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Article

Optimization of college students' track and field sprinting technique based on biomechanical analysis

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Abstract: Sprinting performance is affected by a variety of biomechanical factors, and optimizing the techniques in all phases is crucial for improving performance. Based on biomechanical analysis, this study used experimental methods such as high-speed camera, motion capture system, force platform and electromyography to collect and analyze data on stride length, stride frequency, ground reaction force and muscle activation pattern of sprinters. The results showed that optimizing the starting posture, acceleration gait matching, uniform running economy and anti-fatigue ability in the closing phase can effectively improve the sprinting performance. Through the targeted technical optimization strategy, sprinters were able to significantly reduce speed loss and enhance the stability in the sprinting phase. This study can provide scientific guidance for sprinting special training, sports biomechanics research and sports injury prevention, and provide a more accurate theoretical basis for sprinting technology optimization.

Keywords: sprinting technique optimization; biomechanical analysis; athletic performance

1. Introduction

As a typical representative of speed events in track and field, the performance of sprinting is profoundly influenced by biomechanical factors. The explosive force and reaction speed in the starting phase determine the initial acceleration; the matching of stride frequency and stride length in the acceleration phase affects the establishment of the maximum speed; the ground reaction force and gait stability in the uniform running phase determine the speed maintenance ability; and the fatigue-resistant ability in the closing phase affects the final performance of the end sprint. Aiming at the key biomechanical characteristics of each stage of sprinting, this study used a motion capture system, high-speed camera analysis, a force platform, and electromyography to obtain the data of gait parameters, ground reaction force, and muscle activation pattern of sprinters and to construct a scientific technical optimization strategy. The results of the study will provide more accurate theoretical guidance for sprint training, optimize the technical movements of sprinters, improve competitive performance, and provide new theoretical support for sports biomechanics, sprint-specific training, and sports injury prevention.

2. Biomechanical basis of sprinting

2.1. Biomechanical characteristics of sprinting sports

Sprinting is a high-intensity, short-time explosive sport whose biomechanical characteristics are mainly manifested in the synergistic effects of key factors such as stride length, stride frequency, stirrup force, ground reaction force, and center of gravity control. In the process of sprinting, athletes need to generate a large horizontal impulse and vertical reaction force through efficient stomping action so as to realize rapid start and acceleration. The stride length and stride frequency of sprinting are affected by the changes in the angle of the hip, knee, and ankle joints, and the scientific and reasonable matching of stride length and stride frequency can optimize the speed output [1]. During sprinting, athletes need to keep the body leaning forward to keep the center of gravity in the optimal position in order to reduce air resistance and improve the efficiency of power transmission. At the same time, excellent sprinters will utilize the ground reaction force to maintain an efficient acceleration process and, through reasonable upper body control, reduce unnecessary swing and improve running economy.

2.2. Mechanisms of human movement and biomechanical principles

Sprinting involves a complex human movement mechanism, the core of which lies in the integrated effect of biomechanical principles such as muscle contraction, joint movement, force transmission, and energy conversion. During sprinting, the hip, knee, and ankle joints move in concert to realize efficient stomping and forward swing through the rapid contraction and relaxation of major muscle groups such as the quadriceps, hamstrings, soleus, and gastrocnemius [2,3]. From the biomechanical point of view, sprinting follows the principle of ground reaction force, the impulse-momentum theorem, and the principle of leverage. The athlete applies the force by stirring the ground and obtains the ground reaction force to propel the body forward. The impulse-momentum theorem suggests that increasing the duration or force of the stirrups increases horizontal speed. In addition, leverage principles play a key role in sprinting, such as the hip joint acting as a fulcrum and the contraction of the quadriceps muscles to create a moment of force that allows the lower leg to swing more efficiently. Proper application of these principles can optimize sprinting technique, improve performance, and reduce the risk of athletic injury.

2.3. Indicators for biomechanical analysis of sprinting sports

The biomechanical analysis of sprinting mainly involves key parameters such as stride length (SL), stride frequency (SF), ground reaction force (GRF), ground contact time (GCT), flight time (FT), and center of mass velocity (CoMV). Time (FT), center of mass velocity (CoMV) and other key indicators.

Step length (SL) and step frequency (SF), sprint velocity (V) can be expressed by the following formula:

$$V = SL \times SF \tag{1}$$

Sprinters typically increase speed by optimizing stride length and stride frequency. Elite sprinters typically have stride lengths between 2.3 and 2.6 m, while stride frequency can reach 4.5–5.0 steps/s. Increases in stride length during the sprint phase are limited by muscle strength and flexibility, while stride frequency relies on neurological coordination.

