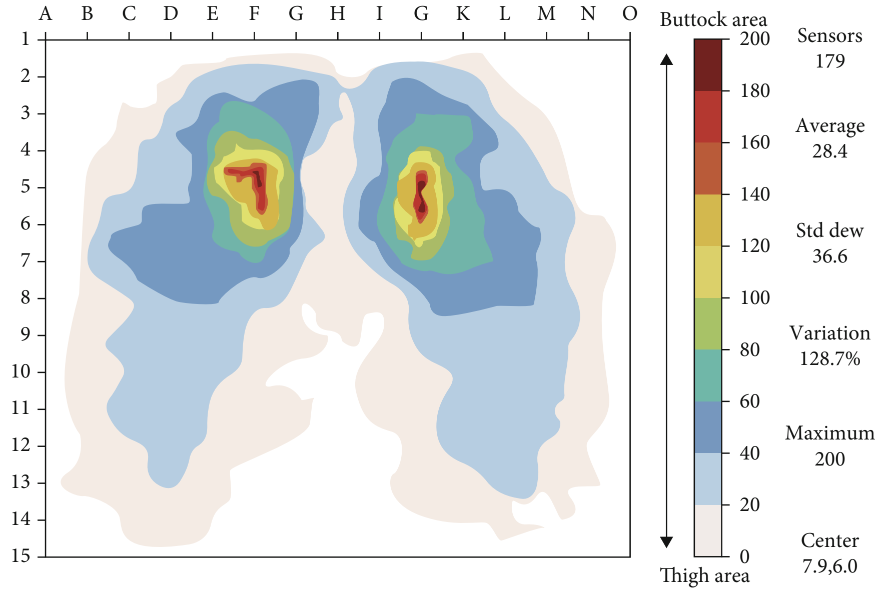

Figure 2: Pressure distribution diagram of human sitting seat surface.

range is from 0 to 10, with 0 being extremely uncomfortable and 10 being extremely comfortable. Through this method, the overall evaluation scores of 16 subjects on the comfort of five types of wheelchairs could be obtained. As shown in Table 2, from the perspective of wheelchair subjective comfort scores, seat C2 has the highest overall comfort score of 7.24. Additionally, the overall comfort score of C3 was 7.01, which also exceeded 7 points. Besides, the overall comfort score of C4, C1, and C5 was 6.97, 6.95, and 6.68, respectively. Combining the above data of the body pressure distribution experiment, this study found that the subjects' subjective comfort score is basically consistent with the objective test result of the body pressure distribution, and the order of comfort from high to low is C2 > C3 > C4 > C 1 > C5.

2.3. Evaluation of Wheelchair Comfort Based on BPNN. The BPNN was used as the analysis method for wheelchair evaluation. Beyond that, the three-layer network structure was divided into input, output, and hidden three layers. The training process includes two forms of positive and negative propagation. Apart from that, Wi, j and Wk, j were used. The two sets of data, respectively, represent the weights of neurons input to the hidden layer and hidden layer to the output layer. Figure 4 presents the structure of the neural network.

The first thing that needs to be performed is encoding and normalization. The 13 sets of sitting pressure data were selected as sample data, and the remaining 3 sets of codes X, Y, and Z were chosen as verification samples. The input parameters of the neural network are contact area, average pressure, maximum pressure, total cushion pressure, height of the occupant, and weight of the occupant, of which the contact area, average pressure, maximum pressure, and total cushion pressure are important descriptors of pressure characteristics The parameters of the occupant's height and weight are important anthropometric parameters, and these factors are significant indicators of the pressure distribution on the surface of the wheelchair. What is more, the neural network output is the occupant's subjective comfort score. Since the training function needs to output parameters in the interval $[0, 1]$, the values obtained by the interviewee's perceptual evaluation results are not completely within this interval. In order to get the due attention to each evaluation index, the parameters in the evaluation results are prenormalized. As shown by the research results, when the output layer activation function uses a logarithmic function, it is relatively best to normalize the input and output variables into the $[0.1, 0.9]$ interval. Apart from that, a simpler and faster normalization algorithm was used to predict the comfort of office chairs. The equation can be expressed as

