The Impact of Velocity-Based Strength Training on Lower Extremity Explosiveness in Butterfly Swimmers

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Abstract. This study aims to compare Velocity-Based Strength Training (VBT) and Traditional Physical-based Training (PBT), analyze the differences in lower extremity explosiveness between the two training modes, explore the effects of the two training modes on butterfly swimmers' performance, and provide practical recommendations based on data comparison.

Results: After 8 weeks of training intervention, the VBT group showed a significant increase in average weight (23.75kg, P=0.00) for 1RM back squat after neck. Additionally, the VBT group exhibited significant improvements in squat jump (SJ) (average increase of 2.28cm, P=0.016), countermovement jump (CMJ) (average increase of 2.51cm, P=0.047), 30m sprint ability (average improvement of 0.14s, P=0.039), and 100m butterfly performance (average improvement of 1.6s, P=0.003). The PBT group also showed significant improvements in 1RM back squat after neck (average increase of 20kg, P=0.006) and 100m butterfly performance (average improvement of 1.45s, P=0.005).

Conclusion: (1) Velocity-based Strength Training offers the advantage of better adaptability to the subjects' body conditions, timely assessment of fatigue status and action quality, and compensates for the limitations of traditional strength training through equipment. This contributes to improved training efficiency and helps prevent injuries resulting from excessive fatigue. (2) The VBT group demonstrated significant differences in SJ, CMJ, and 30m sprint ability after the experiment, while the PBT group did not show significant differences. However, both groups showed average score improvements, with the VBT group outperforming the PBT group.

Keywords: speed-based strength training, butterfly stroke; lower limb explosive power; traditional strength training.

1. Introduction

The General Administration of Sports of China promulgated and implemented the "14th Five-Year Plan for Sports Development" in October 2021 (hereinafter referred to as the “Plan”). The “Plan” emphasizes the importance of developing basic sports events such as swimming and athletics, promoting sports project construction, strengthening the integration of sports and education, cultivating reserve sports talents through multiple channels, improving competitive ability, and consolidating the foundation for training Chinese swimmers.

Compared with the other swimming styles, butterfly stroke is known for its high difficulty and technical complexity. It not only requires stable core strength but also excellent lower limb explosive power. Explosive power is mainly manifested in the speed of contraction of skeletal muscles. The stronger the contraction ability, the faster the speed, and the greater the power[1]. Currently, velocity-based training (VBT) is the most popular method for strength and speed training in China and abroad. It is favored because it can select different velocity ranges according to different training goals to improve training efficiency. Therefore, this study discusses the impact of VBT and physical-based training(PBT) on the lower limb explosive power and performance of butterfly swimmers, providing a theoretical basis for the cultivation of excellent butterfly swimmers.

2. Research Subjects and Methods

2.1 Research Subjects

This study focuses on the impact of velocity-based strength training on the lower limb explosive power of butterfly swimmers.

2.2 Research Methods

2.2.1 Literature Review

The researchers conducted a literature search on databases such as CNKI, PubMed, Web of Science, and Google Scholar. Keywords used in the search included "velocity-based training," "traditional strength training," "butterfly stroke," "explosive power," and "lower limb explosive power." This ensured a comprehensive search for reliable data and theoretical support for this study.

2.2.2 Experimental Method

2.2.2.1 Experimental Subjects

Eight butterfly swimmers from Nanjing Sport Institute (four males and four females) were selected as test subjects (Table 1 for details). The eight subjects were randomly divided into two groups, with two males and two females in each group. The control group was the PBT group, and the experimental group was the VBT group. The subjects were required to have reached the national second-level athlete level or above, have experience in lower limb training, and have no lower limb injuries or illnesses within the past year. The subjects needed to understand the test content and movement standards and voluntarily participate.

