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Review article

BIODYNAMIC CHARACTERISTICS OF MAXIMUM SPEED DEVELOPMENT

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Abstract. *The purpose of the present review article is to bring together some of the most important findings from the field of maximum speed development from the aspect of biomechanical, motor and neuro-muscular factors. Maximum speed is a complex biomotor ability, which manifests itself in real sports situations and is an important generator of the success of athletes in various sports disciplines. Efficiency of maximum speed is defined in terms of frequency and the length of one's stride. Both parametres are mutually dependent; they also depend on the processes of the central regulation of the motor stereotype. From the biomechanical point of view, a running stride as a basic structural unit depends on the eccentric-concentric muscular cycle of take-off action. Utilisation of elastic strength in the muscular-tendon complex and pre-activation of m. gastrocnemius is highly important in this segment. Maximum speed is a very limited hereditary biomotor ability which is characterized by a reduced possibility for controlling movement. The cerebellum, co-activation of muscles in the kinetic chain and the frequency of activation of motor units play important roles in controlling the activation of agonists and antagonists. The primary goal of training is to create an optimal model of the motor stereotype in the zone of maximum speed. Such a process has to be long-term and methodical.*

Key words: *sprint, motor steretype, take off-action, controling movement, EMG activation.*

INTRODUCTION

The maximum speed, which people produce in movement, depends on various factors. These factors are related to morphological and physiological characteristics, energy mechanisms, age, gender, bio-motor abilities, inter- and intra-muscular coordination and optimal biomechanical technique of movement. Locomotive speed in the form of a sprint

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is one of the most important abilities, which defines the success of athletes in many sports situations. From the genetic (hereditary) motor programme aspect, speed can be classified as a primary phylogenetic human movement. In specific sports situations, speed is manifested in the form of a »three-segment model«. The model consists of speed, strength and coordination. An analysis of the individual segments of this model depends on the particularities of specific sports disciplines. Maximum speed is a product of the frequency and length of stride. Both parameters are mutually dependent; they are also linked to the processes of central regulation of movement, morphological characteristics, bio-motor abilities and energetic processes. The relationship between the frequency and the length of a stride is individually defined and automated. Changing one parameter results in the changes of a second parameter as well. When the length of a stride is increased, the frequency decreases and vice versa.

THE NEURO – MUSCULAR CHARACTERISTICS OF SPEED

Take-off action in sprinting stride is a key generator for the development of maximum speed. The movement of sprinters is evaluated according to their horizontal velocity. The largest inhibitor in this movement is gravitational force; therefore, sprinters need to primarily develop sufficiently large vertical reactive force on the surface in a take-off action, which in itself consists of three phases. The first phase is placing a foot on the surface, followed by the amortisation phase and extension phase. Take-off action of the stride in sprinters is the best example of an eccentric-concentric muscular cycle (stretch-shortening cycle). During the eccentric phase a certain amount of elastic energy is accumulated in the muscular-tendon complex, which can then be utilised during the second phase. When looking at the production of reactive force onto a surface, muscles in the eccentric phase need to develop the greatest amount of force in as short a time span as possible. Transition time needs to be as short as possible and has an important effect on the efficiency of eccentric-concentric contractions. Tendons and ligaments, which resist the extension, can store up to 100 % more elastics energy than muscles (Luhtanen & Komi, 1980; Mero, Komi & Gregor, 1992). Pre-activation of m. gastrocnemius (the calf muscle) is extremely important for the mechanics of take-off; this muscle is activated 80 milliseconds prior to the foot touching the surface (see Figure 1a). Pre-activation creates a stiffness of the plantar flexors (muscles) in the moment when the front part of the foot touches the surface. Increased stiffness of the muscles together with the minimal amplitude of movement in the ankle joint enable better transfer of elastic energy from the eccentric to the concentric contraction (Mero et al., 1986; Kyrolainen et al., 2001). When loaded during sprint, tendons elongate up to 3-4% of their length. Any elongation above this limit represents a potential danger for rupture. Tendons and ligaments act as springs, which store elastic energy. Excessive elongation of the tendons results in the transformation of elastic energy into heat, namely into chemical energy. High temperature in the cells – fibroblasts and collagen molecules, which are building material for tendons, could facilitate the possibility for injuries in this part of the locomotor apparatus (Huiling, 1999).