$$X_i = 0.1 + 0.8\frac{X_i - X_{\min}}{X_i - X_{\min}}. \tag{1}$$

Among them, $X_{\min}$ represents the minimum value of X, and the maximum value is $X_{\max}$. Then, 13 groups of schemes were selected into the model for random training. In the training, 0.01 was set as the learning rate, the expected error was set to 0.001, and 3000 times was set as the maximum number of learning. As shown by the data, when the number of iterations reaches the 2310th time, the mean square error is $0.00099 < 0.001$. At this time, the training achieves the goal and stops iterating. At this point, the BPNN model of wheelchair comfort could be obtained.

3. Results

After the BPNN model of wheelchair comfort was obtained, this study used the acquired network to simulate 13 sample simulation programs so as to obtain the simulated value score of the training sample score. As shown in Table 3, the relative

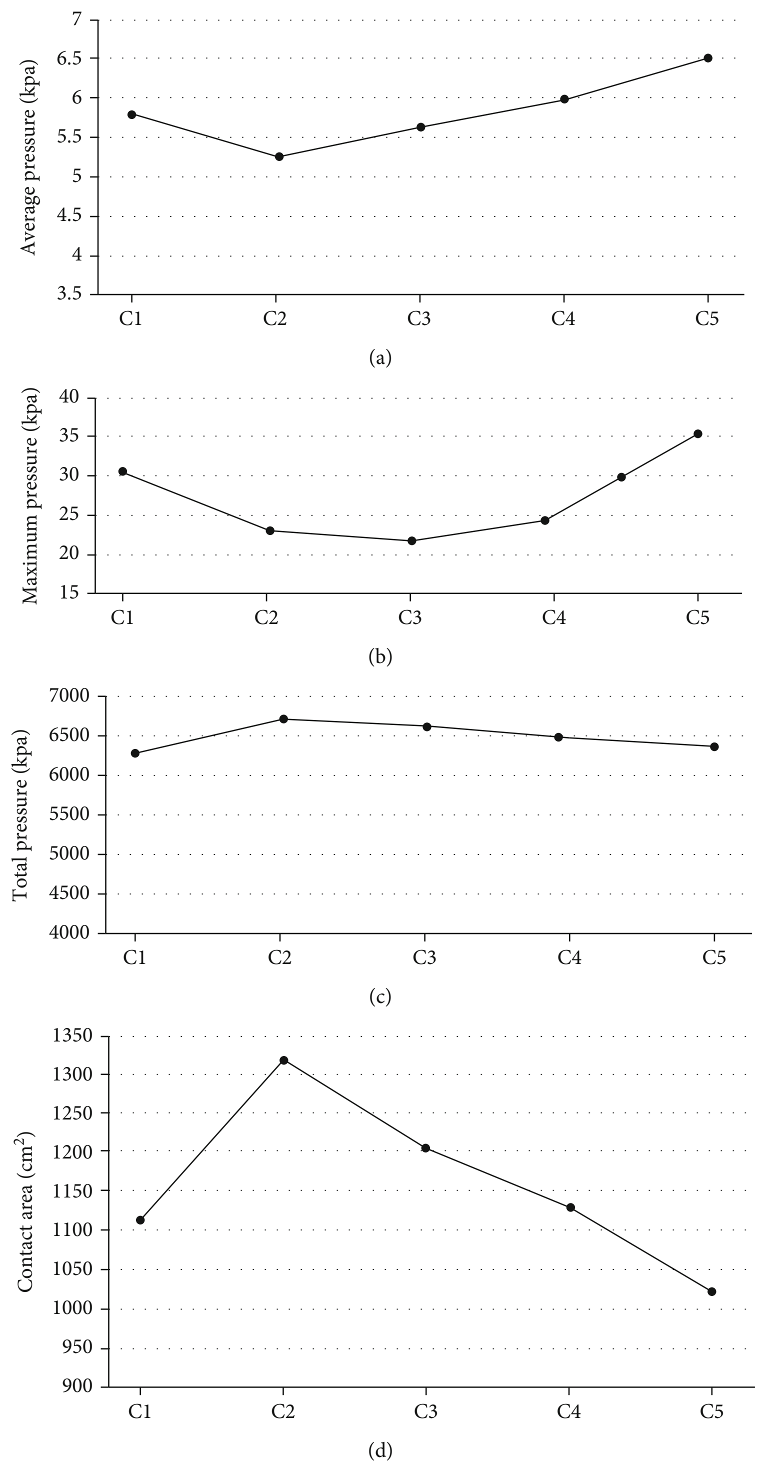

Figure 3: Test chart of body pressure distribution (a–d).

error between the BPNN simulation score of the 13 groups of wheelchair comfort levels obtained from the analysis of the BPNN on the wheelchairs of the elderly and the actual score of the comfort level is basically within 5%. Meanwhile, the results of small changes in the simulated and actual values during training show that the accuracy of the sample scheme reached a higher accuracy during training.

In order to further verify the overall performance of the evaluation system, the remaining three schemes X, Y, and Z were used to verify the BPNN system for comfort evaluation after training. If the verification fails, the network needs to be trained a second time. Besides, the training can be performed multiple times until the verification accuracy meets the requirements. The relative error is used to evaluate the

