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Prospects for the application of conjugate influence exercises in sprinting, a brief review and research analysis

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Abstract. Speed, power and acceleration ability are important components for most of the summer sports, such as athletics, football, rugby, handball and basketball. Our analytical review compiles and systematizes by physical criteria (conditions change and influence of external or internal factors) the long-term studies of experts on the use of non-traditional means and methods in sports training to improve the ability to speed up and develop the maximum speed and power of running. The non-traditional methods include conjugate influence used in sprinters' training, which correspond or slightly exceed the basic kinematic and dynamic criteria of the basic competitive exercise. Research analysis confirmed the efficiency of conjugate influence exercises and their impact on kinematic spatial and temporal parameters and on the dynamic parameters of the running stride reflecting the interaction of internal and external forces. Studies have also confirmed a positive immediate and long-term post-training trace effect. The survey research confirms that the use of traditional sprint training along with non-traditional means and methods enables the athlete to avoid the formation of a speed barrier, to improve acceleration, maximum speed, and running power.

1 Introduction

According to Y. Verkhoshansky, exercises of conjugate influence "should correspond to a basic sport exercise in the magnitude and nature of force development, the angular amplitude of the working movements and its section, to which the maximum muscular tension corresponds, the force impulse developed in a proper time and mode of muscular activity" [1]. The fundamental difference between the methods creating hindered or facilitated running conditions is in the intensification of the power or speed component in the structure of the running stride. In the first case, the power and speed-power potential of the sprinter is increased. In the second case, conditions are provided to improve dynamic and kinematic characteristics in different phases of the running stride. As a result, the speed capabilities of the athlete can be improved, the motor skills able to help the athlete run at excessive maximum speed can be formed, these achievements can be stored and applied in normal conditions [2].

The purpose of our brief analytical review is to explore the methodological differences between the two approaches. Practical evaluation of the effectiveness of conjugate influence exercises for the construction of training programs that enable the targeted development of the planned motor qualities, acceleration ability, the athlete's speed and power is carried out.

2 Materials and Methods

While working on the analytical review, we searched the publications in the Scopus, Web of Science Core Collection, SPORT Discus, RSCI, and HAC databases. Relevant scientific papers were searched on the Academic One File, Academic Search, eLIBRARY data platforms. This review includes 33 literary sources, representing both Russian and foreign studies, in which various aspects of the problem of interest are described in detail. The considered works studied the qualified athletes and students.

3 Results

3.1 Running with resistance or extra load

The rational use of difficult conditions makes it possible to surpass (in power) the effort exerted by an athlete in normal running, which contributes to the development of speed and power qualities of the athlete. In the future, the athlete can use these qualities to increase his or her running speed [2].

The methods used to create additional resistance include sled towing, resistance running, uphill running, parachute running, weighted waistcoat, cuffs.

3.1.1 Sled towing

Running with resistance allows an athlete to develop greater horizontal efforts in support, which increases the efficiency of intra and intermuscular coordination, forces to increase nerve activation and involve more muscle fibers of various types [2].

N. Lavrinenko et al. (1988) studied the resistance running with sleds (5-8% of an athlete's body mass). They observed an 8.6% increase in the power of efforts developed in a push-off phase. At the same time, there was a 12% decrease in running speed, due to a 8% shortening of running stride length and a 3% decrease in running frequency. If the resistance exceeds 8% of the body mass, the pushing force and damping time increase, the push-off angle changes, and the running stride length and frequency decrease by 12% and 6.5%, respectively [3].

R.G. Lockie et al. (2013) investigated the impact of resistance in 15 m acceleration with a sled towing capacity of 12.6% and 32.2% body weight (BW). At 32.2% BW resistance, the running speed decreased by 23%, the stride length decreased by 24%, the athlete's body slope increased by 15%, and acceleration time increased by 20%. Heavy loads resulted in greater kinematic changes during the acceleration phase compared to light loads. The authors came to the conclusion that sled towing with lighter weights would be preferable for training [4].