Table 1. Subject basic information

Name	Sex	Age	Height (cm)	Weight(kg)	BMI	Training years
Wang**	Male	19	175	70	22.9	7.5
Jiang**	Male	19	175	75	24.5	7.5
Qian**	Male	19	176	80	25.8	7.5
Tian**	Male	19	178	80	25.2	8
Xu*	Female	20	170	65	22.5	9
Liu**	Female	20	160	55	21.5	8
Liu**	Female	19	165	58	21.3	8
Li**	female	19	168	62	22.0	7.5

2.2.2.2 Experimental Site, Time, and Equipment

Testing was conducted at the physical fitness testing center and swimming pool in Nanjing Sport Institute. The testing period was from March 8, 2023, to May 11, 2023.(Table 2)

Table. 2 Test time

Test partition	Start-stop time
Pre-intervention test	March 4, 2023 - March 7, 2023
Test in intervention	March 8, 2023 - May 8, 2023
Post-intervention test	May 8, 2023 - May 11, 2023

Equipment used included height and weight scales, squat racks and barbells, a 3D force sensor platform, a JVC high-speed camera, a GymAware Powertool sensor, a Smart speed tester, a computer, etc.

2.2.2.3 Testing Content

Before the testing, the subjects were required to warm up for 10-15 minutes (Table 3 for details) and stabilize their breathing before the test. The SJ, CMJ, 30m sprint, and 100m butterfly test were conducted 24 hours after the 1RM back squat. The ambient temperature was around 26℃, and the underwater temperature was around 27℃.

Table 3. Warm-up tissue

Action name	Action	Sets × times	Intermittent time
Warm-up	Stride jump, acceleration run, small step run, hip adduction jump, hip abduction jump, forward leg press during marching, backward leg kick during marching, caterpillar crawl.	20 times × 2 sets	30s
Stretch	The greatest stretching, dynamic stretching for the hips, dynamic stretching for the quadriceps, ankle joint flexion and extension, hamstring stretching.	15×2 sets (15 for each side)	30s

The testing items included maximum lower limb strength testing, lower limb explosive power testing, and 100m butterfly performance testing.

(1) Maximum lower limb strength testing - 1RM back squat

According to the American Physical Fitness Association (NSCA),the testing procedure for the maximum weight back squat test was as follows[2]: fully warm up, perform about 10 back squats with a weight that can be easily completed, rest for 1 minute; increase the weight by 10%-20% based on the previous weight, perform 3-5 reps, rest for 2 minutes; increase the weight by another 10%-20%, perform 2-3 reps, rest for 2-4 minutes; increase the weight by the same amount and attempt one rep. If failed, decrease the weight by about 5%-10% and successfully complete the rep. The final weight is recorded as the 1RM. It is ideal to determine the 1RM within 5 sets.

The back squat movement requirements:

Firstly, remove the barbell from the squat rack, with the feet about shoulder-width apart, toes in line with the knee joint, tighten the core, and place the barbell on the upper trapezius. Secondly, when squatting downward, use diaphragmatic breathing, tighten the core for the second time, flex the hip joint first and then flex the knee joint, descend until the thighs are parallel to the ground. Thirdly, press the feet against the ground, exert force from the lower limbs, exhale, and maintain the standing position to complete one rep[3].

Fig.1 The back squat

(2) Lower limb explosive power testing

The subjects' squat jump (SJ) and countermovement jump (CMJ) heights were measured using a force platform. Each subject performed two trials for each jump, with a 2-minute rest between trials. The best result was recorded. There was a 5-minute rest between different jump types, and the final test results were displayed by the computer software connected to the force platform.

The requirements for SJ were as follows the subject stood with arms crossed in front of the trunk (to avoid the influence of arm swinging on power output), knee joints flexed to 90°, held for 2 seconds, and then quickly jumped vertically after hearing the command from the researchers. The hip, knee, and ankle joints fully extended, and landing was cushioned.

The requirements for CMJ were as follows: the subject stood still with hands on hips before the test. After hearing the command from the researchers, the subject quickly squatted down and jumped up[4].

Fig.2 Bounce test

(3) 30m sprint test

The test was conducted on an indoor athletics field using Smart speed equipment. Before the test, the researchers placed the equipment at the starting and finishing points, and the subjects warmed up sufficiently. The test used a standing start, and the subjects sprinted at their maximum speed. Each subject had two chances, and the best result was recorded, with a 5-minute rest between the two trials.

Fig. 3 30m sprint

(4) 100m butterfly performance test

Two researchers used a stopwatch to time the subjects' 100m butterfly performance. Before the test, each subject warmed up adequately. The subjects stood on the starting platform in pairs to prepare for the test. After hearing the command "Take your mark" from the researchers, the subjects assumed the starting position on the starting platform. After hearing the command "go," the subjects quickly entered the water and performed the 100m butterfly at full speed. Each subject had two test chances, and the best result was recorded.

