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ARTICLE

The Effect of Specialized Digital Training on Double Poling Technique for Para Seated Cross-Country Skiing Athletes

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ABSTRACT

Purpose: In order to satisfy the requirements of Chinese Para seated cross-country skiers special training for Double poling scientifically, and the individualized strength training of Paralympic athletes, this study aims to explore the effect of the full-dimensional servo-driven intelligent training system on para cross-country skiers' strength training. **Methods:** 12 Para seated cross-country skiing athletes were included (6 males and 6 females: LW10.5-LW12), 4 weeks of training of the Double poling based on the centripetal isotonic mode of the full-dimensional servo-driven intelligent training system, the special strength quality indicators include the speed and power of the Double poling in the centripetal phase. The SPM1d paired-sample *t*-test was used for statistical analysis of each index before and after training. **Results:** After 4 weeks of special movement training through the full-dimensional servo-driven intelligent training system, the speed and power of the Double poling of 12 seated cross-country skiers were significantly improved compared to before training. In the Double poling period, the speed index of female athletes increased significantly in the 92%–100% stage, and the male athletes in the 20%–23% and 72%–73% stages. The power index of female athletes increased significantly in the 17%–18%, 21%∼30% and 70%∼82% stages, and the male athletes in the 49%–58% and 91%–100% stages. **Conclusion:** The full-dimensional servo-driven intelligent training system can significantly improve the special strength quality index of Para seated cross-country skiers' Double poling techniques and enhance the special ability on snow. In addition, the system can meet the personalized and specialized training needs of disabled athletes to a great extent, monitor and feedback training data in real-time, and further reduce the risk of sports injuries.

KEYWORDS

Specialized digital training; Double poling techniques; Paralympic; cross-country skiing

1 Introduction

Paralympic cross-country skiing is a winter event with high physical fitness requirements. According to different functional impairments, it is divided into sitting and standing positions. Double poling is a special technique necessary for sitting cross-country skiing. The upper limb strength and explosive force have a high to nearly perfect correlation with the Double poling performance [1]. Stoggl et al. [2] found that world-class athletes will have specific strength exercises for the upper limbs and trunk during training to improve the lean mass of the corresponding parts, and to obtain better athletic performance. At present, the Paralympic cross-country skiing training team mainly uses traditional strength equipment for special strength training, supplemented by high-elastic rubber bands, suspension simulators, and Thorax Trainer ski machines for indoor special exercises. The resistance mode is single, dominated by gravity. Due to the inertial participation of the weight plate in the exercise process, the resistance during the training process is extremely unbalanced. When performing equipment exercises too fast, it is easy to produce greater inertia, which can cause joint, muscle, and ligament damage, which increases the probability of sports injury for disabled athletes [3]. At the same time, the resistance level is relatively large, it is difficult to achieve refined training, resistance adjustment is tedious and time-consuming, causing much inconvenience to disabled athletes, and a single device can only train a single movement or muscle group. The lack of real-time exercise data during the training process makes it difficult to evaluate and feedback in time.

The "Trinity" training model consisting of training, scientific research, and training guarantee has put forward higher requirements for training facilities. Wearable, intelligent, digital, and fast feedback have become indispensable basic requirements for current training equipment. Aiming at the personalized characteristics and digital training requirements of disabled athletes, to improve the self-efficacy of disabled athletes [4], a full-dimensional servo-driven intelligent training system was developed. This system precisely controls the motor with a control frequency exceeding 2000 Hz to provide the resistance and speed always required for training. The initial parameter setting, target parameter selection, and the design of multiple preset programs realize a variety of strength test training modes. At the same time, data were displayed and recorded in real-time, data fitting and comparative analysis was performed, and the athletes' exercise data were recorded each time. The coach can view the trend on the WEB chart, and analyze the exercise rules and physical conditions of the athletes, ensuring the scientific and safety of the training, and making the training truly digital.

At present, the system has been applied in the special training of Chinese Paralympic snowboarding starting movements and has a promoting effect on improving the special strength quality indexes of male athletes while starting movements. However, the application effect of this system on Paralympic cross-country skiers, especially seated athletes who only use the Double poling technique, is not yet clear. This, study compares and analyses the strength indicators before and after the special training of 12 seated cross-country skiing athletes in the Paralympic Winter Games in China based on the full-dimensional servo-driven intelligent training system, and explores the digital training effects of the special actions. This study hypothesized that after 4 weeks of special movement training through the full-dimensional servo-driven intelligent training system, the Double poling speed and power should be increased both in male and female athletes.