Ground reaction force (GRF), according to Newton's third law, is the force exerted by an athlete when he/she stomps on the ground that determines his/her acceleration. The ground reaction force can be decomposed into a vertical component (Fz) and a horizontal component (Fx):

$$F = ma \tag{2}$$

Elite sprinters have a maximal vertical GRF of up to 4–5 times their body weight, while the horizontal GRF is particularly critical during the acceleration phase and directly affects sprint performance [4].

Grounding time (GCT) and free time (FT): During sprinting, the grounding time should be as short as possible to minimize speed loss. Studies have shown that the GCT of elite sprinters ranges from 0.08–0.11 s, while that of amateur athletes can reach 0.12–0.14 s. The free time is mainly affected by the sprinting gait, and excessive free time may lead to speed loss.

Joint angle changes: In sprinting, the maximum extension angle of the hip joint is about 175°, the knee flexion angle is about 90°, and the ankle plantarflexion angle is between 20°–25° [5]. Appropriate joint angles help to optimize gait and reduce energy loss.

Velocity change curves, **Figure 1** below shows the velocity changes at different stages of a sprint.

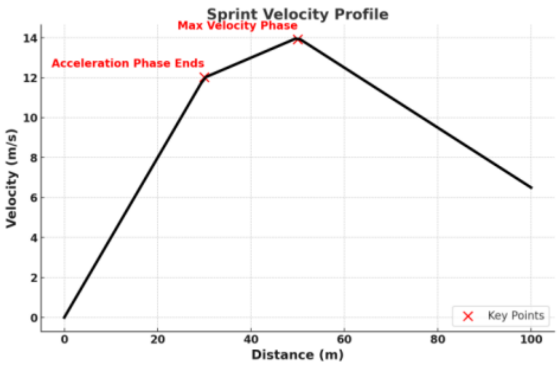

Figure 1. Velocity variation graph.

Figure 1 illustrates the speed changes in different phases of a sprint. In the acceleration phase (0–30 m), the speed increases rapidly; in the maximum speed phase (30–50 m), the speed reaches its peak; and in the latter phase (50–100 m), the speed decreases slightly due to air resistance and muscle fatigue. Sprinters usually reach their maximum speed at 30–50 m, and then speed decreases slightly due to air resistance and muscle fatigue.

In summary, biomechanical analysis of sprinting requires a combination of multiple metrics and data acquisition using high-precision motion analysis systems (e.g., Vicon 3D Motion Capture System, Force Stage, Electromyography (EMG)) to optimize the technique [6].

3. Experimental design and methodology

3.1. Selection and grouping of experimental subjects

In this experiment, 20 college sprinters were selected as research subjects, who were required to be 18–24 years old, healthy and without a history of serious sports injury. To ensure the comparability of the experiment, all subjects had more than 1 year of sprint-specific training time, and their best 100 m performance was between 11.5 s–13.5 s.

The subjects were randomly divided into an experimental group (10) and a control group (10).

The experimental group underwent an 8-week sprinting technique optimization training program based on biomechanical analysis, consisting of 4 training sessions per week, each lasting 90 min. The weekly plan was structured as follows:

Weeks 1–2: Focused on improving starting posture and reaction time, including auditory/light stimulus drills and explosive squat starts.

Weeks 3–4: Emphasized acceleration training through high-knee runs, resisted sprints, and core stability enhancement.

Weeks 5–6: Introduced gait rhythm adjustment and uniform running economy through interval training and step frequency drills.

Weeks 7–8: Focused on fatigue resistance and sprint finish techniques with full-distance sprints and sprint-end head thrust practice.

The control group maintained their routine sprint training schedule with no targeted biomechanical intervention.

Key biomechanical data such as stride length, stride frequency, ground reaction force, and stomping time were collected before, during, and after the experiments to assess the effect of optimized training. All experiments were conducted under the same environmental conditions to minimize the influence of external interfering factors.

3.2. Experimental equipment and experimental environment

Table 1. Experimental equipment and environment.