Table 2: Seat comfort score.

Number	X1	X2	X3	X4	X5	X6	X7	X8	X9	X10	X11	X12	X13	X14	X15	X16	Mean
C1	6.0	5.0	6.5	6.5	6.3	7.5	8.6	7.5	6.5	6.8	8.0	8.0	7.6	6.0	7.6	6.8	6.95
C2	7.0	6.6	8.5	8.0	6.5	6.0	7.0	7.5	7.0	6.5	7.0	9.0	6.5	7.0	8.0	7.8	7.24
C3	7.2	6.0	7.0	6.5	8.1	7.0	6.5	6.5	7.5	6.0	6.9	7.4	7.5	7.0	8.0	7.5	7.01
C4	6.5	6.5	7.5	6.5	6.5	8.0	6.8	6.5	7.0	7.0	8.0	7.2	8.0	5.5	6.5	7.5	6.97
C5	7.0	5.9	6.5	6.2	7.0	7.5	7.0	6.2	6.5	8.0	6.0	6.5	6.5	6.0	6.5	7.5	6.68

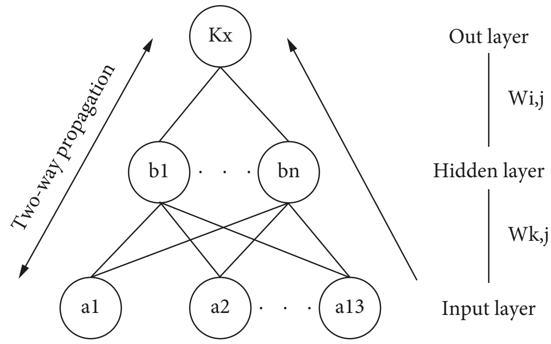

Figure 4: Three-layer BPNN structure.

Table 3: Errors between actual comfort data and virtual network data (partial data).

Number	Actual comfort score	Network output score	Relative error (%)
1	6.0	5.918	-1.4
2	7.0	7.112	1.6
3	7.2	7.413	3.0
...	...	...	...
13	6.5	6.625	1.9

error of the verification scheme (see the verification results in Table 4). The simulation output values of the three verification schemes X, Y, and Z are 7.132, 7.881 and 7.086, respectively, and the relative errors with the actual value of the evaluation are recorded as 1.9%, -1.5%, and 1.2%, respectively, which has high accuracy. Therefore, this comfort evaluation model is judged to be the optimal combination plan, which provides an effective method for the elderly wheelchair comfort evaluation and prediction. Apart from that, this evaluation model can be used as a scientific guide for evaluating the elderly wheelchair tactile comfort.

