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Quantitative assessment of the training effect of taijiquan on adolescents' physical coordination based on particle swarm optimization algorithm

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ABSTRACT

Taijiquan is a kind of sport that can be used as a national fitness program, and its effect on the training effect of adolescent physical coordination has important research value. In this paper, particle swarm optimization algorithm is applied to the optimization of taijiquan training program, and independent samples test and analysis of variance (ANOVA) are used to investigate the quantitative impact of taijiquan training on adolescents' physical coordination. The results show that the particle swarm optimization algorithm can effectively improve the effect of taijiquan training, and the algorithm convergence and other properties have obvious superiority compared with other algorithms. At the same time, after the experiment, all the physical coordination test indexes of the experimental group were significantly improved compared with the pre-test and the control group, which explains the important role of taijiquan training in the physical coordination training of adolescents.

Keywords: particle swarm optimization algorithm, independent sample test, analysis of variance, physical coordination

1. Introduction

Particle swarm optimization algorithm is a kind of optimization algorithm based on group intelligence, which simulates the behavior of biological groups such as flocks of birds or schools of fish, and searches for the optimal solution through continuous iteration. The basic idea of particle swarm optimization algorithm is to transform the problem to be optimized into a search problem in a multi-dimensional space, each solution is regarded as a particle in the space, the position of each particle represents the parameter value of the solution, and the velocity represents the direction and speed of the solution [1-4]. In each iteration of the algorithm, each particle will update its speed and position according to its own historical optimal solution and the group optimal solution, in order to find a better

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solution. It has been widely used in various optimization problems [5-8].

Youth is the future of the motherland, and the physical quality of the youth will directly affect the physical fitness and health of the whole nation. However, with the continuous improvement of people's living standard, the overall physical quality of adolescents has been declining instead of rising, the physical fitness indicators continue to show a downward trend, and the overweight and obesity rate continues to show an upward trend, which seriously affects the health and psychology of adolescents [9-12]. Taijiquan is a traditional Chinese martial art with rich cultural connotations, and the functions of Taijiquan in strengthening the body and cultivating the mind have received more and more attention. Especially for the physical and mental health development of young students, it has a very important role [13-16]. By practicing taijiquan, it has an obvious effect on improving the coordination of adolescent body. Enhancing the physical coordination of adolescents helps to increase their physical flexibility, improve the speed of movement, promote the circulation of qi and blood, and safeguard the health of the body. In addition, taijiquan has a great effect on cultivating students' perceptual ability and improving concentration [17-20].

This paper briefly introduces the origin and development, basic movements and characteristics of Taijiquan, and analyzes the applicability of Taijiquan in adolescent physical coordination training. The particle swarm optimization algorithm is used to optimize the parameters in the Tai Chi training program, so as to improve the effect of physical coordination training for adolescents. Indicators applicable to adolescent physical coordination testing were selected through literature review and field observation, and a middle school was selected to carry out a taijiquan training experiment. SPSS software was used to statistically analyze the collected data, and the effectiveness of particle swarm optimization algorithm in the optimization of taijiquan training program was analyzed according to the numerical simulation results of the four standard test functions. The intergroup results of the experimental group and the control group before and after the experiment, as well as the intragroup results of the experimental group and the control group after the experiment, were compared and statistically analyzed to quantitatively and intuitively illustrate the effectiveness of the taijiquan training in improving the physical coordination of the adolescents.

2. Basic Tai Chi movements and characteristics

2.1. The Origin and Development of Tai Chi Chuan

Taijiquan originated in China during the Ming Dynasty by Chen Wangting of Chenjiagou, Wen County, Henan Province [21]. It is an internal martial art that combines martial arts, fitness, and body cultivation. After centuries of development, several schools of Taijiquan have been formed, such as Chen style, Yang style, Wu style, Sun style, etc. Each school has its own unique style. Each school has its own unique style and characteristics, but all of them emphasize the core concept of “combining motion and static, rigidity and flexibility”. Since its birth, Taijiquan has been loved and respected by countless enthusiasts all over the world. Nowadays, it is not only a kind of self-defense martial art, but also one of the important means of national fitness.

2.2. The basic movements of Tai Chi Chuan

The movements of Taijiquan seem to be simple, but they contain rich connotations and profound philosophies, and the contents of its basic movements are shown in Table 1. The names of these movements are not only beautiful, but also each movement has its unique technical and fitness effects.

Table 1. The basic action of taijiquan

Numbering	Action name	Numbering	Action name
1	Potential	13	Right kick

2	Part the wild horse's mane on both sides	14	Shuangfengguan Ear
3	White crane bright wing	15	Turn and kick with left heel
4	Brush knee and twist step on both sides	16	Left bottom independent moment
5	Han strums the lute	17	Right bottom independent moment
6	Left and right inverted humerus	18	Work at shuttles on both sides
7	Left holding sparrow tail	19	Underwater needle
8	Right holding sparrow tail	20	Flash arm
9	Single whip	21	Turn to strike
10	Cloud hand	22	Apparently closing
11	Single whip	23	Cross hands
12	Gaotan Ma	24	Closing form

2.3. Characteristics of Tai Chi Chuan

Unlike other martial arts, Taijiquan has the following distinctive features:

1) Slow. Taijiquan moves softly and slowly, emphasizing on waiting for movement with quietness and overcoming rigidity with softness. Through slow movements, the practitioner can better appreciate the subtle changes in each move and style, thus achieving the purpose of physical and mental exercise.