During the second phase, an extension of the muscular–tendon complex takes place (see Figure 1b), whereas previously stored elastic energy is utilised in the form of efficient propulsion of sprint stride. The main absorber in this phase is m. quadriceps (the thigh muscle). Increased co-activation of agonists and antagonists (m. vastus laterali, m.

biceps femoris, m gastrocnemius and m. tibialis) increases the stiffness of the knee- and ankle joints. In this way, the entire leg is being prepared for contact with the surface. Increased stiffness in the ankle joint in sprint reduces the consumption of chemical energy in the following muscles: m. gastrocnemius – m. lateralis – m. medialis and m. soleus (Kuitunen, Komi & Kyrolainen, 2002). Muscular activation of the plantar flexors and the knee extensors increases in the pre-activation phase in proportion with the increase in speed. In addition, pre-activation of m. triceps surae together with the stretching reflex facilitates a high degree of stiffness in the muscles in the extension phase of the take-off.

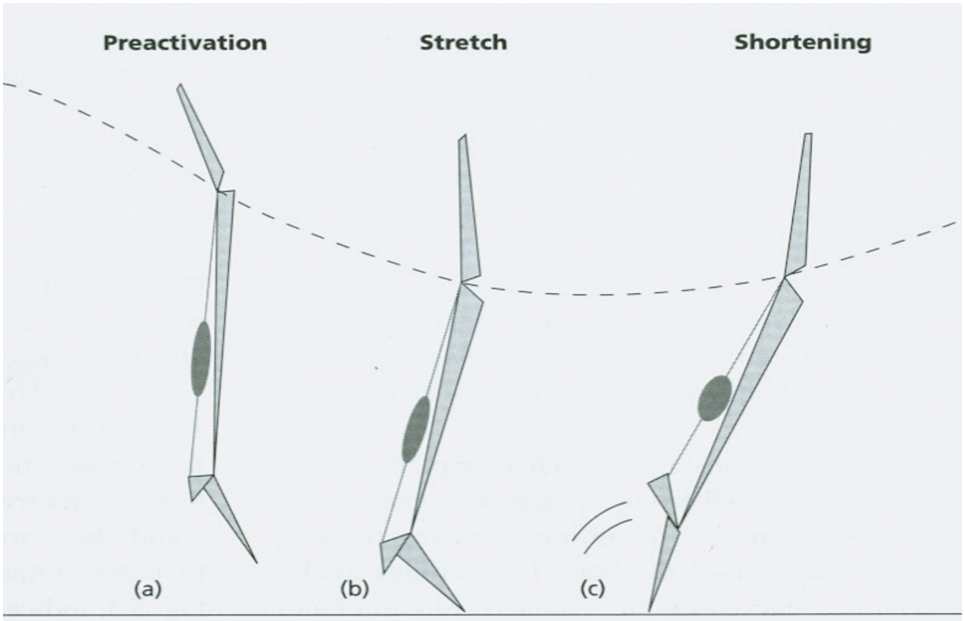

Fig. 1 Eccentric – concentric muscular contraction in the stride of sprinters (Komi, 2000)

The extension of the muscular and tendon complex is managed and coordinated with two motor reflexes: the monosynaptic stretch reflex and the polysynaptic reflex of Golgi tendon organ. These two reflex systems form a recurring coupling for maintaining near optimal muscle length (reaction to stretching) and the reaction to the excessive elongation of tendons. Receptors of stretch reflex–muscle spindles are placed parallel to muscle fibres. When the muscle is being extended as a result of external force acting on it, muscle spindles also extend. As a result of muscle spindle extension, alpha motor neurons are activated, which in turn activate reflex contraction of elongated muscles as a reaction to stretching. Golgi tendon organs are placed serially with muscle fibres. These receptors react exclusively to the forces, which are being developed in the muscles and do not react to any changes in length. If muscle effort increases rapidly, the Golgi tendon complex prevents muscular contraction. Subsequent decrease of muscular effort prevents injuries to muscles and tendons (Jacobs & Ingen Schenau, 1992; Zatsiorsky & Kraemer 2009). During the phase when the foot is placed on the surface and in the amortisation phase, extensors are elongated and they produce contraction in the same muscle on the basis of the stretch reflex. At the same time, the effort of large muscles activates the Golgi tendon organ, which prevents the activity of the muscle. As a result of specific training, the activation of the Golgi tendon organ is being inhibited and thus athletes can withstand large forces at landing without decreasing the produced force of the muscles. As reversible contractions of the muscles represent an integral part in many sports movements, they needs to be specially trained and taught. In the process of training jumps among athletes, the so-called plyometric jumps and plyometric training produce high quality results in the development of take-off strength. In order for such training to be successful, a long term all-around preparation with other means and methods for strength training is required. On the other hand, plyometric jumps can cause serious injuries among athletes.