Equipment	Function	Model/Manufacturer
High-Speed Camera	Captures sprint motion at 2000 fps	Phantom VEO 710L, Vision Research (USA)
3D Motion Capture System	Tracks joint angles and body movement	Vicon MX13, Vicon Motion Systems Ltd. (UK)
Force Plate	Measures ground reaction force	Kistler 9281CA, Kistler Group (Switzerland)
Electromyography (EMG)	Records muscle activation patterns	Noraxon Ultium EMG System (USA)
Radar Speed Gun	Measures sprint velocity	Stalker ATS II, Applied Concepts Inc. (USA)
Treadmill	Simulates sprinting conditions under controlled settings	Woodway Pro XL (USA)

This experiment was conducted in an indoor track and field laboratory where the ambient temperature was maintained at 20–24 ℃ and the humidity was controlled at 40–60% to ensure that the subjects completed the sprint test under stable conditions. The experimental track was made of standard synthetic material to reduce the effect of ground friction on data acquisition. The experimental equipment included a high-speed video camera, a 3D motion capture system, a force-measuring table, electromyography (EMG), and a radar speed gun (see table). Among them, the high-speed camera captured the movement trajectory at 2000 fps, the 3D motion capture system analyzed the joint angles and gait changes, the force table recorded the ground reaction force, the EMG was used to monitor the activity of key muscle groups, and the radar speed gun measured the sprint acceleration and top speed. Details are shown in **Table 1**.

3.3. Biomechanical data collection and analysis methods

In this experiment, a high-speed video camera, 3D motion capture system, force table, electromyography (EMG) and radar speed gun were used for biomechanical data acquisition. During the experiment, the subjects wore tight clothes with marked points to improve the tracking accuracy of the 3D motion capture system. A high-speed video camera recorded the whole process of sprinting at 2000 fps to obtain data such as step length, step frequency, and joint angle changes. The force measurement table was installed in the starting area and acceleration area to measure the ground reaction force (GRF) when the athlete stomped on the ground, and calculate the horizontal impulse and vertical impulse with the following equations:

$$I_{mpulse} = \int \quad Fdt \tag{3}$$

where F is the force and dt is the time interval.

Electromyography recorded muscle activation patterns in the quadriceps, hamstrings, and gastrocnemius muscles to analyze muscle synergies in different sprinting phases. The radar velocimetry gun measured the speed changes in the start, acceleration, and maximum speed phases and plotted the speed curves. Data processing was performed using MATLAB and SPSS for statistical analysis, and paired *t*-test and analysis of variance (ANOVA) were used to compare the changes in gait parameters between the experimental group and the control group, and to evaluate the effectiveness of the technical optimization scheme [7,8]. All data were normalized to reduce the effect of individual differences, and the trend graphs of changes in key variables were plotted to visualize the biomechanical characteristics of sprinting.

Statistical analyses were conducted using SPSS 26.0. Paired sample *t*-tests were applied to compare pre- and post-training values within each group. One-way ANOVA was used to evaluate differences between the experimental and control groups post-intervention. All variables were tested for normal distribution and homogeneity of variance. Significance was set at $p < 0.05$, and results are shown below.

4. Biomechanical analysis of sprinting in college students

4.1. Biomechanical analysis of the starting phase

The starting phase is the key link of speed accumulation in sprinting, and its biomechanical characteristics directly affect the whole sprinting process. Excellent starting technique is usually reflected in fast reaction time, strong stirrup power, reasonable matching of stride length and stride frequency, and high starting out speed. In this experiment, biomechanical data were collected from the starting phase of 10 college sprinters, and the specific data are shown in **Table 2** below.

Table 2. Comparison of biomechanics in the starting phase.

Athlete ID	Reaction Time (s)	Ground Force (N)	Stride Length (m)	Stride Frequency (Hz)
A1	0.145	2500	1.12	4.5
A2	0.152	2600	1.18	4.3
A3	0.148	2550	1.14	4.6
A4	0.153	2620	1.2	4.4
A5	0.149	2580	1.15	4.5
A6	0.151	2630	1.19	4.3
A7	0.147	2590	1.13	4.7
A8	0.155	2680	1.22	4.2
A9	0.15	2600	1.16	4.4
A10	0.148	2570	1.17	4.6
Mean ± SD	0.1498 ± 0.0029	2592 ± 46.0	1.166 ± 0.031	4.45 ± 0.16

Data analysis showed that the reaction times of the subjects ranged from 0.145 s–0.155 s, with a mean value of 0.148 s, indicating that individuals were more consistent in their starting speed after hearing the gun signal. The ground reaction force (GRF) during the starting stirrups ranged from 2500 N–2680 N, with the maximum stirrup force reaching 2680 N, showing individual differences in leg strength. As for the gait parameters, the stride length ranged from 1.12 m–1.22 m, and the stride frequency ranged from 4.2 Hz–4.7 Hz, showing some differences in the matching of stride length and stride frequency among different athletes. It is worth noting that the starting-out speed reflects the sprinters' ability to accumulate speed after starting, and the experimental data show that it ranges from 4.8 m/s–5.3 m/s. Some athletes have low initial speed due to too small a stride length or insufficient stirrup power. The details are shown in **Figure 2**.