2) Roundness. Taijiquan's movements are mainly circular and arc-shaped, emphasizing coherence and roundness, like flowing clouds and water. This kind of movement helps to improve the coordination and flexibility of the body.

3) Internal and External Unity. Taijiquan emphasizes both internal and external movements, i.e., not only practicing external movements, but also focusing on the inner year and the regulation of breathing. Through the practice of guarding the dantian and sinking the qi in the abdomen, one can achieve the realm of unity of body and mind.

4) Combining rigidity and flexibility. Taijiquan emphasizes flexibility in rigidity and rigidity in flexibility. Every move contains a combination of rigidity and softness, and this harmonious beauty of unity of opposites is the unique feature of Taijiquan.

5) Spiral Twisting. The movements of Taijiquan are mostly in the form of spiral, so that the power constantly changes direction and size in operation, forming a kind of winding effect. This spiral movement can effectively exercise the muscles and joints, and enhance the coordination and stability of the body.

2.4. Advantages of Tai Chi in youth training

As a low-intensity and high-efficiency exercise program, taijiquan is very suitable for young people to train their body coordination. Its advantages are reflected in the following aspects:

1) High safety. Taijiquan movements are slow and gentle, not easy to cause sports injuries, which is suitable for the characteristics of adolescents' physical development.

2) Comprehensive. Taijiquan movements cover strength, flexibility, balance and coordination and other aspects of physical quality exercises, which can improve the physical fitness level of adolescents.

3) Interesting. Taijiquan movements are beautifully named and rich in cultural connotations, which can stimulate young people's interest and enthusiasm in learning.

4) Psychological adjustment. Taijiquan emphasizes that the mind is quiet and the body is loose, and through practice, it can help teenagers to relieve pressure, regulate their emotions and improve their psychological quality.

3. Particle swarm optimization algorithms

PSO algorithm is a population smart optimization algorithm, which is a group intelligence algorithm derived after the collective feeding behavior of bird flocks as well as fish schools, which adjusts the distribution trajectory by the position of each particle itself and its neighboring particles in space [22]. They find that the behavior of individuals in a group alone seems extremely simple and aimless, but for the group as a whole, their behavior is highly purposeful and always follows a certain pattern.

3.1. Algorithm overview

Birds and schools of fish have many organized behaviors, for example, bats can fly through dark and narrow caves without any obstacles and geese can change their formation at will while soaring through the air, these phenomena are known as swarm phenomena. Particle Swarm Optimization Algorithm is a population intelligence algorithm that can simulate the behavior of groups of people like flocks of birds and schools of fish to gain insights into social behavior, similar to other evolutionary computation algorithms, this is an iterative population based algorithm.

The particle swarm optimization algorithm solves the optimization problem where each bird is considered as a particle and as a solution problem, the location of food is considered as the global optimal solution and each particle approaches the food to find the optimal solution.

1) The original particle swarm algorithm. The original particle swarm algorithm can be described in a concrete mathematical way, when searching a D-dimensional space, a population with a total of n particles is assigned an initial velocity for each particle. The i rd particle has a velocity vector $v_i = (v_{i1}, v_{i2}, \ldots, v_{id})$ to represent its current velocity, and a position representation vector $x_i = (x_{i1}, x_{i2}, \ldots, x_{id})$ to represent its current position, in addition, particle i will maintain its own historical best position vector of $pbest_i = (pbest_{i1}, pbest_{i2}, \ldots, pbest_{id})$, and the best position vector for all the population particles of $gbest = (gbest_1, gbest_2, \ldots, gbest_d)$. The particles' own velocities and positions are continually updated through iterations, which can be specifically expressed as:

$$v_{id}(t+1) = v_{id}(t) + c_1 r_1 (pbest_{id} - x_{id}) + c_2 r_2 (gbest_{id} - x_{id}) \tag{1}$$

$$x_{id}(t+1) = x_{id}(t) + v_{id}(t+1) \tag{2}$$

where the coefficient c_1 is the cognitive ability of the particle's own learning and c_2 is the cognitive ability of the particle's social learning. c_1, c_2 is usually set to 2, or adaptively controlled according to the update state. These two learning factors should not be set too large or too small, too small will cause the particle to fly away from the search space, and too large will cause the particle speed to be too large and fly through the search space. r_1, r_2 are two random numbers ranging between [0, 1], in order to control the flight speed in a reasonable range, $v_{\max d}$ is used to control the update speed. It can be obtained that the particle velocity updating process consists of 3 parts: 1 is the velocity of the particle before updating, 2 is the self-knowledge part of the particle, and 3 is the social learning part of the particle. The composition of these 3 parts consistently affects the current particle's ability to search the global optimal solution in the feasible domain.