2.2.2.4 Experimental Arrangement

The experiment was divided into pre-test and post-test stages, as well as the intervention stage. The specific arrangements were as follows: Before the formal testing, from March 4, 2023, to March 7, 2023, information was organized, including the basic information of the subjects, standardized test motion standards, explanations of instrument usage, etc. This ensured that the subjects correctly understood the test content, clarified the test process as early as possible, and discovered any potential test issues to ensure the smooth completion of the experiment.

Training intervention was conducted from March 8, 2023, to May 8, 2023, for 8 weeks. The training frequency was three times a week, with a training duration of 50 minutes. Warm-ups and relaxation activities were arranged before and after each training session, and the duration of warm-ups and relaxation activities was determined by the training volume and intensity of the day. For the VBT group, real-time feedback was provided based on the load-speed curve relationship corresponding to 75% of the 1RM as displayed by the GymAware Powertool sensor. When the average concentric velocity deviated by 0.06m/s, the load intensity was adjusted by ±5%. For the PBT group, strength training was performed with a constant intensity of 75% of the 1RM, adhering to consistent training standards and making the best effort to complete the required movements.

The post-test stage was conducted from May 8, 2023, to May 11, 2023, and included the testing of various indicators and recording of the results. The analysis mainly compared the differences between the experimental group and the control group after the VBT and PBT interventions.

2.2.2.5 Experimental process

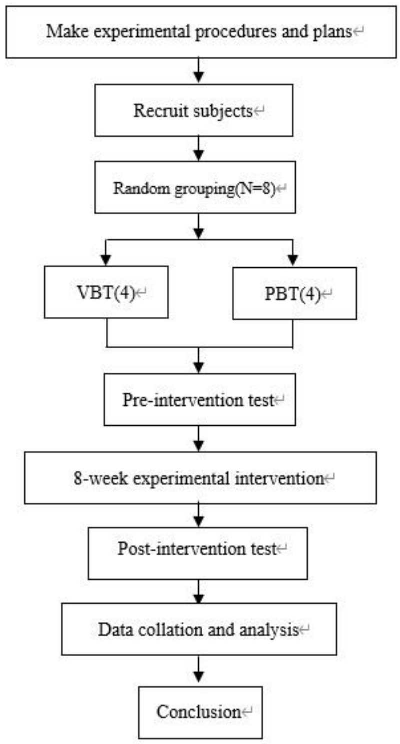

Fig.4 Experimental process

2.2.3 Statistical analysis

The data collected before and after the tests were recorded in Excel and analyzed using SPSS 25.0. Independent-sample t-tests were used to analyze the inter-group differences between the VBT group and the PBT group before and after the experiment. Paired-sample T-tests were used to analyze the intra-group differences before and after the experiment for both groups. The differences were presented as P values, where $P>0.05$ indicated no significant difference between the two groups, $P<0.05$ indicated a significant difference, and $P<0.001$ indicated an extremely significant difference. Before conducting the statistical analysis, the researchers checked for the normal distribution of each group's data to ensure the accuracy of the experimental conclusions.

3. Research Results

3.1 Comparison of data between the VBT group and the PBT group before the intervention

Table 4. Comparison of lower limb strength test between VBT and PBT before experiment

Test index	VBT（$\bar{x}$±S）	PBT（$\bar{x}$±S）	P-value
1RM back squat （kg）	87.5±23.3	90.0±20.4	0.877
SJ（cm）	28.5±3.32	30.6±5.42	0.532
CMJ（cm）	37.25±5.03	37.71±6.43	0.912
30m sprint（s）	4.9±0.47	5.03±0.37	0.738
100m butterfly performance（s）	68.25±4.81	69.24±4.96	0.776

According to Table 4, the average values of 1RM back squat were 87.5kg and 90kg for the VBT group and the PBT group, respectively. The average values of SJ were 28.5cm and 30.6cm, and the average values of CMJ were 37.25cm and 37.71cm for the VBT group and the PBT group, respectively. The average values of the 30m sprint were 4.9s and 5.03s, and the average values of the 100m butterfly were 69.24s and 68.25s for the VBT group and the PBT group, respectively. The average values showed small differences between the two groups, and the standard deviations of the data were also similar, indicating small fluctuations in the data. The P values for all the indicators were greater than 0.05, indicating no significant differences between the two groups and confirming the fairness of the random assignment before the intervention. This reduced the instability of the results caused by large initial differences in the data.