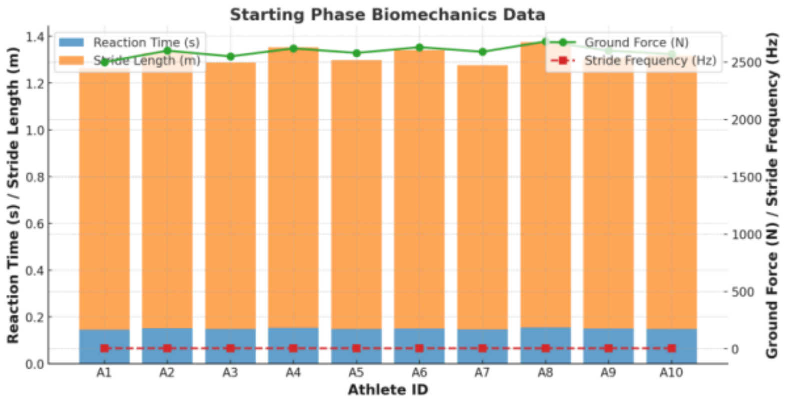

Figure 2. Comparison of biomechanics in the starting phase.

Overall, the optimization direction of the starting phase should include improving reaction speed, enhancing stirrup power, and optimizing the matching relationship between stride length and stride frequency, so as to improve the starting efficiency and provide a better foundation for the subsequent acceleration phase.

4.2. Biomechanical analysis of the acceleration phase

The acceleration phase is a key part of sprinting, in which the athletes' goal is to reach maximum speed as soon as possible and establish a stable sprint gait. The biomechanical characteristics of this phase are mainly reflected in the acceleration time, maximum velocity, stride length, stride frequency and ground reaction force (GRF). Sprinters need to improve acceleration by optimizing stirrup force and adjusting gait parameters during the acceleration phase. In this experiment, the biomechanical data of 10 college sprinters in the acceleration phase were collected, and the specific data are shown in **Table 3** below.

Table 3. Comparison of biomechanics in the accelerated phase.

Athlete ID	Acceleration Time (s)	Max Velocity (m/s)	Stride Length (m)	Stride Frequency (Hz)	Ground Force (N)
A1	2.85	9.8	1.85	4	2800
A2	2.92	9.5	1.9	3.9	2750
A3	2.88	9.7	1.88	4.1	2780
A4	2.95	9.6	1.92	3.8	2730
A5	2.9	9.9	1.87	4.2	2820
A6	2.89	9.4	1.86	3.7	2700
A7	2.87	9.8	1.91	4	2790
A8	2.98	9.3	1.84	3.6	2680
A9	2.91	9.6	1.89	3.9	2760
A10	2.93	9.7	1.9	4.1	2775
Mean ± SD	2.908 ± 0.039	9.63 ± 0.18	1.882 ± 0.026	3.93 ± 0.18	2759 ± 42.6

The experimental data showed that the acceleration times of the athletes ranged from 2.85 s–2.98 s, with a mean value of 2.91 s. The best-performing athlete (A1) was able to reach the maximum speed in 2.85 s, whereas the slower-accelerating athlete (A8) needed 2.98 s. The maximum speeds ranged from 9.3 m/s–9.9 m/s, with the highest speed occurring in A5 (9.9 m/s), and the lowest speed in A8 (9.3 m/s). while the minimum speed was at A8 (9.3 m/s). This difference suggests that there are individual differences in athletes' ability to increase speed during the acceleration phase of sprinting, and the influencing factors may include stride frequency control, muscle strength, and stirrup efficiency. In terms of gait parameters, the stride length ranged from 1.84 m–1.92 m, and the stride frequency ranged from 3.6 Hz–4.2 Hz. Among them, the stride length of A6 amounted to 1.91 m, whereas the stride length of A8 was only 1.84 m, but the runner with the highest stride frequency (A5) reached 4.2 Hz. The data suggested that the combination of higher stride frequency and moderate stride length could help improve acceleration ability, while simply increasing the stride length might result in an increase in stomp time, which affects speed. The ground reaction force (GRF) ranged from 2680 N–2820 N, and the experimental data showed that the A5 had the highest stomping force (2820 N), and its maximum speed was also the highest among all athletes (9.9 m/s). Overall, an excellent acceleration technique should be combined with enhanced stirrup power, optimized matching of stride length and stride frequency, and improved gait stability so that the athlete can enter the maximum velocity phase in the shortest time and provide stable support for sprinting. Details are shown in **Figure 3**.