4. Discussion

This study first analyzed the correlation between the sitting pressure distribution test and subjective comfort. Then, it used the BPNN to establish a comfort evaluation model and trained 13 groups of randomly selected programs through the network to evaluate the generalization performance of the system. Furthermore, the reserved 3 sets of programs were used to verify the trained BPNN. According to the results, the relative error obtained when evaluating the wheelchair comfort of the elderly based on the BP model is basically within a reasonable range of 5% so that the evaluation of the wheelchair comfort of the elderly based on the BP model can be implemented.

Table 4: Network verification data.

Verification scheme	Evaluation actual value	Network output value	Error re. (%)
Scheme X	7	7.132	1.9
Scheme Y	8	7.881	-1.5
Scheme Z	7	7.086	1.2

However, as shown in Table 5, the data screened by correlation analysis still cannot exclude all contradictory parameters or data, and there are still some individual relative errors that exceed this range. Besides, the office chair comfort prediction data in the table is the one with the actual subjective evaluation value. The error rate is 6.1%, and the main reason for the relative error exceeding 5% is that comfort is a very complicated system. Although this study has combined with subjective evaluation to introduce the office chair comfort assessment in terms of the pressure distribution of the person-seat contact surface, the comfort of office chairs can be affected by many factors, such as individual factors including artificial vision and psychological comfort. Meanwhile, this is largely affected by many other factors such as environmental factors and human test status. The forecast is slightly different. Therefore, for the construction of the BPNN, it is best to have computer professionals with more professional computer software knowledge to participate in the construction of a more reasonable office chair comfort evaluation and prediction neural network. Secondly, it is necessary to choose the network input and output parameters more reasonably and focus on the selection of network input parameters, so as to avoid the overlap between the data parameters and ensure that the input data parameters have more obvious characteristics. In response to this problem, this paper can continue to expand the scope of research, increase the sample size, and increase or decrease the neural network input indicators accordingly so that the input parameters of the network training samples could have better representation. In the wheelchair comfort evaluation research, the class of testees, behavior habits, wheelchair use environment, etc. should also be considered.

Table 5: Relative error between actual value and predicted value.

Number	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
Relative error (%)	-1.4	1.6	3.0	2.5	6.1	-1.5	4.6	2.4	-4.1	1.8	3.7	4.0	1.9	1.9	-1.5	1.2

5. Conclusion

This research reference is also related to the research on the comfort of ordinary seats and the comfort of car seats under the sitting posture and physiological characteristics of the human body. First, the American Tekscan body pressure distribution system is used to test the selected 5 wheelchairs in terms of the sitting posture and pressure distribution. Later, it is combined with the assessment of subjective comfort. Furthermore, the obtained parameters and the basic information of the subjects are used as the input data and input into the BPNN prediction model. Besides, the evaluation score of the wheelchair's overall comfort is taken as the output data of the network to establish and train it with good generalization. In short, the fault-tolerant evaluation model has realized the quick and efficient prediction of the tactile comfort of elderly wheelchairs. The difference between the training data value and the actual value of the program is basically not more than 5%, which is within the allowable range of engineering application.

The relative errors of the BPNN after training using the three reserved schemes are 1.9%, -1.5%, and 1.2%, respectively. At the same time, the verification results show high accuracy. Therefore, this evaluation system plays a great role in evaluating the complex system of wheelchair tactile comfort, which can help wheelchair manufacturers evaluate the comfort of wheelchairs, improve the life quality of elderly wheelchairs users, and make products more competitive. With further research, this paper will improve the rational selection of network input and output parameters, research scope, and sample size. In this way, the performance of this BPNN-based wheelchair tactile comfort evaluation system will continue to improve, and the scope of application will also be more extensive.

Data Availability

The datasets of this paper for the simulation are available from the corresponding author upon request.

Conflicts of Interest

The author declares that there are no conflicts of interest.

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