The time that passes since a foot is placed on a surface until the end of the take-off in the stride of sprinters' lasts between 80 – 100 milliseconds. The cumulative contact time is shorter in the case of better sprinters and longer in the case of worse sprinters. The shorter the time of contact, the better the frequency and the higher the force on a surface. The relationship between the contact phase and the flight phase in sprint stride is 20:80. The largest reactive force of the surface is noticed 30 to 40 milliseconds after the first contact with the surface (Mann & Spraque, 1980). According to Mero, Komi and Gregor (1992), the vertical reactive force of the surface in the case of sprinters reaches 200% to 300% of their body weight. The largest reactive force of the surface in their case is developed in the middle phase of the contact – the phase of maximal amortisation (see Figure 2). In order to develop maximal locomotive speed, the largest possible force needs to be developed in the shortest possible time. Mastering the optimal mechanics (technique) of the sprint is a condition for the utilisation of force, which is being generated by the neuro-muscular system.

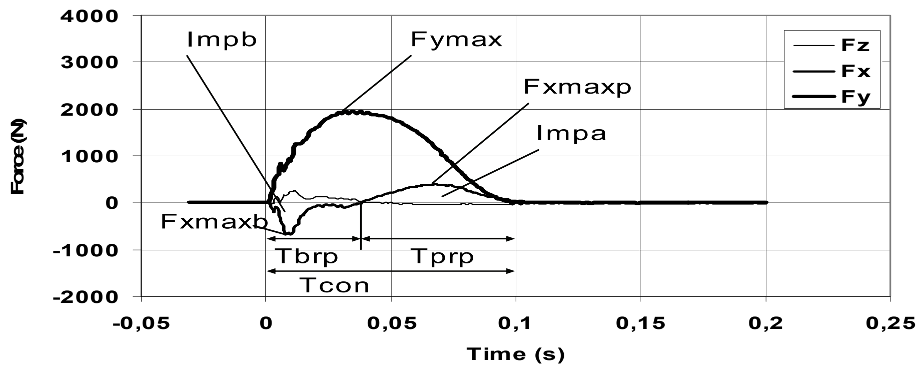

Fig. 2 Development of reactive force of the surface (z, y, x) in the contact phase of sprinters stride (Dolenec & Čoh, 2002)

Fz – force in lateral direction; Fx – force in horizontal direction; Fy – force in vertical direction; Tcon – contact time; Tbrp – time of braking; Tprp – time of propulsion; Fxmaxb – maximum force in the horizontal direction (braking phase); Fxmaxp – maximum force in the horizontal direction (propulsion phase); Fymax – maximum force in the vertical direction; Fzmax – maximum force in the lateral direction; Impb – force impulse in the braking phase; Impa – force impulse in the propulsion phase.

INTRA- AND INTER-MUSCULAR COORDINATION OF SPEED DEVELOPMENT

In order to understand the dynamics and the changes of stride frequency and length in the realisation of maximum speed, the function of the central nervous system needs to be explained. Muscle force is not only defined by the amount of included muscle mass, but also by the degree of participation of individual muscle fibres. In order to manifest muscle force, muscles need to be activated in a certain way. Coordinated movement of several muscle groups depends on inter-muscular coordination. The basic characteristic of elite sprinters is efficient coordination of activated fibres in individual muscles and muscle groups. These sprinters have better inter- and intra-muscular coordination. The nervous system generates muscle force in three ways: with the activation and deactivation of individual motor units, with a frequency of releasing motor units and with the synchronisation of motor units. All three ways are based on motor units, which represent basic elements in the workings of the neuro-muscular system. Every motor unit consists of motor-neurons, which are located in the spinal cord, and of muscles fibres, which are innervated. From the contraction characteristics point of view, motor units can be divided into slow and fast motor units. Slow motor units are specialised for extended use at relatively low speed. They consist of small motor-neurons with a low threshold of release and they are adapted to aerobic activities. Fast muscular or motor units are specialised for relatively short activities, which require manifestation of large strength, speed and a high degree of force development. They consist of large motor-neurons with a high threshold of release, axons with high speed of implementation and muscle fibres, which are adapted to powerful anaerobic activities. Motor units follow the "all or nothing" law, meaning that any motor unit at any time is either active or inactive. The fastest speed of shortening of fast muscle fibres is four times faster than that of slow muscle fibres (Zatsiorsky & Kraemer, 2009). Human muscles in general consist of motor units with slow or fast action. Sprinters and athletes, who are required to develop large speed or force in a unit of time, predominantly have motor units with fast actions.