2 Material and Methods

2.1 Participants

In total 12 seated cross-country skiing athletes preparing for the Beijing 2022 Paralympic Games, 6 male and 6 female. Among them, male age (26.7 ± 5.1) years old, height (171.3 ± 7.9) cm, body weight (59.5 ± 4.6) kg; female age (26.2 ± 6.3) years old, height (160.1 ± 3.6) cm, body weight (49.1 ± 6.1) kg. Four grades were included LW10, LW10.5, LW11.5, and LW12 (Table 1). All athletes had the same training plan, relaxation therapy, diet, and living environment. There had been no upper limb surgery in the past year, and no muscle aches or fatigue on the day of the test. All athletes understood the purpose and procedures of this study, were fully familiar with the test procedures before the test and signed the relevant informed consent instructions.

Table 1: Basic information of national para sitting cross-country skiers

Number	Sex	Age/year	Height/cm	Weight/kg	Disability level
1	female	29	156	42	LW10.5
2	female	22	159	60	LW12
3	female	32	160	45	LW10.5
4	female	20	157	49	LW12
5	female	20	166	48	LW12
6	female	33	162	50	LW10.5
7	male	27	160	52	LW11.5
8	male	29	175	60	LW10
9	male	35	180	65	LW10
10	male	24	175	63	LW12
11	male	20	163	57	LW12
12	male	25	175	60	LW12

Note: LW10, LW10.5, LW11.5: lower limb and trunk injury; LW12: lower limb injury (injury severity ranged from LW10 to LW12).

2.2 Full-Dimensional Servo-Driven Intelligent Training System

According to the characteristics of winter Paralympic sports, the full-dimensional servo drives intelligent training system can be targeted to the core stability of athlete strength training, core basic stability strength training, core specialized dynamic strength training, and upper and lower limb strength training to provide a personalized training platform, comprehensively improve the physical quality of disabled athletes, ensure its better deal with complex competition environment, and improve sports performance.

The training system has seven training modes (constant isotonic, centripetal isotonic, eccentric isotonic, centripetal constant velocity, no inertia, elastic force, and fluid mechanics), which can simulate different special technical actions and satisfy different modes of muscle contraction. At the same time, it is equipped with muscle training modules to freely formulate training plans according to different special needs and individual needs.

The Double poling technique for sitting cross-country skiers is equipped with pole handles and other training accessories. The intelligent interactive display screen records and displays single and single group training speed-power graphs, strength, displacement, time, and other parameters for athletes, intuitively judges the changes in athletes' maximum strength, and strength training effects, and provides quality control during specific training and timely sports performance feedback. At the same time, coaches can arrange training plans on mobile phones and can synchronize training data in real-time (Fig. 1).

2.3 Training Program

Special technical movements and special strength training are the guarantees of the sliding speed ability in cross-country skiing competitions. Because of the disability of the lower limbs of the seated cross-country skiers, the upper limbs and waist and abdomen muscles are dominant, therefore, in terms of special strength training, there are more diversified and individualized needs than healthy athletes. The purpose of the training program of this system is to design special technical training actions based on the special skills of sitting cross-country skiing and the individual characteristics of athletes, to improve the special strength of athletes' upper limbs.