2) Standard particle swarm algorithm. On the basis of the original many scholars have amended the algorithm and introduced the idea of inertia weights, and the speed formula is as follows:

$$v_{id}(t+1) = wv_{id} + c_1 r_1 (pbest_{id} - x_{id}) + c_2 r_2 (gbest_{id} - x_{id}) \tag{3}$$

The improved algorithm is called the standard particle swarm algorithm, and they found that a change in the value of w changes the PSO search ability. When w is on the small side and the speed of the algorithm changes very little, the local search becomes stronger and the global search becomes weaker. Similarly, when w is large, the global search capability becomes stronger with it. So in order to balance the searching ability and achieve the maximum searching effect, a kind of linear decreasing weights has been proposed with the variation of Eq:

$$w(t) = w_{ini} + \frac{w_{fin} - w_{ini}}{t_{\max}} \cdot t \tag{4}$$

In this equation, t is the current iteration number, $t_{\max}$ is the maximum iteration number. $w(t)$ is the value of inertia weights in the tth generation, w_{ini} is the initial inertia weights, and w_{fm} is the final inertia weights. After many tests, the improved inertia weights make the PSO algorithm converge stably.

Some scholars have also introduced a compression factor to the original particle swarm algorithm. After adding the compression factor, the formula becomes:

$$v_{id}(t+1) = \chi(v_{id}(t) + c_1 r_1 (pbest_{id} - x_{id}(t)) + c_2 r_2 (gbest_{id} - x_{id}(t))) \tag{5}$$

Among them:

$$\chi = \frac{2}{|2 - \phi - \sqrt{\phi^2 - 4\phi}\,|} \tag{6}$$

is the compression factor, $\varphi = c_1 + c_2$. If $\varphi \geq 4$, then the algorithm is guaranteed to converge. Generally $c_1 = c_2 = 2.05$ is taken when using this algorithm, which is $\varphi = 4.1, \chi = 0.729$.

3.2. Algorithm Flow

By dissecting the basic principles of PSO, the algorithm steps can be described as follows:

1) Initialization operation. Set the parameters such as the number of iterations, population size and so on, and set all the particle speeds and positions in the specified range, and make distance restrictions on the word change range.

2) Adaptation value calculation. The individuals in the population are taken and the optimal value $pbest$ and global optimal value $gbest$ are calculated by the function, respectively.

3) Iterative Optimization. Update the velocity and position of each particle according to the established rule formula.

4) Evaluation of particles. Every time a particle moves to a new position, it needs to calculate the adaptation value and compare it with its own historical optimal value $pbest$, and the better value is taken as the individual's optimal value, and at the same time, the global optimal particle value $gbest$ is refreshed.

5) Output results. When the end condition is not reached, go to step 2 and continue to execute downward until the end, and find the value $gbest$ in the specified number of iterations and its corresponding position is the final solution.

3.3. Application of Algorithms in Taijiquan Evaluation

In the evaluation of taijiquan training effect, particle swarm optimization algorithm can be used to optimize the training parameters to improve the training effect. The specific application ideas are as follows:

1) Feature extraction. Key features are extracted from the taijiquan training data, such as movement frequency, practice time, and heart rate variation.

2) Adaptation function design. Design the adaptability function to evaluate the effect of different training programs. The fitness function can be based on body coordination test indicators, such as balance, reaction time, etc.

3) Parameter optimization. Use PSO algorithm to optimize the training parameters to find the best combination of training programs. For example, the practice time and sequence of each movement are optimized to maximize the training effect.

4) Model training and validation. Apply the optimized training scheme to actual training, collect data and validate. Evaluate the optimization effect of the PSO algorithm by comparing the test results under different schemes.

5) Result Analysis and Feedback. Analyze the effectiveness of the training scheme according to the validation results and provide feedback to further improve the optimization algorithm.

Through the above steps, the particle swarm optimization algorithm can effectively improve the scientificity and accuracy of taijiquan training effect assessment.

4. Taijiquan training effect evaluation model and experimental design

4.1. Selection of evaluation indicators

The selection of physical coordination test indicators is mainly divided into four steps. First, summarize and analyze the relevant literature by reviewing the test methods of adolescents' physical coordination and the literature on coordination test indexes and methods in various countries. Second, based on the physical development characteristics of adolescents, as well as the observation and analysis of the test site, the selected test indexes are in line with the physical development characteristics of adolescents, and are easy to operate, scientific and other characteristics, so as to preliminarily determine the relevant measurement indexes. Third, the preliminarily selected test indexes were screened for the second time, and modifications and additions were made. Fourth, according to the results of the experts' questionnaire, the scores of the indicators were collated and combined with the experts' suggestions, the indicators were screened for the third time. The final established index system for adolescent physical coordination test is shown in Table 2. The system contains 6 evaluation dimensions (balance, agility, flexibility, strength and endurance, movement accuracy and cardiorespiratory function), and 10 evaluation indexes (standing time on one foot with eyes closed, walking on balance beam, reaction time, speed of change of movement, seated forward bending, grip test, number of sit-ups, rate of basic movement in place, step index, and lung capacity) are the test indexes in this paper.