N. Kawamori et al. (2014) compared the effects of sled towing with 10% and 30% BW loads on acceleration ability. For that purpose, a 10 m test was carried out before and after training, the time was recorded for the 5 and 10 m segments. As a result, the 30% BW group significantly improved the 5 m and 10 m times (by 5.7% ± 5.7 and 5.0% ± 3.5, respectively, $p < 0.05$), whereas the 10% BW group improved only the 10 m time by 3.0% ± 3.5 ($p < 0.05$). It was revealed that running with a heavy weight of 10 to 30% BW was most efficient for increasing running stride length, while running with a weight of 5 to 10% BW was optimal for improving dynamic characteristics of the running stride. Thus, after the training program, the group running with 30% BW significantly increased stride length by 8.1%. It has been established that towing a heavy sled is efficient to increase horizontal support reaction forces in sprinting [5].

A.J. Harrison et al. (2009) performed the sled towing exercises for 6 weeks, twice a week, and examined changes in dynamic strength and running speed. A significant improvement in the 5 m sprint time was achieved when a 12.6 to 13% BW sled was used [6].

A. Zafeiridis et al. (2005) compared the effects of 8 weeks of sprint training with and without resistance and found that the sled towing group significantly reduced running times to 20 m, while the group without running resistance showed no improvement [7].

C.E. Smith et al. (2014), while observing urgent training effects after sled towing with 0%, 10%, 20% or 30% BW load, found that the use of a heavier resistance was more effective in developing speed in the 40 m run [8].

N. Lavrinenko et al. (1988), while investigating the "dynamic disruption" method, established that after dropping the resistance (sled) the athlete had a significant increase in speed. It was found that resistance in the range of 5-11% BW was the most effective. After the "dynamic disruption", a decrease in braking force and the vertical component of the support reaction force is observed when placing the foot on the support, and an increase in the horizontal component of the support reaction force by 5.7% is observed when pushing off. There is also an increase in stride time, with a 12.1% decrease in flight time and a 2.4% decrease in time on the test track. The increase in running speed is due to an increase in step frequency of 4.4%.

The immediate training effect after application of "dynamic disruption" during running under normal conditions is expressed by a reduction of 3.2% in running time and 2.6% in the flying phase. The horizontal component of the support reaction force increased by 1.9%, and the running stride frequency increased by 2.4%. And although the running stride length decreases by 0.7%, the running speed of the test segment increases by 1.9% [3].

A. Murray et al. (2005), while comparing the effects of 0%, 5%, 10%, 15%, 20%, 25%, and 30% BW loads in a sled towing sprint for 10 and 20 meters, found that when the load increased, step frequency did not change, but step length and speed decreased [9].

K.P. Clark et al. (2010), while studying the long-term effects of sled towing with a load of 10% BW, found a significant increase in velocity during acceleration phase without any significant effect on maximal velocity [10].

D.J. West et al. (2013) compared the training effects of traditional (TRAD) and combined (SLED) sprinter training with a 12.6% BW sled towing load, and their impact on speed development over a 6-week period. All participants improved their speed at 10 and 30 m running ($p < 0.001$). In 10 m running, SLED training had an increase by 0.04 ± 0.01 s, compared to TRAD training increase of 0.02 ± 0.01 s; $p < 0.001$. In 30 m running, SLED training had an increase of 0.10 ± 0.03 s, compared to TRAD training increase of 0.05 ± 0.03 s; $p = 0.003$. Significant improvement in 10 m running was achieved in the SLED group by 2.43 ± 0.67 s, and in the TRAD group by 1.06 ± 0.80 s; $p = 0.003$. Significant improvement in 30 m running was achieved in the SLED group by 2.46 ± 0.63 s, compared to the improvement of the TRAD by 1.15 ± 0.72 s; $p = 0.003$ [11].

M. A. Wong et al. (2017) investigated the effect of sled towing with 30% BW on the 30 m start acceleration for 6 months, training was performed twice a week. Analysis showed that after sled towing the athletes improved their start acceleration time from 4.55 ± 0.18 s, to 4.47 ± 0.21 s [12].

3.1.2 Running with loads

The application of loads (belt, waistcoat) of 5 kg or more has a greater influence on the development of the dynamic characteristics in the running support phase and helps to find a reasonable position of the center-of-mass with a minimum vertical oscillation.