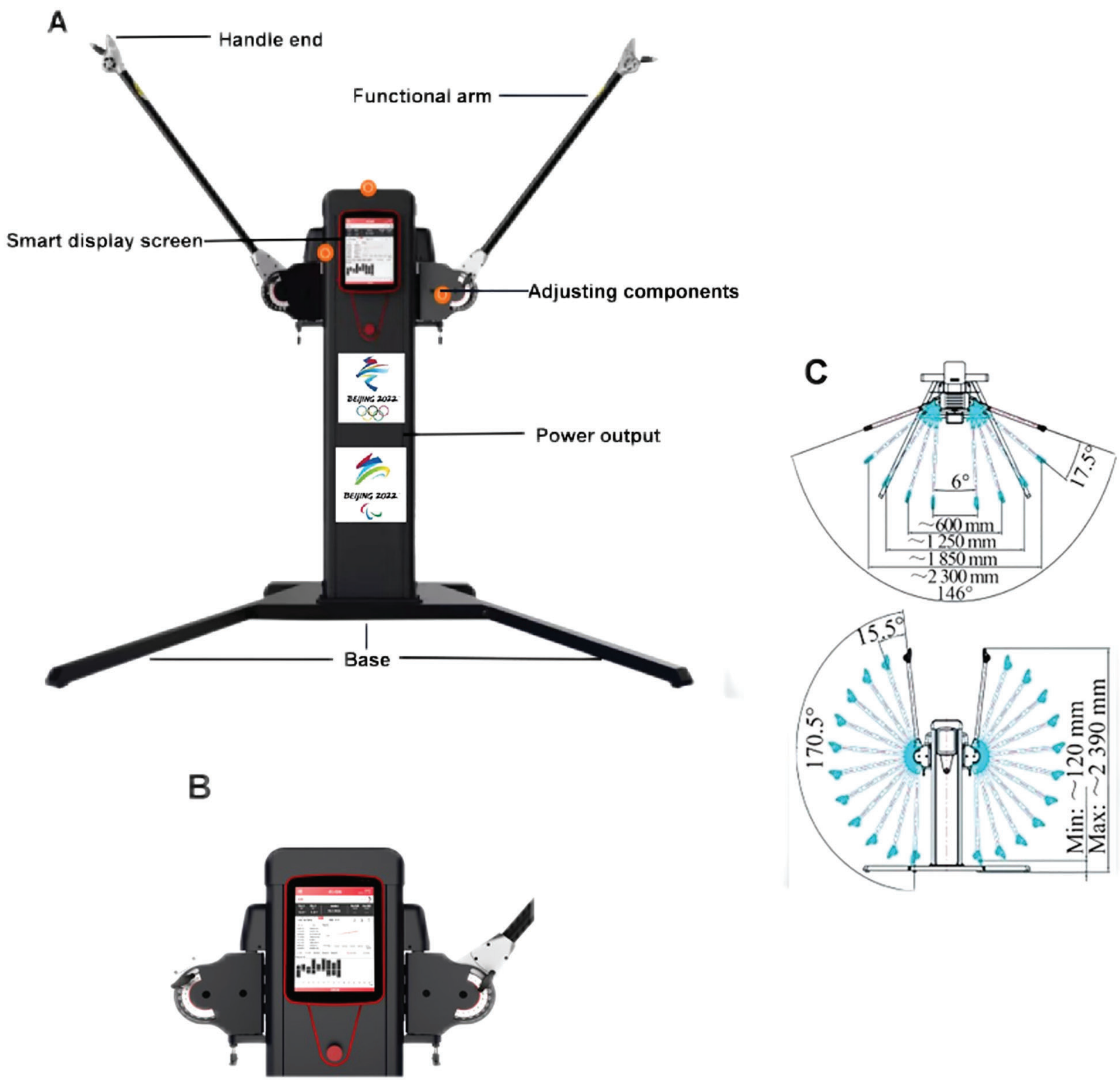

Figure 1: The full-dimensional servo-driven intelligent training system, A is the training system, B is the smart display screen, and C is the horizontal and vertical adjustable position

The special training action is designed according to the structural characteristics and force characteristics of the Paralympic cross-country skiing Double poling technical action. Gastaldi et al. [5] divided the sliding cycle of a ski seated event into three stages: putting, transition and reduction. Based on this, the whole training action is divided into three parts: preparation, Double poling, and reduction. Preparation part: Arrange the athlete to sit on a fixed frame and fix the lower limbs with an inelastic binding belt, the trunk is directly in front, the arms slightly open and kept straight, and the hands grasp the special ski stick handle and fixed with straps. Double poling part: Clenching the handle with both hands, the arm, and the core exerts a force at the same time. It is required to pull downward and backward at the fastest speed. The body and head are slightly pressed down. Athletes pull the handle end to the extreme distance of the Double poling movement according to their strength habits. Reduction part: During the rope return phase of the equipment, the athlete still pulls the handle but does not exert any force. After returning to the initial position, the athlete returns to the ready position before performing the next Double poling movement.

The training program is mainly aimed at the upper limb strength quality of the seated cross-country skier, and the centripetal isotonic mode is used to simulate double poling. Before training, athletes needed to test the maximum strength of the upper limbs (1RM) based on the centripetal isotonic mode of the training system, referring to the measurement method in <NSCA's Essentials of Personal Training> compiled by the American Physical Fitness Association for testing [6]. A single training session included three stages of warm-up, practice, and relaxation, with a total of 45 min. (1) Warm-up phase: Athletes perform 10-min warm-up and 5-min double poling exercises under the leadership of a professional physical coach (resistance is 30% 1 RM); (2) Practice phase: The athlete uses the centripetal isotonic mode to continuously complete 8 times × 4 sets of special exercise training (resistance is 85% 1RM, centrifugal force is 1.5 kg), and the interval time of each group is 90 s; (3) Relaxation phase: follow the coach for 15 min of relaxation and stretching. The entire training process lasts for 4 weeks, 2 times a week, for a total of 8 training sessions.