Table 2. Adolescent physical coordination test index

Evaluation dimension	Evaluation index	Description
Balancing ability(A1)	Closed single foot standing time(A11)	Test the ability of adolescents to maintain balance in a static state and reflect their stability and control
	Balance beam walking(A12)	To assess adolescent dynamic balance and coordination ability by walking on the balance beam
Sensitivity(A2)	Reaction time(A21)	Test the sensitivity of adolescent neuroresponse by testing simple reactions

	Movement change speed(A22)	Record the speed of youth conversion between different movements to assess their sensitivity and coordination
Flexibility(A3)	Sit and reach(A31)	Test the maximum distance of the young people in the precursors, and respond to their flexibility and muscle elongation
Strength and endurance(A4)	Grip test(A41)	Measure the strength of the young hand and forearm by measuring the grip
	Number of sit ups(A42)	The strength and endurance of abdominal muscles that reflect the number of sit-ups completed in a minute
Accuracy of action(A5)	Basic action accuracy rate(A51)	Using the PSO algorithm to evaluate the accuracy of teenagers in performing the basic action of tai chi
Cardiopulmonary function(A6)	Step index(A61)	Test the steps of the steps to assess the youth's cardiopulmonary endurance and aerobic activity
	Lung capacity(A62)	Test the maximum exhalation of the adolescent deep inhalation, response to the pulmonary ventilation function and the muscle strength of the breathing muscle

4.2. Experimental design and methodology

4.2.1. Study population and subgroups. In this study, 30 adolescent students in a middle school were selected as experimental subjects and randomly divided into 15 in the experimental group (receiving taijiquan training) and 15 in the control group (not receiving any training). There was no significant difference between the two groups in terms of gender and age, and they were comparable. The duration of the experiment was 6 months, and the experimental group received taijiquan training 3 times a week for 90 minutes each time. The control group did not undergo any specific training.

4.2.2. Design of training programs. The training content of the 15 people in the experimental group was 24-style simplified taijiquan, and the 15 people in the control group only practiced the physical activities required for daily life and physical education classes, and none of them performed any other additional training activities.

1) Frequency and duration of practice in the experimental group. September 5 to 12, 201 focused on learning taijiquan, September 12 to February 15, 2022 (6 months) for formal training volume, three times a week, Monday and Friday morning 9:00-10:30, Wednesday afternoon 14:00-15:30, 90min each time.

2) Training place. School athletic field.

3) Arrangement of single exercise for the experimental group
(1) 5min preparation activity.
(2) Practicing Taijiquan once with music accompaniment, about 6min.
(3) 4min interval.
(4)Repeat (2) and (3) about 8 times.
(5) Relaxation exercise for 5min

4) Exercise intensity control
During the simplified taijiquan training using a medium-high stance, the heart rate is controlled at 90-100 beats/min.

4.3. Data acquisition and processing

4.3.1. Data collection methods. The data collection was divided into two parts: the measurement of the basic physical indicators of consciousness, but rather the measurement of the effect of taijiquan training. The specific methods are as follows:

1) Measurement of basic body indexes. Before the beginning and after the end of the experiment, all subjects were measured for basic body indexes, including height, weight, blood pressure, etc.

2) Measurement of Taijiquan training effect. Measurements of taijiquan training effects were performed on all subjects before the beginning of the experiment and at the end of each month, specifically including the evaluation indexes selected above. Balance ability was measured by standing time on one foot with eyes closed and balance beam, reaction time was measured by pressing the light test, movement accuracy was scored by PSO algorithm, etc. All measurements were converted to scoring data within [0,100] according to the interval.

4.3.2. Data processing and analysis methods. Data processing and analysis were performed using SPSS software. Statistical methods included descriptive statistical analysis, independent samples t-test [23] and ANOVA, etc., and the specific steps were as follows:

1) Descriptive statistical analysis. Descriptive statistical analysis was performed on the collected data to calculate the mean and standard deviation.

2) Independent sample t-test. Compare the changes in the indicators of the experimental group and the control group before and after the experiment to test the effect of taijiquan training.

3) Analysis of variance. Analyze the trend of each index at different time points to test the time effect of Taijiquan training.

4.4. Application of Particle Swarm Optimization Algorithm

4.4.1. Application Strategies. Particle swarm optimization algorithm is applied to optimize the taijiquan training program in this study with the following steps:

1) Initial parameter setting. Set the initial position and velocity of the particles, each particle represents a possible training scheme.

2) Adaptation calculation. Calculate the adaptation degree value of each particle according to the adaptation degree function. The fitness function is based on the combined score of the above evaluation indexes.

3) Update velocity and position. Update the velocity and position of each particle according to the formula so that it gradually approaches the optimal solution.

4) Judgment of termination conditions. Judge whether to meet the stopping conditions (such as reaching the preset number of iterations or the adaptability threshold), if so, output the optimal training program, otherwise return to step 2 to continue iterating.

5) Result verification. The optimized training scheme is applied to actual training, and data collection and analysis are carried out to verify the optimization effect.

Through the above steps, the particle swarm optimization algorithm can effectively optimize the taijiquan training program and improve the effect of physical coordination training for adolescents.

4.4.2. Effectiveness analysis. In this section, the data on physical coordination of adolescents collected in the training experiment is used. The particle swarm optimization algorithm is implemented in VC++ programming under Visual Studio2005.net environment, where the maximum velocity of the particles is $v_{\max} = 20, c_1 = c_2 = 3, r_1 = r_2 = 0.5$. In order to verify the effectiveness of the algorithm, the number of iterations of the particle swarm algorithm in the experiment is taken as 100, 200, 300, and the number of particles is taken as 50, 100, 150, 200, 250.Then the average and optimal solutions under each group of iterations are solved for Then solve the average solution and optimal solution under each set of iterations.

Hardware environment: Intel(R) Core(TM)2 CPU 6320.