Running with a load equal to 4% of body weight affects the activity of the main muscle groups without causing significant changes in the rhythmic and structural characteristics. In this case, power (reactance factor) increases to a greater extent, and power impulse has a slightly smaller increase in the support phase. A load of 8% BW has a greater effect on the development of strength and strength impulse and smaller effect on the reactance coefficient [13].

P.E. Alcaraz et al. (2008), while investigating the kinematics of sprinting at maximal speed in a 9% BW waistcoat, found no significant difference in kinematics, but observed a shorter flight phase [14].

K. Zafeiropoulos et al. (2014) investigated the immediate effects of loads (weighted waistcoats) of 8%, 15% and 20% BW on different segments of 50 m sprint. The 8% BW weights resulted in a significant improvement (4.6 - 4.7%) in the 40 m sprint, the 15% BW weights significantly improved the 20 and 40 m sprints (by 7.3 and 7.4%, respectively), the 20% BW weights improved the 10 and 40 m sprints (by 9.9% in both distances). It was observed that leg strength and sprint performance were statistically significantly correlated with 0%, 8% and 15% BW weights ($r = -0.440$ and -0.553) in the 10, 20, 30, 40, and 50 m run, leg strength and 20% BW weight correlated ($r = -0.419$ and -0.565), only for the 30, 40 and 50 m run [15].

3.1.3 Running with localized weights

Many experts see certain prospects in the use of weights in different parts of the athlete's body to create conditions of artificial hypergravity. Adding weights to different segments of the body changes the moment of inertia of the swing arm, which can increase the power of the muscles and generally improve the intensity of the exercise. The process of developing a fast-running stride depends largely on mastering inertial and reactive forces.

Controlled correction of the moment of inertia of the flywheels in sprinting is an effective factor of directional change of running kinematics in the phases of acceleration and deceleration of the limbs. By using an additional load on the limbs, with different variants of removal from the center of rotation, one has the possibility to change the moment of force by changing the value of the thrust arm. Thus, by changing the contribution (gravitational, inertial, reactive forces) to the biomechanics of the swing links, we contribute to stimulation of neuromuscular forces on a new quality level of control by the central nerve system [2]

Leg loads of 4-8% of foot weight have a positive impact on the movement system and develop the specific qualities of a sprinter [13].

Running with 250-300 g weights on the distal ends of the one leg in the training of short distance runners provides an increase in running speed indicators by increasing the length of the running stride and, to a lower extent, the frequency of steps. The mean value of indicators in running for 50 meters in the experimental group improved by 0.19 s, ($p < 0,01$), the mean stride length increased by 0.03 m, ($p < 0.05$) and stride frequency increased by 0.04% ($p > 0.05$) [16].

S.A. Oreschuk believes that 200-400 g weights placed on the leg change the structure of running stride with a slight decrease in running speed, increase in stride length, support time and flight phase, which improves the internal rhythm of running. The use of 500 g cuffs on the distal part of the thigh results in longer running strides, a sharper pushing angle and increased pushing power [17].

3.2 Assisted running

The use of conjugated influence exercises performed under facilitated conditions improves dynamic and kinematic characteristics in different phases of a running stride and puts into action the properties of elastic muscle energy [2], enhances the formation of an effective speed-rhythm structure of a running stride, reconstructs an old inefficient dynamic stereotype into a more perfect one, enabling athletes to develop over the maximum speed and helps to overcome the speed barrier.

The main training methods are running with elastic tractions and towing devices, facilitating running conditions, running downhill, running on a treadmill, facilitating lead system trainer, and running with additional elastic ties.

3.2.1 Athlete towing

N. Lavrinenko et al. (1988), while investigating the efficiency of towing an athlete by his belt, determined that with a pulling force of 2-3 kg, the running speed was 0.5 - 1 m/s, higher than the highest possible speed of a sprinter. The running speed increased by 5%, running stride length increased by 2.2% and frequency increased by 2.6%, shock absorption time decreased by 11%, push-off time decreased by 3.5% and push-off force increased slightly [3].

A. Mero et al. (1986) discovered that an increase in speed when towing a sprinter result from an increase in stride frequency [18].