2.4 Data Acquisition and Statistical Analysis

The training data of 12 athletes were downloaded from the cloud background of the full-dimensional servo-driven intelligent training system, delete the data of the centrifugal stage, and intercept the speed and power data of the centripetal stage. SPSS 23.0 statistical software was used for statistical processing, and the data were expressed as mean ± standard deviation (M ± SD). A Paired-sample t-test was used to analyze the indicators before and after training. $P < 0.05$ was defined as a significant difference. Then, using Matlab2020 software, normalized by time (ms), the data were normalized to 101 data points by cubic B-Spline for statistical parametric mapping (SPM) or statistical non-parametric mapping (SnPM).

Statistical analysis of speed (m/s) and power (w) of the centripetal phase before and after training, before the statistical test, test whether the residual values satisfy a normal distribution, if it meets the normal distribution, use SPM test, if it does not meet the normal distribution, use SnPM test, use paired-sample *t*-test to test the data before and after training. SPM or SnPM statistical analysis was performed according to the formula and the significance level was set to 0.05:

$$\mathrm{SPM\&SnPM(t)} = \frac{\overline{y_1}(t) - \overline{y_2}(t)}{\sqrt{\frac{1}{n_1}\mathrm{var}[y_1(t)] + \frac{1}{n_2}\mathrm{var}[y_2(t)]}} \tag{1}$$

In the formula, $y_1(t)$ and $y_2(t)$ represent two sets of variables, paired-sample t-test refers to the data before and after training; $\overline{y_1}(t)$ and $\overline{y_2}(t)$ refer to the two sets of variables corresponding to each point mean; n_1 and n_2 refer to the sample size of the two groups of variables; $\mathrm{var}[y_1(t)]$ and $\mathrm{var}[y_2(t)]$ respectively refer to the variance of the two sets of variables.

Based on the random field theory, the maximum difference between each continuous point between the two sets of data is calculated by a formula. If it exceeds the threshold level, it is statistically significant (α = 0.05).

$$P(t(q)_{max} > t^*_{1D}) = 1 - \exp\left(-\int_{t^*_{1D}}^{\infty} f_{1d}(x) - dx - ED\right) = \propto \tag{2}$$

In the formula, $t(q)_{max}$ is the maximum difference between the two sets of data; t^*_{1D} is the threshold value of the statistical difference (α = 0.05) of SPM or SnPM; $f_{0d}(x)$ is the probability density function of the *t*-test; ED is a smoothly related Euler density function.

3 Results

3.1 SPSS Paired-Sample t-Test (Average Speed/Power, Peak Speed/Power for the Centripetal Phase of Double Poling)

Through the 4-week special exercise training, the average speed of the centripetal phase of Double poling of 12 athletes increased significantly ($P < 0.05$), and the growth range was 0.4~3.52 m/s. The peak speed increased significantly ($P < 0.05$), and the growth range was 0.4~3.56 m/s (Table 2).

Table 2: The speed comparison of centripetal phase before and after training

Number	Average speed/($m{\cdot}s^{-1}$)		Peak speed/($m{\cdot}s^{-1}$)	
	Pre	Post	Pre	Post
1	4.20 ± 1.78	5.59 ± 0.92*	5.41 ± 2.29	6.71 ± 0.58*
2	4.73 ± 0.71	5.24 ± 0.90*	4.61 ± 0.33	5.37 ± 0.34*
3	4.48 ± 0.89	6.62 ± 1.87*	5.43 ± 0.68	8.99 ± 0.51*
4	4.50 ± 0.94	4.91 ± 0.76*	5.23 ± 0.68	5.82 ± 0.22*
5	4.48 ± 0.85	4.88 ± 0.75*	5.34 ± 0.27	5.74 ± 0.28*
6	3.87 ± 0.68	4.77 ± 0.55*	4.49 ± 0.54	5.52 ± 0.31*
7	3.54 ± 0.94	4.97 ± 0.83*	4.44 ± 0.91	5.74 ± 0.36*
8	3.59 ± 0.59	5.13 ± 1.20*	4.18 ± 0.46	6.42 ± 1.01*
9	4.11 ± 0.69	4.14 ± 0.70	4.69 ± 0.73	5.29 ± 0.57*
10	4.07 ± 0.71	4.90 ± 1.32*	4.69 ± 0.73	6.44 ± 1.31*
11	4.51 ± 0.76	5.72 ± 0.88*	5.11 ± 0.29	6.41 ± 0.67*
12	5.45 ± 1.45	8.93 ± 1.40*	7.17 ± 0.73	11.27 ± 2.34*

Note: * is a significant difference compared with before training, $P < 0.05$.