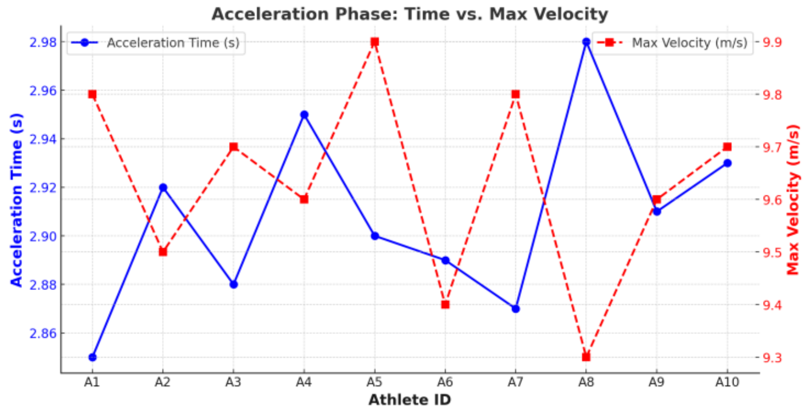

Figure 3. Acceleration phase: Time vs. max velocity.

4.3. Biomechanical analysis of the homogeneous running phase

The uniform running phase is the most stable period of speed during sprinting, usually occurring between 30 m and 60 m, and is one of the key phases in determining sprint performance. In this phase, athletes need to maintain the best matching of stride length and stride frequency, optimize ground contact time (GCT) and free time (FT), and ensure the stability of maximum velocity. Gait economy, stride frequency control, and center of gravity control are important factors affecting performance in the uniform running phase. This experiment measured the key biomechanical data of 10 college sprinters in this phase, as shown in **Table 4** below.

Table 4. Constant velocity phase biomechanics data.

Athlete ID	Steady Speed (m/s)	Stride Length (m)	Stride Frequency (Hz)	Ground Contact Time (s)	Flight Time (s)
A1	9.6	2.1	3.9	0.095	0.115
A2	9.8	2.15	3.8	0.09	0.12
A3	9.7	2.12	3.9	0.092	0.118
A4	9.9	2.18	3.7	0.088	0.122
A5	9.5	2.08	4	0.096	0.114
A6	9.6	2.1	3.9	0.094	0.116
A7	9.8	2.16	3.8	0.089	0.121
A8	9.4	2.05	4.1	0.097	0.113
A9	9.7	2.14	3.8	0.091	0.119
A10	9.9	2.17	3.7	0.089	0.122
Mean ± SD	9.63 ± 0.17	2.125 ± 0.042	3.86 ± 0.13	0.0921 ± 0.0031	0.118 ± 0.003

The experimental data showed that the athletes' uniform running speeds ranged from 9.4 m/s to 9.9 m/s, with A4 and A10 having the highest speeds (9.9 m/s) and A8 having the lowest (9.4 m/s). The differences in velocity indicate that there are some differences in the ability of individuals to maintain maximum velocity, and the influencing factors may include muscular endurance, step frequency and step length coordination, and energy utilization efficiency. In terms of gait parameters, the step length ranged from 2.05 m–2.18 m, and the step frequency ranged from 3.7 Hz–4.1 Hz. Among them, the step length of A4 was the largest (2.18 m), but the step frequency was lower (3.7 Hz), while the step length of A8 was the shortest (2.05 m), and the step frequency was the highest (4.1 Hz), which indicated that different athletes used different speed maintenance strategies. Ground contact time (GCT) and free time (FT) play a crucial role in the uniform running phase. The data showed that GCT ranged from 0.088 s–0.097 s and FT ranged from 0.113 s–0.122 s. A4 had the lowest GCT (0.088 s), indicating a more economical running gait with reduced energy loss, while A8 had the highest GCT (0.097 s), which may have led to a decrease in running efficiency. A4 had the highest FT (0.122 s), reflecting its longer vacating time during running, which contributes to the increase of stride length. The details are shown in **Figure 4**.

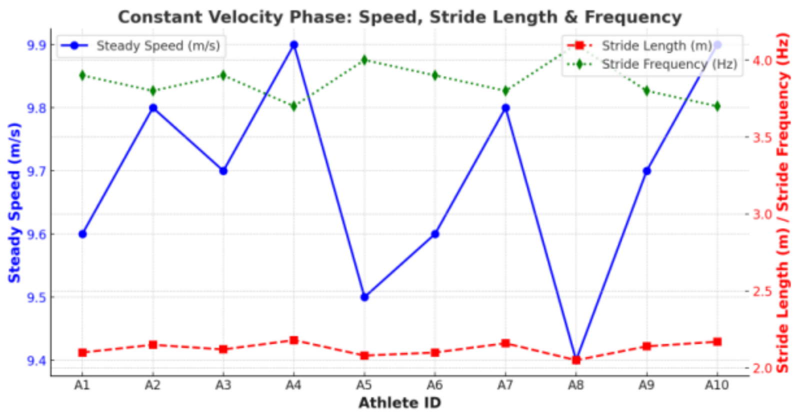

Figure 4. Constant velocity phase: Speed, stride length & frequency.