3.2 Comparison of various indicators before and after the intervention in the VBT group

Table 5. Comparison of various indicators before and after intervention in VBT group

Test index	pre-intervention（$\bar{x}$±S）	post-intervention（$\bar{x}$±S）	Rate of increase and decrease	P-value
1RM back squat （kg）	87.5±23.4	111.25±24.9	27.14%	0.00
SJ（cm）	28.53±3.32	30.81±4.04	8%	0.016
CMJ（cm）	37.25±5.03	39.76±6.49	6%	0.047
30m sprint（s）	4.93±0.47	4.79±0.48	-2%	0.039

According to Table 5, after 8 weeks of velocity-based strength training intervention, the average 1RM back squat weight in the VBT group increased from 87.5kg to 111kg, an increase of 27.14% ($P=0.00<0.001$), indicating a significant statistical difference. The average SJ height increased from 28.53cm to 30.81cm, an 8% increase ($P=0.016<0.05$), indicating a significant statistical difference. The average CMJ height increased from 37.25cm to 39.76cm, a 6% increase ($P=0.047<0.05$), indicating a significant statistical difference. The average time for the 30m sprint decreased from 4.93s to 4.79s, a 2% decrease ($P=0.039<0.05$), indicating a significant statistical difference.

3.3 Comparison of various indicators before and after the intervention in the PBT group

Table 6. Comparison of various indicators before and after the intervention in the PBT group

Test index	pre-intervention（$\bar{x}$±S）	post-intervention（$\bar{x}$±S）	Rate of increase and decrease	P-value
1RM back squat （kg）	90.0±20.4	110±26.12	22.2%	0.006
SJ（cm）	30.6±5.42	31.5±6.63	3%	0.261
CMJ（cm）	37.71±6.43	39.65±8.96	5%	0.228
30m sprint（s）	5.03±0.37	4.94±0.46	-1%	0.209

According to Table 6, after 8 weeks of constant 75% of 1RM strength training intervention, the average weight of the 1RM back squat in the PBT group increased from 90kg to 118.7kg, an increase of 22.2% ($P=0.006<0.05$), indicating a significant statistical difference. The average SJ height increased from 30.6cm to 31.5cm, a 3% increase ($P=0.261>0.05$), indicating no significant statistical difference. The average CMJ height increased from 37.71cm to 39.65cm, a 5% increase ($P=0.228>0.05$), indicating no significant statistical difference. The average time for the 30m sprint decreased from 5.03s to 4.94s, a 1% decrease (P=0.209>0.05), indicating no significant statistical difference.

3.4 Comparison and analysis of various test results between the VBT group and the PBT group after the intervention

Table 7. Comparison and analysis of various test results between the VBT group and the PBT group after the intervention

Test index	post-intervention: VBT（$\bar{x}$±S）	post-intervention: PBT（$\bar{x}$±S）	Rate of increase and decrease: VBT	Rate of increase and decrease: PBT	P-value（post-intervention: VBT）	P-value（post-intervention: PBT）
1RM back squat（kg）	111.25±24.9	110±26.12	27.14%	22.2%	0.00	0.006
SJ （cm）	30.81±4.04	31.5±6.63	8%	3%	0.016	0.261
CMJ （cm）	39.76±6.49	39.65±8.96	6%	5%	0.047	0.228
30m sprint（s）	4.79±0.48	4.94±0.46	-2%	-1%	0.039	0.209
100m butterfly performance （s）	66.65±4.65	67.79±4.79	-2.3%	-2.1%	0.003	0.005

According to Table 7, the VBT group showed significant differences in all indicators after the experimental intervention: the average increase in 1RM back squat weight was 23.75kg (P=0.00<0.001), representing a 27.14% increase; the average increase in SJ height was 2.28cm (P=0.016<0.05), representing an 8% increase; the average increase in CMJ height was 2.51cm (P=0.047<0.05), representing a 6% increase; the average improvement in the 30m sprint time was 0.14s (p=0.039<0.05); and the average improvement in the 100m butterfly time was 1.6s (P=0.003<0.05), representing a 2.3% improvement. All the p values were less than 0.05, indicating significant statistical differences. These results indicate that 8 weeks of velocity-based 1RM 75% strength training effectively improved the results of these tests, demonstrating the effectiveness of velocity-based strength training in improving the lower limb explosive power and performance of butterfly swimmers. The PBT group also showed significant improvements in 1RM back squat weight and 100m butterfly time, with p<0.05, indicating significant statistical differences. However, there were no significant statistical differences in SJ, CMJ, and 30m sprint. The results showed varying degrees of improvement in test scores, and the sample size needs to be increased for further analysis of the reasons.