The average power of the centripetal phase of Double poling of 12 athletes increased significantly ($P < 0.05$), the growth range was 25.98~413.80 W. The peak power increased significantly ($P < 0.05$), and the growth range was 24.27~501.92 W (Table 3).

Table 3: The power comparison of centripetal phase before and after training

Number	Average power/(W)		Peak power/(W)	
	Pre	Post	Pre	Post
1	458.03 ± 153.98	871.90 ± 137.24*	613.55 ± 183.35	1086.86 ± 48.24*
2	527.62 ± 116.79	588.29 ± 170.11*	724.90 ± 62.64	815.73 ± 92.12*
3	458.03 ± 153.98	871.90 ± 137.24*	613.55 ± 183.35	1086.86 ± 48.24*
4	486.84 ± 87.20	522.89 ± 93.29*	559.49 ± 80.88	654.27 ± 30.45*
5	437.34 ± 66.46	463.32 ± 70.36*	536.27 ± 35.36	560.54 ± 38.26*
6	405.60 ± 86.96	547.42 ± 82.41*	510.903 ± 91.81	642.51 ± 40.45*
7	543.36 ± 158.12	692.20 ± 64.06*	567.21 ± 49.76	735.33 ± 164.39*
8	500.67 ± 83.72	727.44 ± 176.07*	592.02 ± 60.09	966.42 ± 101.15*
9	736.20 ± 139.16	897.11 ± 144.54*	871.13 ± 117.28	956.58 ± 123.19*

(Continued)

Table 3 (continued)

Number	Average power/(W)		Peak power/(W)	
	Pre	Post	Pre	Post
10	665.69 ± 135.92	855.38 ± 265.93*	863.92 ± 170.01	1365.84 ± 218.44*
11	811.56 ± 117.68	1133.47 ± 186.39*	908.11 ± 53.58	1330.59 ± 181.84*
12	845.48 ± 269.26	1156.81 ± 526.44*	1189.48 ± 148.79	1953.08 ± 330.78*

Note: * is a significant difference compared with before training, $P < 0.05$.

3.2 Normal Distribution

The normality of the speed and power data of the centripetal phase of Double poling before and after the training of the male and female athletes was tested respectively, and it was found that the speed indicators of the Double poling before and after the training of the female athletes were in line with the normality, and the SPM test was used; For the male athletes before and after training, the speed index of Double poling did not conform to the normal distribution, and then the SnPM test was used. The power indicators of all athletes before and after training in the centripetal phase of Double poling did not conform to the normal distribution, and the SnPM test was used.

3.3 SPM1d Paired-Sample t-Test (Speed Index for the Centripetal Phase of Double Poling)

Based on the characteristics of normality, the SPM1d paired sample *t*-test was used for the speed indicators of female athletes before and after training. It was found that the threshold was exceeded in the 92%–100% stage of the Double poling period ($\alpha = 0.05$, $t^* = 3.406$), and it increased significantly ($P < 0.001$); The SnPM1d paired-sample *t*-test was used to test the speed indicators of male athletes' Double poling before and after training. It was found that the threshold was exceeded during the 20%~23% and 72%~73% stages of the Double poling period($\alpha = 0.05$, $t^* = 4.066$), and it showed a significant increase ($P = 0.001$, $P < 0.046$) (Fig. 2).

3.4 SPM1d Paired-Sample t-Test (Power Index for the Centripetal Phase of Double Poling)

The SnPM1d paired sample *t*-test was used for the power indicators before and after training for male and female athletes. Male athletes were found to exceed the threshold in the 49%~58% and 91%~100% stages of Double poling ($\alpha = 0.05$, $t^* = 3.421$), and the power was increased significantly ($P = 0.008$, $P = 0.024$); Female athletes exceeded the threshold in the 17% to 18%, 21% to 30%, and 70% to 82% stages of the Double poling period ($\alpha = 0.05$, $t^* = 26.433$), and the power increased significantly ($P = 0.048$, $P < 0.001$, $P < 0.001$) (Fig. 3).

4 Discussion

The results from the present study demonstrate that special training based on the full-dimensional servo-driven intelligent training system can improve the upper limb strength indicators of disabled seated cross-country skiers. Both the male group and the female group improved the speed and power indicators during the double poling. From the point of view of speed indicators, female athletes show a significant increase in the 92%~100% stage, and male athletes have a significant increase in the 20%~23% and 72%~73% stages. In terms of power indicators, female athletes showed a significant increase in the 17%~18%, 21%~30%, 70%~82% stages, and male athletes showed significant increases in the 49%~58% and 91%~100% stages.