During willing contractions, the activation of muscle fibres depends on the size of motor-neurons with a "size principle" being applied. First, small motor-neurons with a low threshold of excitation are activated. With increasing demand for the development of large force, larger motor-neurons with the fastest contraction twitch and highest threshold of excitation are recruited last. Mixed muscle types consist of motor units with slow and fast activation regardless of the degree of muscular effort and the speed being manifested. Only highly trained athletes manage to activate motor units with fast activation.

The realisation of maximal locomotive speed is related to high coordination of movement. In a cycle of sprint stride, more than 60 lower-leg muscles are active, which have to work in a synchronised and coordinated way. During the execution of precise movements, motor units usually do not work at the same time. In order to produce maximum force, which is one of the key factors of maximum speed, the largest amount of slow and fast motor units needs to be recruited as well as the maximum frequency of release and simultaneous work of motor units in a period of maximum voluntary effort. The primary goal in speed training is the creation of an optimal movement model, which is based on the coordination of muscle group work.

CONTROLLING MAXIMUM SPEED

Speed is a highly rigid ability with a strong fixated programme in the central nervous system. A shortage of neuro-muscular coordination is one of the limiting factors of speed, as the possibility for optimal control of movement decreases with the increase in the speed of movement. The larger the speed, the higher the deviation from the ideal movement model. Movement control is at the lowest level precisely under the conditions of maximum speed. Maximum speed belongs in the category of so-called terminal movements, which have aprecisely set structure with a defined beginning and end of movement (Latash, 1994). Terminal movements differ according to their dynamic and kinematic volumes. Every terminal movement requires its adequate motor programme. The motor programme is defined as a group of simultaneous and successive commands to muscles in order to start and later end a desired movement. On the level of the central nervous system and spinal cord, motor programme is represented by a group of efferent signals, which travel down the motor nerves to the muscles. It is known that the large number of various fast movements is controlled as the "open loop" process with a centrally stored programme and without any feedback information (Schmidt, 1990). The cerebellum and spinal cord have the most important functions in these movements. The high speed of movement does not allow any analyses or correction of movement. Precise movement control lies therefore in the work of the cerebellum and relies on the information which arrives there mostly via proprio-receptors that are located in the joints and connective tissues of muscles. Spinal reflexes of the muscular-tendon source in the area of the spinal cord also play an important part in movement control. Any change in the length and tension of muscles is transferred via the stretch reflex path. The stretch reflex serves as a servo-mechanism, which enforces the excitation effect on alpha motor neurons, thus increasing the precision of control of muscle group work.

One of the most important problems in motor control is the role of agonist and antagonist muscles and their direct effect on the kinematics and dynamics of movement through appropriate type, intensity and time sequence of the muscle force effect. In fast terminal movements, such as sprinting, development of force is a key factor of movement efficiency. The variables of motor programme include the force of agonist muscles, the maximum force of the antagonist muscles, time delay of the antagonist muscles, the time for achieving maximum force of the antagonist muscles, the co-activated relationship of muscles in the function of their place in the kinetic chain, the length of a movement, the terminal position, starting position, time length of a movement and the speed of a movement (Ilić, 1999).

The development of maximum speed requires very subtle inter-muscular coordination of the muscle groups of lower extremities. The most important are the following muscles: m. gluteus maximus, m. tibialis anterior, m. soleus, m. gastrocnemius, m. rectus femoris, m. biceps femoris, m. vastus lateralis (see Figure 3). Identifying strategic muscles, which generate the take-off force, is very important from the sports training point of view in order to optimise technique and prevent any injuries. In the take-off phase, muscles develop the reaction force with a magnitude of 280 to 350 kp in a time interval of 85 – 95 milliseconds (Dolenec & Čoh 2002). Some studies from the field of electromyography and isokinetics of sprint stride have revealed that m. biceps femoris (the hamstring muscle) is one of the most important muscles for developing maximum speed (Mero et al., 1992; Dolenec & Čoh, 2002; Čoh, 2008). This muscle often gets injured during sprint training; therefore, its prevention with adequate training is very important.