4. Analysis and Conclusion

4.1 1RM Neck Squat Value

Both the VBT group and the PBT group used the same squat movement pattern - explosive rapid squatting. The independent variable in the experiment was the adjustable load variable based on the corresponding value of 75% of the subject's 1RM squat strength for the VBT group, while the PBT group used a constant 75% of 1RM squat weight.

The study found that the average difference in squat values before and after for the VBT group was approximately 23.75kg, with a growth of 27.14% compared to before the experiment. The average difference for the PBT group was approximately 20kg, with a growth of 22.2%. The VBT group had a greater average difference than the PBT group (23.75kg > 20kg), and both groups showed significant differences, indicating that velocity-based strength training is superior to constant load strength training for 1RM neck squats. Loturco [5]compared the effects of velocity-based strength training on maximum strength and reached the same conclusion as this study, that velocity-based strength training significantly improves the maximum strength of subjects. The reason for this result may be that velocity-based strength training allows for real-time adjustment of training load when athletes enter a fatigue period, reducing the possibility of excessive fatigue and maintaining an appropriate training load throughout the training cycle, thereby enhancing the subjects' training enthusiasm and adaptation to training stimulation.

4.2 Squat Jump (SJ)

After 8 weeks of strength training, the VBT group showed an average improvement of 2.28cm (P=0.016), a growth of 8%; the PBT group showed an average improvement of 0.9cm (P=0.261), a growth of approximately 3%. The VBT group showed significant differences in test results before and after the experiment, while the PBT group showed no significant differences. The VBT group had higher average growth values and growth rates than the PBT group, indicating that velocity-based strength training is superior to traditional strength training in improving subjects' squat jump performance. Christou [6]conducted a study on 8 weeks of biweekly physical training and found that progressive and monitorable training is helpful in improving maximum lower limb strength and has a significant impact on SJ and CMJ jump height (P<0.05). The study showed that lower limb strength training improves squat jump ability by significantly increasing power output during initiation, thereby increasing the rigidity and explosiveness of lower limb muscle strength while maintaining an eccentric state[7]. The reason for this is that squat jumps (SJ) require more focused attention and efficient and stable lower limb strength output. During testing or training competitions, reducing unnecessary power consumption is a necessary condition for saving physical energy. Therefore, velocity-based strength training has better monitoring and identification of movement and fatigue levels in organisms, and better control of muscle and neural fatigue.

4.3 Countermovement Jump (CMJ)

According to the experimental results, the VBT group showed an average improvement of approximately 2.51cm (P=0.047), a growth rate of approximately 6% in countermovement jump performance; the PBT group showed an average improvement of approximately 1.94cm (P=0.228), a growth rate of approximately 5%. The results show that the VBT group had significant differences in test results before and after the experiment, while the PBT group showed no significant differences. The VBT group had higher average growth values and growth rates than the PBT group, indicating that velocity-based strength training is superior to traditional strength training in improving subjects' countermovement jump performance. Zhang[8]conducted a meta-analysis on the effects of VBT on lower limb maximum strength, strength endurance, jumping, and sprinting performance, and concluded that VBT has a significant improvement effect on countermovement jumps (SMD = 0.53; $p < 0.001$; $I2 = 0\%$). An I2 value of 0 indicates low heterogeneity, indicating that the selected literature data is reliable and the experimental results are highly persuasive. The $p < 0.001$ indicates a significant difference in the meta-analysis of countermovement jump performance, and VBT experiments have a significant improvement effect on countermovement jumps. Countermovement jumps (CMJ) significantly improve swimming performance, especially in platform entry and wall-kicking turns. This requires minimizing unnecessary power consumption and maintaining persistent and powerful lower limb strength output. Therefore, velocity-based strength training has better monitoring of muscle and neural fatigue in organisms. It can be seen that after 8 weeks of strength intervention training, velocity-based strength training has better effects on improving subjects' jumping performance compared to traditional strength training.