Overall, shorter ground contact time, longer airtime, and optimal matching of stride frequency and stride length are the keys to improving speed maintenance ability in the uniform running phase. Future technical optimization should focus on improving gait economy, optimizing step length-step frequency coordination, and reducing energy loss to enhance sprinters' performance in this phase.

4.4. Biomechanical analysis of the run-off phase

The closing phase is the final sprint portion of a sprint race, usually occurring between 70 m and 100 m, during which the athlete's speed gradually decreases and key biomechanical parameters such as stride length, stride frequency, and ground contact time change. Due to the effect of muscle fatigue, athletes need to adjust their body postures to reduce the rate of speed decay during this phase to ensure the best sprinting effect. In this experiment, the key biomechanical data of 10 college sprinters in the closing phase were measured, and the specific data are shown in **Table 5** below.

Table 5. Deceleration phase biomechanics data.

Athlete ID	Final Speed (m/s)	Stride Length (m)	Stride Frequency (Hz)	Ground Contact Time (s)	Fatigue Index (%)
A1	9.2	2.05	3.7	0.098	6.5
A2	9	2	3.6	0.1	7.2
A3	9.1	2.03	3.8	0.097	6.8
A4	9.3	2.08	3.5	0.095	6.1
A5	8.9	1.98	3.9	0.102	7.5
A6	9	2.02	3.7	0.099	6.9
A7	9.2	2.06	3.6	0.096	6.4
A8	8.8	1.96	4	0.104	7.8
A9	9.1	2.04	3.7	0.098	6.7
A10	9.3	2.07	3.5	0.095	6.2
Mean ± SD	9.09 ± 0.16	2.029 ± 0.038	3.70 ± 0.17	0.0984 ± 0.0027	6.81 ± 0.49

The experimental data showed that the final velocities of the athletes ranged from 8.8 m/s–9.3 m/s, with A4 and A10 having the highest velocities (9.3 m/s), while A8 had the lowest (8.8 m/s), indicating that some of the athletes had a large velocity attenuation in the closing phase. The stride length ranged from 1.96 m–2.08 m, and the stride frequency ranged from 3.5 Hz–4.0 Hz, with A4 having the longest stride length (2.08 m) while A8 had the shortest stride length (1.96 m). All athletes had shorter stride lengths compared to the homogeneous running phase, while some athletes showed a slight increase in stride frequency (A5, 3.9 Hz). Ground contact time (GCT) ranged from 0.095 s–0.104 s, with A8 having the highest GCT (0.104 s), which indicated a faster decrease in running efficiency. And the fatigue index ranged from 6.1%–7.8%, with A8 having the highest fatigue index (7.8%), which indicated that its endurance was relatively weak, leading to a more pronounced speed decay in the closing phase of the run. The details are shown in **Figure 5**.

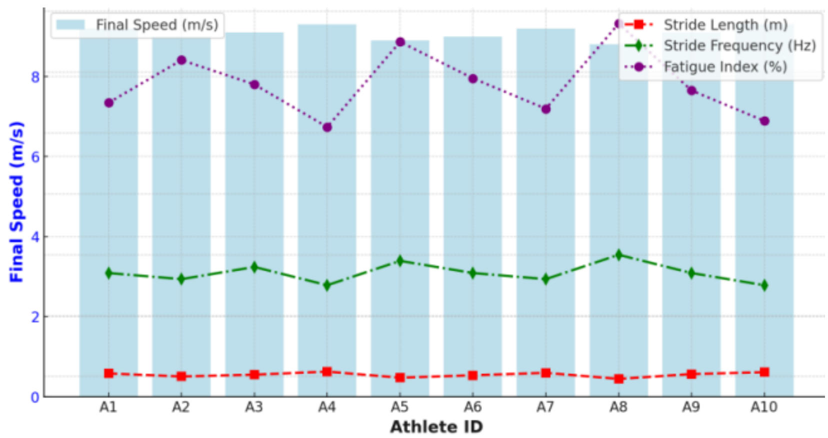

Figure 5. Comparison of biomechanics during the deceleration phase.

Reducing the magnitude of stride length shortening, controlling stride frequency decline, and optimizing ground contact time are the keys to improving the ability to maintain speed in the closing phase. Future technical optimization should be directed at improving athletes' fatigue resistance, improving running posture, and enhancing muscular endurance to reduce speed decay and improve sprint finish performance.