G. B. Dintiman et al. (1998) believe that the use of sprinter towing can improve the ratio of stride frequency to stride length and improve the 40-yard run to 0.6 seconds, with a distance of no more than 30 to 50 yards [19].

D.E. Upton et al. (2011) compared the effects of different training programs using resistance, towing, and traditional sprinting at maximum speed and acceleration. The 1st group used 12.6% BW resistance, achieving a speed equal to 90% of their maximal speed. The 2nd group used towing with a partner, and the 3rd group used a 20 m sprint. The study showed that the maximum speed in 40 m running increased for both groups, by 0.08 m/s in the 2nd group and by 0.06 m/s in the 1st group, while there was no change in speed in the 3rd group [20].

V. Aksenov (1975) investigated changes in biomechanical features, immediate and distant trace effects under the influence of an athlete's towing. An increase in the amplitude of acceleration of the lower limb links (shin and thigh) was observed during towing and flight. The support force increased by 14.2%, while support time decreased by 11.7%, running speed increased by 14.5%, stride length increased by 8%, and stride frequency increased by 4%. Trace effects analysis in the immediate aftermath showed an increase in speed by 0.4 m/s (4%) and an increase in frequency by 2.7%. After 6-8 days, the increase in speed was observed due to an increase in running stride length by 6.4 cm (3.2%) [21].

3.2.2 Elastic cord running

R.J. Corn et al. (2003) examined the kinematic differences between the 20 m sprint and the elastic cord towing with a pulling force of 40-50 N. There was no significant difference in stride pace. However, elastic cord towing led to changes in sprint kinetics in the acceleration phase compared to the maximum sprint [22].

D. A. Clark et al. (2009) investigated the kinematics of the sprinter's running stride when pulling with an elastic cord at 0, 2.0%, 2.8%, 3.8% and 4.7% of BW, in a 60 m run. The results revealed reduced running times under all conditions. A thrust value exceeding 3.8% BW had a negative effect on the running mechanics of the athlete. The stride time decreased under all towing conditions ($p < 0.01$), whereas the running stride frequency increased only slightly (by <2.0%). Significant differences ($p < 0.05$) were observed in stride length and horizontal center-of-mass velocity [23].

J.A. Bartolini et al. (2011) investigated the optimum level of elastic cord traction (0, 10, 20, 30, and 40% BW) in a 20-yard sprint. It was found that when BW traction force increased, the running time decreased (by 3.20 ± 0.12 s for 0% BW; by 3.07 ± 0.09 s for 10% BW; by 2.96 ± 0.07 s for 20% BW; by 2.81 ± 0.08 s for 30% BW, and by 2.77 ± 0.10 s for 40% BW). These results indicate that a 30% BW traction on the elastic cord appears to be optimal for improving sprint times [24].

3.2.3 Downhill running

Downhill running increases the maximum running speed. When running on a track at an incline of 2-3°, running speed increases to a greater extent due to the frequency of running steps - by an average of 13% (N.G. Ozolin, D.I. Obbarius, V.P. Petrovsky, D.P. Ionov).

Running pace increased by an average of 17% when entering the horizontal section of the athletics track (D.I. Obbarius) [25].

G.P. Paradisis et al. (2001), while investigating factors contributing to the speed increase in downhill running, found that the parameters of stride length were the first to respond to speed changes. For example, on a downhill slope of up to 3°, running speed increased by 9.2% and stride length increased by 7%. However, after 6 weeks of training, it was observed that an increase in stride frequency was the main factor for the increase in distance running speed [26].

The study of G.P. Paradisis et al. (2009) involved students who were randomly allocated into two training groups: the 1st used a combined ascent-descent running training, the 2nd trained on a horizontal surface and the 3rd was a control group. Pre- and post-training tests were performed to investigate the impact of 8 weeks of training on peak running speed, stride frequency, support time and flight time. The 35 m sprint test for the 1st group showed a significant improvement ($P < 0.01$) in speed (by 4.3%), step frequency (by 4.3%), support time (by 5.1%) and flight time (by 3.9%). The 2nd group showed smaller improvements of these characteristics (by 1.7% ($P < 0.05$), 1.2% ($P < 0.01$), 1.7% ($P < 0.01$) and 1.2% ($P < 0.01$), respectively). There were no significant changes in control group [27].