Operating system: Microsoft Windows.

Software environment: Visual Studio.

1) Solution results. Table 3 shows the solution results of the particle swarm optimization algorithm for the taijiquan training scheme. From the table, it can be seen that the PSO algorithm can effectively solve the optimal training program, and with the number of iterations and the number of particles increasing, the weight value of the particles will gradually decrease. When the number of particles increases to 250, the result of particle solving becomes larger, which shows that the particle swarm algorithm has a greater impact on the results of solving the problem according to the setting of the appropriate parameters, the number of particles is set to 200 is more ideal, and the average solution is better, so it can realize the effective optimization of the taijiquan training program.

Table 3. The result of PSO algorithm

Particle number	Iteration number		
	100	200	300
50	34073.62	32731.43	30536.83
100	30483.71	30172.11	28473.54
150	29826.53	28433.64	26715.94
200	27468.49	26828.19	24836.47
250	29836.74	29534.23	27954.38
Mean solution	30337.82	29539.92	27703.43
Optimal solution	27468.49	26828.19	24836.47

2) Comparison of training effect before and after optimization. In order to verify the effect of particle swarm optimization algorithm, this study applies it to the optimization of taijiquan training program. Figure 1 shows the comparison of training effect before and after optimization. From the figure, it can be seen that the optimized training program is better than the unoptimized program in all evaluation indexes. In particular, there is a significant improvement in balance and movement accuracy, in which the average value of balance score increased from 42.65 to 82.69. The mean value of the movement accuracy score increased from 51.35 to 83.91, which indicates that the particle swarm optimization algorithm has an important role in improving the training effect of taijiquan.

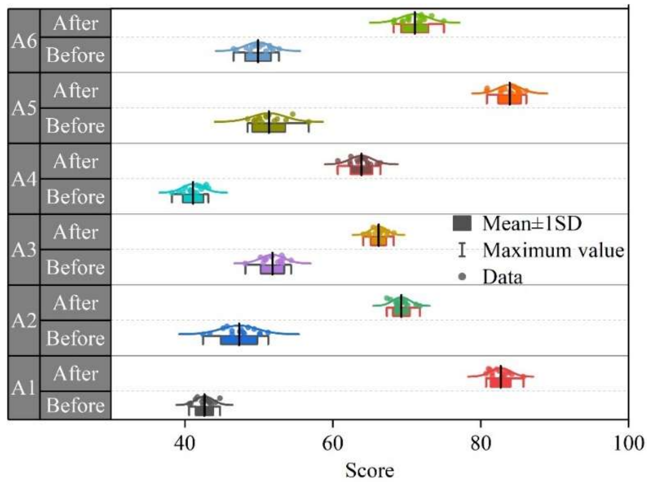


Fig. 1. Compare the training effects before and after optimization

3) Algorithm performance analysis. In order to verify the performance and effectiveness of the PSO algorithm, four commonly used standard test functions are selected for numerical simulation. Among them, functions f_1 and f_2 are single-peak functions, and f_3 and f_4 are multi-peak functions. The single-peak function f_1 is bowl-shaped, f_2 is valley-shaped, the two single-peak functions are smooth surfaces and there is only one point of minimal value, mainly to test the algorithm's optimization accuracy, function f_3 is a bowl-shaped multi-peak function, the function of the minimum mechanism is surrounded by a number of peaks hidden, mainly to test the function's ability to search for the global optimal ability and optimization accuracy of the comprehensive performance. Multi-peak function f_4 is a plane-shaped multi-peak function, the minimum extreme value is in the middle of many valleys, the main test function of the global optimization ability.

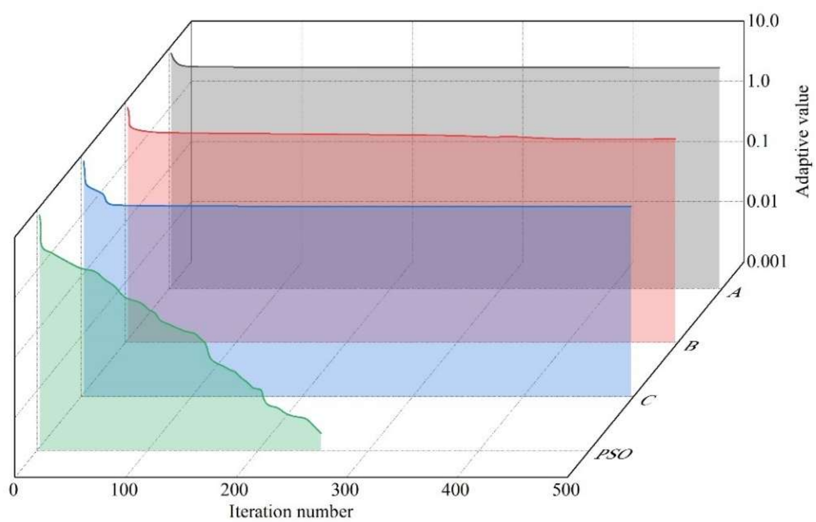
In order to show the superior performance of the PSO algorithm in this paper relative to other algorithms, three optimization algorithms (A, B and C) are selected for comparative analysis. The four test functions are taken in order of dimension $D=10, D=20, D=30$, number of particles $N=200$, 500 iterations and 30 independent runs. Table 4 shows the experimental results of the algorithms on the test functions, the data in the table show that when the dimensions of the test functions are set to 10, 20, 30, respectively, whether it is a single-peak function or a multi-peak function, the PSO algorithm's optimization stability and optimization amplitude are significantly better than that of Algorithm A. Compared with Algorithm B and Algorithm C, there is a certain degree of optimization effect on functions f_2 and f_3. For the single-peak function, the optimization results of PSO algorithm for function f_1 are better than the other three algorithms, and the optimization accuracy is obviously improved. For function f_2, the optimization result of PSO algorithm is better than the other algorithms, but the improvement effect is not ideal, because function f_2 provides little information to the algorithm, the algorithm is not easy to find the guiding point, and it cannot accurately identify the search direction, and it is difficult to search globally, and the algorithm falls into the local optimum. For the multi-peak function, as the function f_3 dimension increases, the change of the search accuracy is not obvious, the PSO algorithm's search accuracy is better than other algorithms, and significantly better than Algorithm A. The PSO algorithm can effectively jump out of the local optimum for the function f_4, and take the ropeway global optimal solution, with strong robustness.