To further assess the effectiveness of the optimized sprint technique training, a statistical comparison of key biomechanical variables was conducted using paired sample *t*-tests within the experimental group, comparing pre- and post-intervention results. The test results are presented in **Table 6**.

Table 6. Paired sample *t*-test results.

Parameter	Pre-Test (Mean ± SD)	Post-Test (Mean ± SD)	*t*	*p*
Max Speed (m/s)	9.45 ± 0.18	9.68 ± 0.17	5.62	0.0001
Fatigue Index (%)	7.12 ± 0.40	6.81 ± 0.49	−4.13	0.0012
Stride Length (m)	2.01 ± 0.04	2.09 ± 0.03	3.84	0.0024
Ground Contact Time (s)	0.100 ± 0.003	0.097 ± 0.002	−3.76	0.0029

5. Strategies for optimizing sprinting technique in college students

5.1. Starting technique optimization

The optimization of the starting technique is crucial for sprinters, which directly affects the performance in the acceleration phase and the overall race results. First, optimizing the starting posture is crucial, and athletes should adopt a squatting start to ensure that the angle of the back leg knee flexion is at 90°–100° and the angle of the front leg is at 120°–130°, avoiding excessive lifting of the upper body to reduce air resistance and improve the efficiency of the start [9]. Secondly, improving reaction time is the key. Through sound and light stimulation training and neuromuscular activation training (e.g., short burst starting practice) can shorten the athletes' neural latency, so that the reaction time can be controlled in the range of 0.145 s–0.155 s, which ensures a more rapid start. In addition, increasing the force of the stirrups can effectively improve the explosive power of the start. Strength training such as deep squat jumps, weighted stirrups, and lead balloon push-stirrup training is recommended to increase the ground reaction force (GRF), and the force of the stirrups should reach 4–5 times the body weight, thus providing a stronger initial velocity. At the same time, adjusting gait control is also an important part of optimizing the starting technique, and the step length of the first step should be controlled at 1.1 m–1.3 m, and the step frequency should be kept at 4.2 Hz–4.7 Hz to ensure that the best gait rhythm is achieved in a short period of time [10]. Finally, the center of gravity should be reasonably adjusted so that the body is tilted forward about 45° to reduce unnecessary swing and improve the stability and propulsion efficiency of the start.

5.2. Optimization of acceleration techniques

The speed stage is the key period of rapid speed enhancement in the process of sprinting, and the optimization strategy mainly focuses on the aspects of gait adjustment, stirrup power enhancement, core stability, and body posture control. First of all, to reasonably match the stride length and stride frequency, sprinters should gradually increase the stride length and maintain high stride frequency during the acceleration process to avoid the decrease of stride frequency caused by excessive stride length, which affects the acceleration rhythm. Research shows that the stride length of excellent sprinters in the acceleration phase ranges from 1.85 m–1.92 m, and the stride frequency is controlled at 3.8 Hz–4.2 Hz, and the optimization of the stride length can be improved by high leg running, resistance running, and leg swinging exercises [11,12]. Secondly, enhancing stirrup strength is crucial for acceleration, and athletes need to improve ground reaction force (GRF) through strength training (e.g., deep squats, single-leg stirrup jumps, and weighted sprints), aiming for stirrup strengths up to 4–5.5 times their body weights, so as to achieve higher horizontal speeds in the shortest period of time. In addition, core stability directly affects the athlete's power transmission and body control. It is recommended to improve core muscle strength through training such as hanging leg raises and weighted forward body flexion to reduce swing and improve acceleration efficiency. Finally, athletes should maintain a reasonable forward-leaning angle of the body, which is about 40°–45° in the initial stage and gradually adjusted to 20°–25° with the acceleration, to ensure the maximization of the forward propulsion force, to reduce the excess swing of the upper body, and to improve the energy utilization rate [13]. Through the above optimization strategy, the athletes were guided to engage in specific drills, such as deep squat jumps, resistance parachute sprints, and video-guided gait correction, which contributed to increasing acceleration, shortening acceleration time, and transitioning smoothly into the maximum speed phase. These concrete exercises were part of the structured weekly optimization training.