W.P. Ebben et al. (2008) investigated the optimum incline for downhill running at 0°; 2.1°; 3.3°; 4.7°; 5.8°, and 6.9°. The authors found that running downhill at 3.4° to 5.8° was most optimal to increase the maximum speed and acceleration in athletes, while an incline of 6.9° disrupted running kinetics, forcing sprinters to decelerate [28].

P. William et al. (2008) investigated the effects of downhill running on speed and acceleration. The results of running for 10 and 40 yards at five different inclines (from 2.1° to 6.9°) show that in 10-yard acceleration at an incline of 5.8° the pro-run time decreased by 6.54% ± 1.56. In the 40-yard sprint at an incline of 5.8° the run time decreased by 7.09% ± 3.66 compared to 0° incline [29].

3.2.4 Mechanized treadmill running

S. Dorgo et al. (2016) compared the effectiveness of 6 weeks of traditional sprint training (TR) and high-speed training (HST) on a treadmill. The TR group used traditional workout and the HST group practiced high speed workout on a treadmill. The 20-yard sprint improved significantly in both groups: from 2.46 ± 0.30 s to 2.41 ± 0.29 s; $p = 0.007$ for TR, from 2.39 ± 0.29 s to 2.35 ± 0.27 s; $p = 0.02$ for HST [30].

F. González et al. (2016) compared the main kinematic effects of high-speed training in treadmill running: running stride length (SL), frequency (SF), leaning time (SL), flight time (SF), and maximum speed. A statistically significant high correlation was observed for SF ($p = 0.004$, $r = 0.881$) and maximum speed ($p < 0.001$, $r = 0.952$). Statistical correlation was observed for SL ($p = 0.102$, $r = 0.667$) and SF ($p = 0.056$, $r = 0.695$) [31].

3.2.5 The "antigravity suspension" towing

Running with reduced gravity uses an "anti-gravity suspension" or kite, the main purpose of tractions in the vertical direction is to reduce the need to exert effort to overcome gravity, braking forces arising in the initial phase of the support period and vertical support reaction forces. Using this trainer, the athlete becomes 10-30 kg lighter due to vertical elastic tractions, and he can considerably exceed his speed capabilities. The performed studies demonstrated a significant reduction in running stride support time and an increase in momentum of force, which makes it possible to achieve super-maximal running speed [32].

J.A. Bartolini et al. (2011) compared the effects of a number of different elastic shock absorbers for vertical towing up to 40% of body weight over sprint distances up to 20 yards. They found that when body weight was reduced progressively to 30%, there was a similarly progressive increase in speed [24].

3.2.6 Running with artificial muscle pulls

Running with artificial muscle pulls is called recuperation, the process of recovering part of the energy to put it back into use. Recuperators consist of a set of elastic cords that act as an "elastic extra muscle" - from the foot to the knee joint and beyond, or between the distal ends of both leg joints. The tractive force of the elastic ties must be kept to a minimum of (1 - 18% of the athlete's weight). It was experimentally proved that the calculated energy saving due to its transfer from link to link was 8.8%, the real energy saving was 7% [33]. The use of additional "energy-power" forces in the structure of a running stride gives an increase in the maximum running speed with an increase in the frequency of a running stride and a slight decrease in the leaning time and stride length [2].

4 Discussion

The performed analytical review shows that conjugate influence exercises contribute to the formation of a rational biomechanical structure of the running stride and the development of special physical qualities of the athlete.

Resistance or extra-load running improves the dynamic characteristics of the running stride, with the immediate "after-effect" being an increase in the horizontal component of the support reaction force during the push-off phase and in the running stride length. The long-term after-effect is expressed by a reduction in the support time and flight phase, an increase in the horizontal component of the support reaction force in the push-back phase and an increase in the frequency and average length of the running strides. Resistance training for 6-8 weeks can improve the acceleration ability and increase the strength and power of the sprinter, which subsequently gives an advantage in the strength to speed ratio at higher speeds.