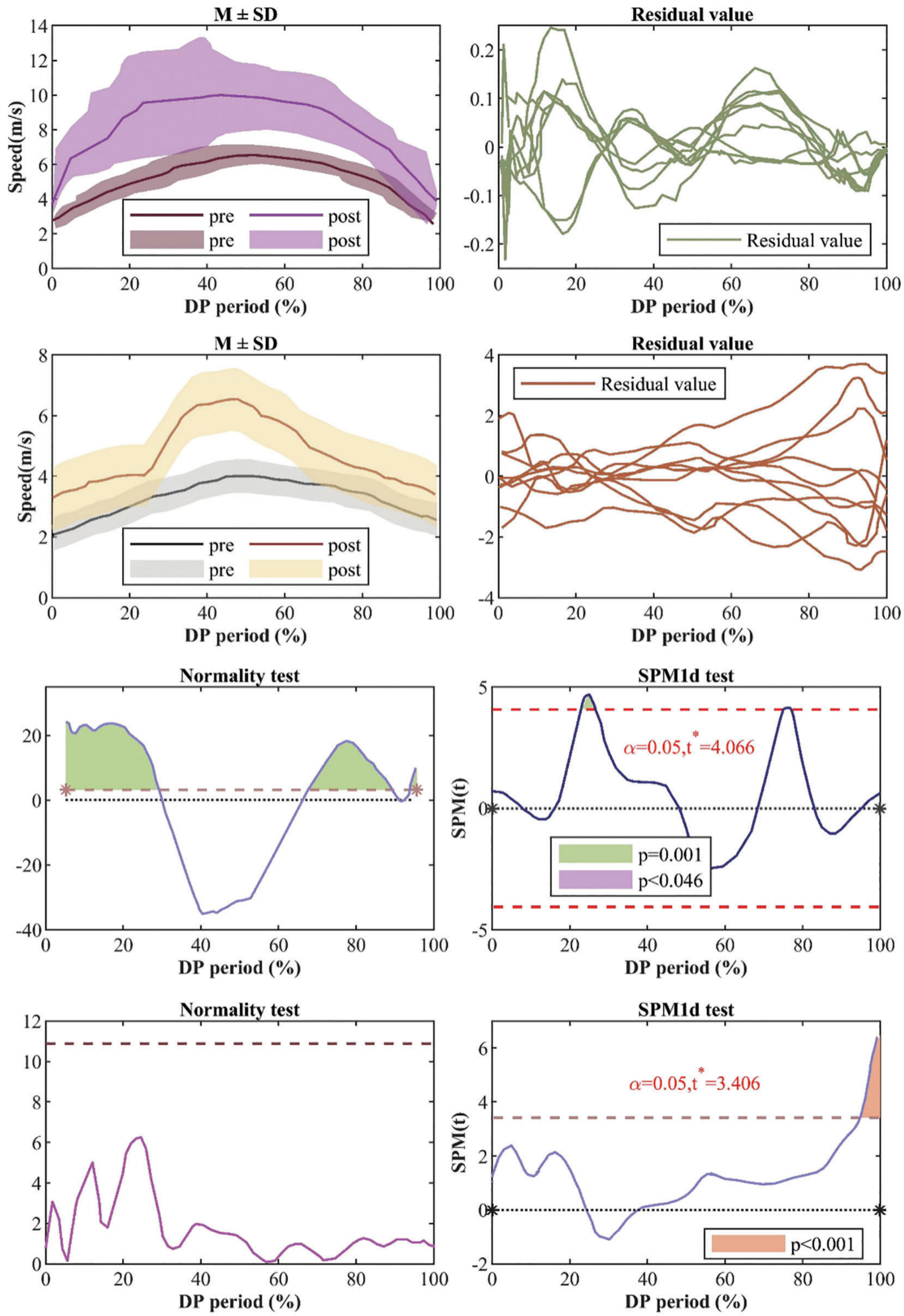

Figure 2: Normality and SPM/SnPM test of double poling speed at pre and post training between male (top) and female (bottom) athletes