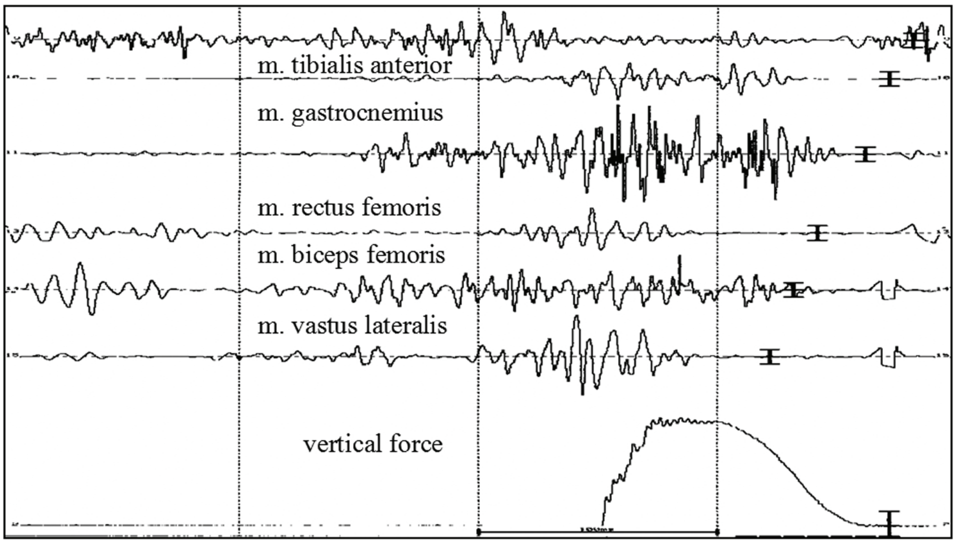

Fig. 3 EMG activation of muscles of lower extremities in the phase of maximum speed (Dolenec & Čoh, 2002)

Training of maximum speed is, from the aspect of the physical preparation of athletes, related to the running technique, which is particularly difficult to control in the conditions of maximum speed. Optimal neuro-muscular coordination is the main limiting factor of maximum speed. Therefore, the forming of correct dynamic stereotypes is a long term process, which has to have a precisely defined technique and has to begin at a very early age.

CONCLUSION

Speed is a complex and subtle biomotor ability, which in real sports situations occurs in various forms. One of the most important segments of the speed potential of athletes is maximum speed. From the biomechanical point of view, maximum speed is structured with the length and frequency of the stride. The goal of the training process is the improvement of these two segments, which are relatively highly genetically determined and depend on several neuro-muscular factors. The development of maximum speed is a long term process, which is related to optimal control of the agonist and antagonist muscles of the sprinting movement pattern.

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BIODINAMIČKE KARAKTERISTIKE RAZVOJA MAKSIMALNE SNAGE

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Cilj ovog preglednog rada je da poveže neke od najznačajnijih otkrića na polju razvoja maksimalne snage sa aspekta biomehaničkih, motoričkih i neuro-mišićnih faktora. Maskimalna brzina je kompleksna biomotorička sposobnost, koja se manifestuje u sportskim situacijama i koja je važan faktor uspeha u različitim sportskim disciplinama. Efikasnost maksimalne brzine definiše se u pogledu učestalost i dužine jednog koraka. Oba parametra zavise jedan od drugog; takođe zavise i od procesa centralne regulacije motoričkog stereotipa. Sa biomehaničke tačke gledišta, trčeći korak je osnovna strukturalna jedinica koja zavisi od ekcentrično-koncentričnog mišićnog ciklusa. Upotreba elastične snage u kompleksu mišića i tetiva i predaktivaciji m. Gastrocnemius-a je jako bitna za ovaj segment. Maksimalna brzina je veoma ograničena nasledna biomotorička sposobnost koja se odlikuje umanjenom sposobnošću za kontrolisanje pokreta. Mali mozak, ko-aktivacija mišića u kinetičkom lancu i učestalost aktivacije motoričkih jedinica igraju važnu ulogu u kontrolisanju aktivacija agonista i antagonista. Primarni gol treniranja je da se stvori optimalni model motoričkog stereotipa u zoni maksimalne brzine. Ovakav process mora se odvijati na duge staze i mora biti sistematski sproveden.

Ključne reči*: sprint, motorički stereotip, start, kontrola pokreta, EMG aktivacija.*