Table 4. Algorithm comparison results

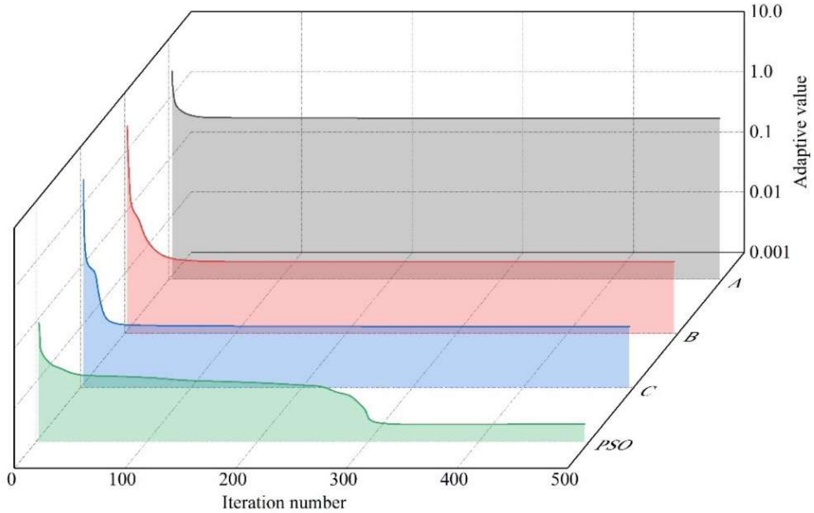
Function	Algorithm	D=10		D=20		D=30	
		Mean	SD	Mean	SD	Mean	SD
f_1	A	1.836	1.382	1.547	1.289	1.328	1.173
	B	1.132	1.178	1.084	1.043	1.036	1.009

	C	0.978	1.236	0.953	1.172	0.837	1.047
	PSO	**0.274**	**1.087**	**0.146**	**0.959**	**0.098**	**0.728**
f_2	A	1.935	1.282	1.733	1.271	1.614	1.159
	B	1.352	1.071	1.247	1.013	1.138	1.001
	C	1.276	1.094	1.258	1.054	1.124	1.015
	PSO	**1.176**	**0.953**	**1.113**	**0.858**	**1.097**	**0.756**
f_3	A	2.828	1.837	2.674	1.796	2.611	1.732
	B	2.816	1.825	2.653	1.784	2.608	1.767
	C	2.807	1.829	2.612	1.788	2.594	1.714
	PSO	**2.794**	**1.735**	**2.573**	**1.692**	**2.525**	**1.683**
f_4	A	0.983	1.031	0.874	0.989	0.734	0.852
	B	0.351	0.547	0.213	0.532	0.187	0.241
	C	0.236	0.583	0.104	0.556	0.004	0.252
	PSO	**0**	**0**	**0**	**0**	**0**	**0**

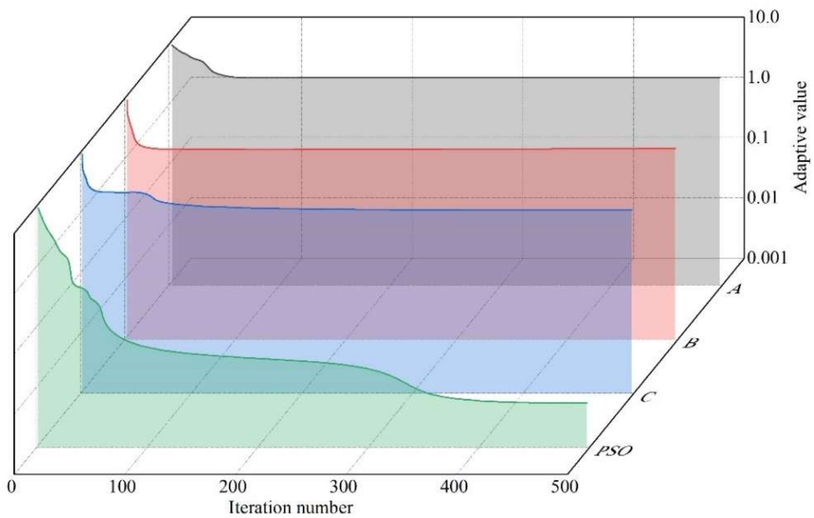
In order to reflect the dynamic convergence of the PSO algorithm more intuitively, the convergence curves of the four optimization algorithms for the four test functions at the bit number D = 20 are given in Fig. 2, where (a)-(d) represent the convergence results of the four algorithms under the functions f_1 - f_4, respectively. As can be seen from the figure, for functions f_1, f_3 and f_4, the PSO algorithm is significantly better than the other three algorithms in terms of convergence speed and optimization accuracy, and the exploratory performance in the early iteration and the exploratory performance in the late iteration and the search performance in the late iteration are also better than the other three algorithms, which indicates that the PSO algorithm has the ability to explore globally as well as the ability to mine locally without losing the diversity of populations and the stability of the search for the best. For function f_2, although the algorithm's convergence speed and optimization accuracy are not obviously improved, the local search ability is improved compared with the other algorithms. Overall, PSO compared with other algorithms, the population can effectively jump out of the local optimum in the early stage, and improve the accuracy of optimization in the later stage, the algorithm performance has a high superiority, and its application to the optimization of taijiquan training program can get the desired results.