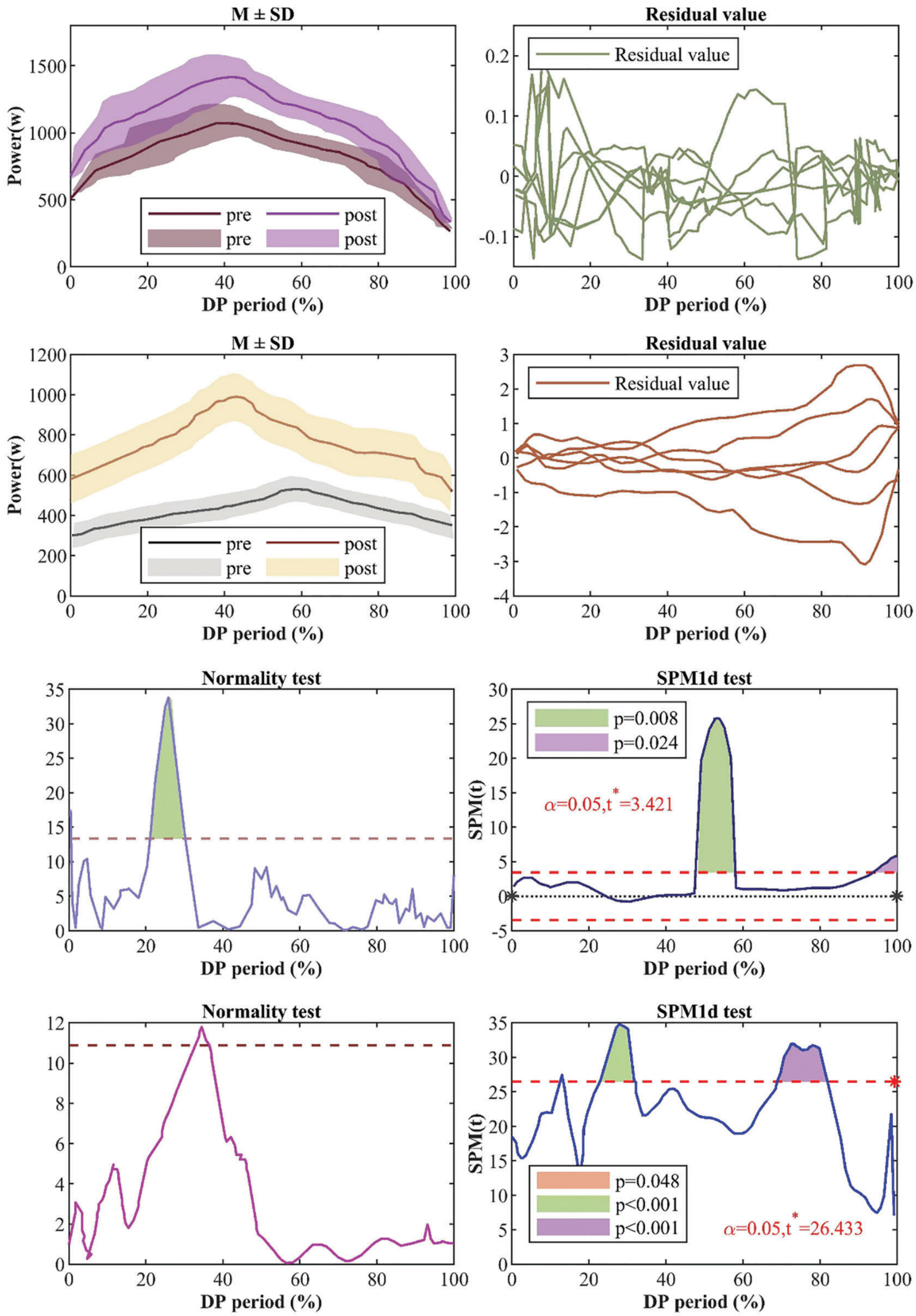

Figure 3: Normality and SPM/SnPM test of double poling power at pre and post training between male (top) and female (bottom) athletes

Previously, a group of elite male skiers found that the maximum speed has improved after a period of comprehensive strength training and specialized ski training [7]. However, previous studies did not investigate the impact of special strength training on disabled seated cross-country skiers. In the current study, both training groups had increased speed and power; therefore, to generate a higher maximum double poling explosive force, a concomitant increase in upper body strength was a prerequisite. Higher muscle strength and higher technical skills will help athletes show higher pole strength and longer cycles in double poling [8]. The positive correlation between the increase in ski speed and cycle length and the duration of the swing phase emphasizes the importance of the effective thrust phase in a short period [9,10].