The sprinter's training in facilitated conditions includes additional overdrive incentives to avoid the development of a speed barrier. The immediate and distant trail effect is expressed by an increase in maximum running speed, effort applied to the support, frequency and length of running strides, a reduction in support time in the damping and rebound phases, and a reduction in flight time.

When planning sprint training using exercises of conjugate impact, various means and methods are used systematized by physical characteristics (changing conditions and the impact of external or internal forces). Based on the literature analysis and the results of practical application, we have formulated and outlined the critical variables (rest, intensity, volume, etc.) necessary for the development of local programs in sprint trainings, shown in Tables 1-2.

A variety of running techniques with resistance or extra load can be used to improve acceleration ability and running power (Table 1).

Table 1. Examples of training programs for sprinting with resistance or extra load

Types of exercise	**Duration**	**Exercise load / Intensity**	**Amount**	**Rest**	**Goals and objectives**
Sled towing	2-3 sessions per week for 4-8 weeks	from 5-12.6% to 30% BW	3-5 repetitions, 5-40 m, 1 to 3 sets	2-3 min. between runs, 5-6 min. between sets	Light loads to develop dynamic power and starting acceleration. Heavy loads to develop power, starting acceleration
Running with loads (waistcoat, belt)	2-3 sessions per week for 4-6 weeks	4-9% to 20% BW	3-5 repetitions, 5-40 m, 1-4 sets	2-3 min. between runs, 5-6 min. between sets	Start run-up and acceleration improvement, dynamic strength and running power development
Running with cuffs	2-3 sessions per week for 4-6 weeks	4-8% of the leg weight	3-5 repetitions, 30-50 m, 1-3 sets	2-3 min. between runs, 5-6 min. between sets	Start run-up and acceleration improvement, dynamic and reactive strength and running power development

Using assisted running programs in sport training athletes can achieve above maximum running speeds, which has an impact on time of support and flight, frequency and length of running steps, etc. This makes it possible to improve the ability to accelerate and develop the maximum running speed (Table 2).

Table 2. Examples of training programs for sprinters performed under facilitated conditions

Types of exercise	**Duration**	**Exercise load / Intensity**	**Amount**	**Rest**	**Goals and objectives**
Athlete towing	2-3 sessions per week for 4-6 weeks	2.0-4.7% of BW or at a pull force of 2-3 kg.	3-5 repetitions, 20-60 m, 1- 3 sets	2-3 min. between runs, 5-6 min. between sets	Start run-up and peak speed improvement
Elastic cord running	2-3 sessions per week for 4-6 weeks	10, 20, 30, and 40% BW or with 40-50 N load	3-5 repetitions to 20 m 1-3 sets	2-3 min., between runs, 5-6 min. between sets	Start run-up improvement

Downhill running	2-3 sessions per week for 4-6 weeks	Incline of 2-5.8°	4-5 repetitions 20-50 m 1-3 sets	2-3 min., between runs, 5-6 min between sets	Start run-up and peak speed improvement
Mechanised treadmill Running	2-3 sessions per week for 6-8 weeks	Exceeding the maximum speed by 0.4-1.8 m/s	Duration 3-5 sec., 2-6 repetitions, 1-2 sets	Rest until recovery	Peak run speed development
The "antigravity suspension" towing	2-3 sessions per week for 4-6 weeks	10-40% of body weight	3-5 repetitions, 20-60 m, 1-2 sets	2-3 min. between runs, 5-6 min. between sets	Peak run speed development
Running with artificial muscle pulls	2-3 sessions per week for 4-6 weeks	1-18% of body weight	3-5 repetitions, 20-60 m, 1-2 sets	2-3 min., between runs, 5-6 min. between sets	Peak run speed development

Conclusion

The proposed approach of application in the training process of exercises of conjugate influence makes it possible to perform the necessary changes in the dynamic and kinematic stereotype of the running stride using an individual approach correctly, purposefully and dosed. The use of traditional sprinter training, along with non-traditional means and methods will allow specialists to develop the planned motor qualities in a directed way, and to improve the ability to accelerate and increase the maximum speed and power of an athlete.

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