4.4 30m Sprint Ability

According to the analysis of the experimental results, the VBT group showed an average improvement of approximately 0.14s (P=0.039), a speed increase of approximately 2% in the 30m sprint; the PBT group showed an average improvement of approximately 0.09s (P=0.209), a speed increase of approximately 1%. By comparing the results, it can be seen that the VBT group had significant differences in test results before and after the experiment, while the PBT group showed no significant differences. The VBT group had higher average growth values and growth rates than the PBT group (0.14s > 0.09s), indicating that velocity-based strength training is superior to traditional strength training in improving subjects' 30m sprint ability. Liao Kaifang [9] obtained results in the application research of velocity-based strength training, showing that the VBT group can better improve their 30m sprint ability. Similarly, Zhang [8] also obtained results on 30m sprint ability (SMD time = -0.40; $p < 0.001$; I2 = 0%), with an I2 value of 0 indicating low heterogeneity and strong persuasiveness of the experimental results. The $p < 0.001$ indicates a significant difference in the meta-analysis of 30m sprint ability, and VBT experiments have a significant improvement effect on subjects' 30m sprint ability. 30m sprint ability is one of the indicators to evaluate lower limb explosive power[10], allowing subjects to quickly transition from a stationary state to a moving state by generating propulsive force from the lower limbs pushing off the ground. Short-distance sprints can effectively test subjects' reaction ability to commands, namely reaction speed, and the running pattern during the sprint is helpful for coordinating the relationship between the upper and lower limbs. Performing a 30m sprint after high-load exercises can improve subjects' neural excitability and recruit more nerves [11]. Velocity-based strength training can balance the relationship between high-load training and excitability, keeping the body at a higher level.

4.5 Specialized 100m Butterfly Stroke

The VBT group showed an average improvement of approximately 1.6s (P=0.003), a performance increase of approximately 2.3% in the 100m butterfly stroke after intervention; the PBT group showed an improvement of approximately 1.45s (P=0.005), a growth of approximately 2.1%. The butterfly stroke requires coordinated movement of the upper and lower limbs and the torso to overcome water resistance and achieve greater speed. It can be seen that improving subjects' lower limb explosive power significantly improves their sports performance. The VBT group showed an improvement of approximately 0.15s compared to the PBT group, and both groups showed significant differences. This indicates that velocity-based strength training and traditional strength training have a significant impact on improving subjects' specialized performance, but overall, velocity-based strength training is more effective. Research has indicated that increasing lower limb explosive power can improve wall-kicking effects and achieve faster entry and turn times in swimming [12]. This study's results show that lower limb strength has an impact on improving swimming start performance and overall swimming progress. After comparing velocity-based strength training with traditional strength training, both groups of subjects showed significant improvements in useful performance, but velocity-based strength training had a more significant improvement (1.6s > 1.45s). This may be related to reaction speed before entering the water, displacement speed during swimming, and the power and speed of wall-kicking turns.

4.6 Summary

(1) The advantages of velocity-based strength training lie in its better adaptation to the individual's body condition, timely response to the individual's fatigue status and movement quality, and compensation for the shortcomings of traditional strength training. This is helpful in improving training efficiency and avoiding injuries caused by excessive fatigue.

(2) For the impact of 1RM back squat and 100m butterfly performance, there were significant differences between the VBT group and the PBT group, and both groups showed effective improvement in these indicators. However, velocity-based strength training showed superior performance compared to traditional strength training.

(3) For SJ, CMJ, and 30m sprint, there were significant differences in the VBT group after the intervention, while the PBT group showed no significant differences. The average improvement in all these indicators was higher for the VBT group.

5. Suggestions

(1) GymAware Powertool sensors are effective for velocity-based lower limb strength training. Future studies can focus on training and testing small muscle groups such as ankle extension and wrist flexion, as well as larger upper limb muscle groups, to improve the overall athletic level of the target population.

(2) Improve swimmers' butterfly stroke performance by using technology, such as GymAware, to enhance lower limb explosive power and improve start speed, wall push-off, turns, and kick speed.

(3) Strengthen the construction of grassroots sports to recruit young athletes who meet the selection criteria and provide them with more reasonable and standardized training to cultivate a reserve of talented athletes.

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