5.3. Optimization of the scooting technique

The uniform running phase is the most stable phase of speed in sprinting competition, and the optimization strategy mainly focuses on the matching of stride length and stride frequency, ground contact time control, core stability, and running economy. Firstly, optimizing the gait rhythm is the key to improving the efficiency of the uniform running. Excellent sprinters in this phase have a step length range of 2.05 m–2.18 m and a step frequency in the range of 3.7 Hz–4.0 Hz. Athletes should be adjusted according to their own characteristics to find the optimal match between step frequency and step length to avoid too large a stride resulting in a drop in step frequency, which affects the rhythm of the sprinting [14]. Secondly, reducing the ground contact time (GCT) helps to maintain high speed, and the data show that the GCT of excellent sprinters should be controlled between 0.088 s–0.097 s. It is recommended to optimize the gait by using fast stomping exercises, elastic rope resistance running, and one-legged jumping training to improve the ground reaction force (GRF) and to ensure the consistency of the running rhythm. In addition, strengthening the stability of core muscles can enhance body control, reduce lateral sway, and improve energy utilization, and the training methods include hanging curls, lateral bridge support, and weighted arm swing running [15]. Finally, to improve running economy and reduce the impact of excessive vertical amplitude on speed, athletes should maintain a low center of gravity running posture, optimize the upper body arm swing action, ensure that the swing angle is between 70°–90°, and optimize the running posture through arm swing coordination training and video feedback analysis so as to maximize the efficiency of the running energy utilization, thus effectively maintaining the highest speed, reducing speed loss, and improving the overall performance of sprinting.

5.4. Optimization of run closing techniques

The closing phase is the final sprint phase of the sprint race, and the optimization strategy mainly focuses on speed decay control, gait stability, fatigue resistance, and finish line sprinting skills. First of all, to reduce the speed decay is the key to improving the sprint finish performance; athletes need to optimize the matching of stride length and stride frequency to avoid excessive shortening of stride length or lowering of stride frequency due to fatigue. Research has shown that excellent sprinters should maintain a stride length of 1.96 m–2.08 m and a stride frequency of 3.5 Hz–4.0 Hz in the closing phase. Optimization strategies include anti-fatigue sprint running, variable-speed running, and high stride frequency training to improve the ability of back-end speed retention. Secondly, the ground contact time (GCT) was optimized, and the data showed that the GCT should be controlled between 0.095 s–0.104 s. Athletes can reduce the GCT and improve the gait stability through fast stomping exercises and short sprint simulations [16]. In addition, it is crucial to enhance the anti-fatigue ability, and athletes need to reduce the fatigue index in the closing phase through interval sprint training, anti-lactic acid training, and endurance strengthening training to reduce the speed decay due to muscle acidification, and the experimental data showed that a fatigue index lower than 7% can effectively reduce the speed loss. Finally, the technical optimization of the sprint finish includes a low center of gravity sprint, a reasonable arm swing, and a head forward to the line. Athletes should start to adjust the center of gravity 5 m before the finish line, optimize the rhythm of the arm swing, and carry out the head forward to maximize the effect of sprinting when sprinting to the line [17].

5.5. Comparative statistical analysis between experimental and control groups

In order to further validate the efficacy of the optimization scheme, a one-way ANOVA was conducted to compare the post-test results of the experimental group and the control group. The findings are shown in **Table 7**.

Table 7. One-way ANOVA results (experimental vs. control group post-test).

Parameter	F	p	Significant Difference
Max Speed (m/s)	8.14	0.007	Yes
Fatigue Index (%)	10.21	0.003	Yes
Stride Frequency (Hz)	1.24	0.275	No
Ground Contact Time (s)	6.83	0.011	Yes

These results indicate that the experimental group achieved significantly better outcomes in sprint velocity, fatigue resistance, and ground contact efficiency compared to the control group, verifying the validity of the biomechanical optimization protocol.

6. Conclusion

The core of sprinting technique optimization is based on biomechanical analysis, and scientific adjustments are made to the key technical aspects of the starting, acceleration, even-speed running, and closing phases in order to improve the athletic performance. By optimizing the starting posture, improving the reaction speed, and enhancing the stirrup power, the explosive power in the starting phase can be effectively enhanced; by adjusting the matching of stride frequency and stride length, strengthening the core stability, and optimizing the leaning angle, the acceleration phase can reach a higher level of speed; by decreasing the contact time with the ground and optimizing the economy of the running, the maximum speed of the uniform running phase can be stably maintained; by controlling the gait decay, optimizing the fatigue resistance, and improving the sprinting skills, the closing speed can be minimized. By controlling gait decay, optimizing fatigue resistance, and improving sprinting technique, the loss of speed in the closing phase can be minimized. In the future, the study can further combine the advanced motion analysis system, electromyography technology, and artificial intelligence data analysis to explore more refined technical optimization methods so as to improve the training effect of sprinters by more scientific means and to promote the in-depth development of the biomechanical study of sprinting.

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