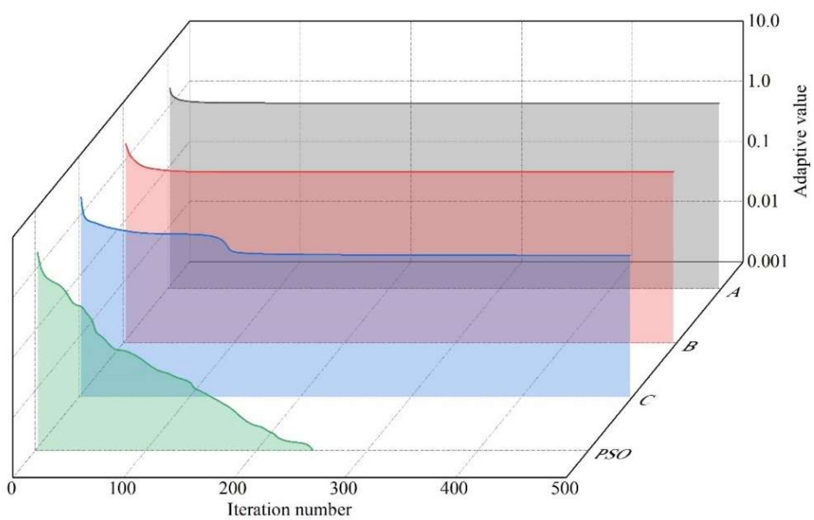
(a) Function f_1



(b) Function f_2



(c) Function f_3



(d) Function f_4

Fig. 2. The convergence curve of algorithm

5. Quantitative assessment of physical coordination in adolescents

5.1. Comparison of differences in physical coordination indicators among adolescents before the experiment

Table 5 shows the results of independent samples t-test between the experimental group and the control group before the experiment, where E denotes the experimental group and C denotes the control group. The experimental data show that before the experiment, through the analysis of the significance monitoring of the two groups of students' physical coordination test indexes found that: the mean and P value of the six indexes including balance ability, agility, flexibility, strength and endurance, movement accuracy and cardiorespiratory fitness indicate that there is no big difference in the coordination of the two groups before the experiment. Comparisons based on ANOVA chi-square yielded data of P=0.058 for balance, P=0.174 for agility, P=0.236 for flexibility, P=0.079 for strength and endurance, P=0.089 for movement accuracy, and P=0.143 for cardiorespiratory function. The p-values of all evaluated dimensions in the data are greater than 0.05, so it indicates that there is no significant difference between the control and experimental groups in the dimensions and overall level of physical coordination indicators before the experiment.

Table 5. Independent sample t test results

Test dimension	Group	N	Mean	SD	t	P
A1	E	15	54.38	3.31	1.872	0.058
	C	15	52.17	7.48		
A2	E	15	51.36	8.72	1.236	0.174
	C	15	51.08	4.03		
A3	E	15	53.84	1.39	-1.798	0.236
	C	15	54.48	1.67		
A4	E	15	49.38	2.71	1.037	0.079
	C	15	49.26	2.86		
A5	E	15	53.48	1.85	1.493	0.089
	C	15	52.96	1.92		
A6	E	15	47.69	3.57	1.544	0.143
	C	15	47.44	3.86		

5.2. *Comparison of changes in physical coordination indexes before and after the experiment in the control group*

Table 6 shows the changes in body coordination before and after the experiment in the control group. The experimental data show that the students in the control group did not take any training methods and only carried out daily physical exercise activities, and the coordination-related indexes of the students changed, but the degree of change was small. According to the data, the P-value results of the control group before and after the experiment were not less than 0.01 and 0.05, indicating that there was no significant change in the students' physical coordination when they did not train in taijiquan. However, as shown by the mean and standard deviation of the data, all six coordination indicators have been improved to different degrees, and physical exercise in the traditional way can also improve the physical coordination of adolescents, but the overall improvement effect is not obvious. The reason for the small increase is that during the exercise process, the repetitive exercise movements are practiced to create memory in the muscles, which improves the proficiency of the movements and develops the students' body control, which in turn has a small effect on the balance and other aspects.