Seated cross-country skiing is a physical endurance sport that requires a series of well-developed physical, technical, and tactical abilities [11–13]. Muscle endurance and explosive power are important strength qualities required for the game and are also the key guarantee for upper body techniques. In cross-country skiing, seated athletes must rely on suitable seated skis to drive forward through the muscles of the trunk, shoulder joints, and arms due to the loss of lower limb motor function. Therefore, the double poling technique has become the only option for ski seated athletes [14]. The mode of action of cross-country skiing mainly activates upper limb muscles, including the pectoralis major, deltoid muscle, and latissimus dorsi. A common factor affecting thrust generation and balance maintenance is the athlete's ability to control the trunk. Today's cross-country skiers do more specialized training than before, systematically incorporating roller skiing, strength, and speed training into their regular training [15], and pay more attention to upper body strength training [16]. Stoggl et al. [10] recommended in the study to increase the proportion of training aimed at the improvement of specific explosive strength and maximal power to increase the impulse of force. Elite cross-country skiers will also perform maximum strength training for upper limbs and trunk muscles during strength and technical training to improve cross-country skiing performance [17]. Meanwhile, a few studies demonstrated that movement-specific maximal upper-body strength training is beneficial for double poling [18,19]. Ofsteng et al. [20] found that 3 times a week of special strength endurance training for the upper limbs can not only effectively improve the endurance performance of cross-country skiers in sliding, but also help optimize the economic performance of Double poling. Muscle strength of the upper limbs is also considered to be a key factor in aerobic and anaerobic capacity [21,22]. Therefore, it is necessary to simulate the Paralympic cross-country skiing double poling action for special strength training to develop explosive power.

Studies have shown that excellent special strength (Double poling explosive power and strength endurance) can increase the sliding speed, distance, and efficiency of a single action, reduce the frequency of actions along the way, realize energy economy, and help maintain the efficiency of single propulsion [23–25]. Cross-country skiing performance can indeed be affected by skills, and a good technique can compensate for the ultimate physiological impairments, bringing to a higher skiing economy [8,26,27], and vice versa. Moreover, it is well known that after the maximum repetition exercise, fatigue will reduce the strength and speed of the muscle level [28–30], thereby reducing the strength and effectiveness of dynamic muscle movements. After training, the athlete's performance can be improved and the impact of fatigue in the long-distance cross-country skiing competition can be reduced.

In the context of the rapid development of competitive sports for the disabled and the assistance of technology for the Winter Olympics, a higher level of scientific training is required. In scientific training, the testing and evaluation of the sports performance of athletes is an important guarantee for scientific training. It is necessary to further strengthen the upgrading of training equipment, improve the ability of training data collection, analysis, and feedback, evaluate the physical function of athletes, improve training programs, and train scientifically. The improvement of the level of chemistry provides timely and accurate guidance. Due to the particularity of disabled athletes, compared to able-bodied athletes, disabled athletes have higher individual and scientific requirements for training methods, loads, and special equipment. For Paralympic seated cross-country skiers, many traditional training methods are not applicable in the process of special strength training due to various degrees of physical defects. The SPM results showed that, compared with healthy athletes, disabled athletes need to consume more physical energy in the process of special training. Therefore, special strength training needs to be combined with the particularity of the disabled athletes to set the training methods and load patterns. The training tracking of this research found that the full-dimensional servo-driven intelligent training system may be an effective means to meet the special strength training requirements of disabled athletes. It can simulate the special movements of Paralympic seated cross-country skiers to the greatest extent and meet the individualized training needs and digital load monitoring of athletes with different disability levels. Most importantly, the constant resistance output and weak centrifugal force mode of the training system avoid the loss of strength caused by the inertia of traditional equipment during the training process. At the same time, the system is equipped with an emergency brake button to protect the training safety of disabled athletes to a greater extent.

5 Conclusion

This research finds that after 4 weeks of training based on the full-dimensional servo-driven intelligent training system, it is beneficial to improve the upper limb strength of the sitting cross-country skiers in the Winter Paralympics and enhance their Double poling skills. The training system can simulate special training actions according to the characteristics of each special event, to a large extent meet the individual needs and training load monitoring of disabled athletes, and effectively reduce sports injuries caused by traditional training. However, whether this system can be applied on the special training of other Paralympic athletes needs further research.

Authorship: The authors confirm contribution to the paper as follows: study conception and design: Dong Sun and Yaodong Gu; data collection: Yong Wang; analysis and interpretation of results: Yong Wang and Julien S. Baker; draft manuscript preparation: Yong Wang and Anand Thirupathi. All authors reviewed the results and approved the final version of the manuscript.

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Conflicts of Interest: The authors declare that they have no conflicts of interest to report regarding the present study.

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