Table 6. Index changes before and after the experiment(Control group)

Control group	Pre-experiment	After the experiment	t	P
A1	52.17	59.42	1.882	0.069
A2	51.08	58.39	1.673	0.134
A3	54.48	61.78	1.485	0.072
A4	49.26	67.46	1.769	0.093
A5	52.96	66.82	1.306	0.059
A6	47.44	56.73	1.252	0.084

5.3. *Comparison of changes in body coordination indexes before and after the experiment in the experimental group*

The results of the changes in the indicators of physical coordination before and after the experiment in the experimental group are shown in Table 7. Significance monitoring and analysis of differences in students' physical coordination before and after the experimental group experiment revealed that the mean and P-value of six indicators, including balance ability and other indicators, showed significant changes in the number of physical coordination indicators before and after the experimental group experiment. Balance P=0.000, agility P=0.000, flexibility P=0.001, strength and endurance P=0.001, movement accuracy P=0.000, and cardiorespiratory function P=0.001. The P-value is less than 0.05, which indicates that the students of the experimental group showed significant improvement in their physical coordination according to the abilities corresponding to the coordination indexes after the training of taijiquan. The reason for the significant difference in the above indicators is that the taijiquan training makes the students' muscles contract and relax continuously, while cooperating in time and space, which in turn improves the dynamic balance and coordination of the adolescent students. When the stability of vestibular receptors is improved, the stimulus response of the vestibular organs becomes less, the smoother the demonstrated movements are, and the coordination of the upper and lower limbs is further improved.

Table 7. Index changes before and after the experiment(Experimental group)

Experimental group	Pre-experiment	After the experiment	t	P
A1	54.38	83.38	4.78	0.000
A2	51.36	81.47	4.64	0.000
A3	53.84	80.49	4.32	0.001
A4	49.38	82.94	4.57	0.001
A5	53.48	85.97	5.13	0.000
A6	47.69	82.11	4.26	0.001

5.4. Analysis of changes in physical coordination indicators in adolescents after the experiment

Table 8 shows the results of independent samples t-test between the control group and the experimental group, and E and C in the table indicate the experimental group and the control group respectively. The experimental data show that the mean value change of the physical coordination test indexes of the experimental group and the control group after the experiment is an upward trend, and among the six indexes, balance P=0.000, agility P=0.000, flexibility P=0.000, strength and endurance P=0.000, accuracy of movement P=0.000, and cardiorespiratory fitness P=0.000 The data show that the P-values of all indexes are less than 0.05, with significant differences. It shows that taijiquan training can effectively improve the physical coordination of adolescents. At the same time, due to the optimization of the particle swarm optimization algorithm for the taijiquan program, it further highlights the effect of taijiquan training on the enhancement of adolescents' physical coordination.

Table 8. Independent sample t test results(After the experiment)

Test dimension	Group	N	Mean	SD	t	P
A1	E	15	83.38	3.31	8.976	0.000
	C	15	59.42	7.48		
A2	E	15	81.47	8.72	8.428	0.000
	C	15	58.39	4.03		
A3	E	15	80.49	1.39	8.954	0.000
	C	15	61.78	1.67		
A4	E	15	82.94	2.71	8.738	0.000
	C	15	67.46	2.86		
A5	E	15	85.97	1.85	8.979	0.000
	C	15	66.82	1.92		
A6	E	15	82.11	3.57	8.552	0.000
	C	15	56.73	3.86		

6. Conclusion

In this paper, the particle swarm optimization algorithm is used to optimize the parameters of the taijiquan training program, so as to find the optimal training program solution. The statistical analysis methods such as independent sample t-test were used to quantitatively assess the effect of taijiquan training on the improvement of physical coordination of adolescents.

1) The PSO algorithm can effectively solve the optimal training program of taijiquan. When the number of particle swarms is 200, a more ideal average solution and optimal solution can be obtained to realize the effective optimization of the taijiquan training program. The mean values of balance and movement accuracy scores of the subjects after the optimization of the scheme increased from 42.65 and 51.35 to 82.69 and 83.91 respectively, with an improvement of 93.88% and 63.41% respectively. In terms of algorithm performance, the PSO algorithm has a stronger ability to find the best and a higher accuracy of finding the best compared to the other three algorithms, and overall shows good performance superiority. It shows that the particle swarm optimization algorithm used in this paper is practical and feasible to optimize the taijiquan training program and has good results.

2) The difference between the mean and p-value of each test index of physical coordination of the experimental group and the control group before the experiment is small, and the p-value is greater than 0.05, which is not a statistically significant difference. After the experiment, the control group's physical coordination test indexes produced a small increase, but it was not significant compared to the preexperiment. In the experimental group, the indexes of physical coordination test increased from 54.38, 51.36, 53.84, 49.38, 53.48, 47.69 before the experiment to 83.38, 81.47, 80.49, 82.94, 85.97, 82.11 respectively, and the p-value was less than 0.05, which indicated that the physical coordination of the experimental group after the experiment was significantly improved compared with that before the experiment. The P-value is less than 0.05, indicating that the physical coordination ability of the experimental group after the experiment is significantly improved compared with that before the experiment. At the same time, the P-value of each index in the analysis of the change of body coordination indexes between the experimental group and the control group after the experiment is less than 0.05, which deeply reveals the significant enhancement effect of taijiquan training on the body coordination of adolescents.

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