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DYNAMIC FACTORS AND ELECTROMYOGRAPHIC ACTIVITY IN A SPRINT START

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Abstract. The aim of the study was to establish the major dynamic parameters as well as the EMG activation of muscles in a sprint start as the first derivative of sprint velocity. The subject of the analysis was block velocity, the production of force in the front and rear starting blocks, the block acceleration in the first two steps and the electromyographic activity (EMG) of the following muscles: the erector spinae muscle, gluteus maximus muscle, rectus femoris muscle, vastus medialis muscle, vastus lateralis muscle, biceps femoris muscle and gastrocnemius–medialis muscle. One international-class female sprinter participated in the experiment. She performed eight starts in constant laboratory conditions. The 3-D kinematic analysis was made using a system of nine Smart-e 600 cameras operating at a frame rate of 60 Hz. Dynamic parameters were established by means of two separate force platforms to which the starting blocks were fixed. A 16-channel electromyograph was used to analyse electromyographic activity (EMG). It was established that the block velocity depended on the absolute force produced in the front and rear starting blocks and that it was 2.84±0.21 $m.s^{-1}$. The maximal force on the rear and front blocks was 628±34 N and 1023±30 N, respectively. In view of the total impulse (210±11 Ns) the force production/time ratio in the rear and front blocks was 34%:66%. The erector spinae muscle, vastus lateralis muscle and gastrocnemius–medialis muscle generate the efficiency of the start. The block acceleration in the first two steps primarily depends on the activation of the gluteus maximus muscle, rectus femoris muscle, biceps femoris muscle and gastrocnemius–medialis muscle. A sprint start is a complex motor stereotype requiring a high degree of integration of the processes of central movement regulation and an optimal level of biomotor abilities.

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Key words: Sprint start - Block acceleration - Dynamics - Electromyography

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Introduction

An efficient start is one of the crucial factors of a competitive performance in sprint disciplines. Some of the studies conducted so far, most of which were partial biomechanical studies, have identified the following main start parameters: reaction time, optimal position of the starting blocks with regard to the starting line, height of the sprinter's centre of gravity (CG) in the set position and the block velocity which is mainly a result of an efficient force impulse on the rear and front starting blocks [1,2,5,6,8,9,11,12,14,18,19,21,23,24]. A sprinter seeks to optimally implement and integrate all of the above parameters. These parameters are interdependent and each is conditional on the central movement regulation processes, biomotor abilities, energetic processes and morphological characteristics of the athlete [3,4,15,17,21,22,24,25]. The start as the first sprint derivative directly influences the efficiency of the first phase of the block acceleration. The performance of the sprint start and block acceleration is a specific motor problem requiring the athlete to integrate, in terms of space and time, an acyclic movement into a cyclic movement. The accuracy of analysing a complex motor problem such as the efficient performance of a sprint start largely depends on proper measurement procedures and the available technologies.

The aim of the study was to analyse and identify the major dynamic parameters as well as the EMG activation of the muscles in a sprint start. The subject of the analysis was the block velocity in a dependent relationship with the development of force in the rear and front blocks, the block acceleration in the first two steps and the EMG activation of the following muscles: the erector spinae muscle, gluteus maximus muscle, rectus femoris muscle, vastus medialis muscle, vastus lateralis muscle, biceps femoris muscle and gastrocnemius–medialis muscle. As a result of these investigations it should be easier to understand the start mechanisms and to develop appropriate training methods for starting.

Meterials and Methods

Subject sample: The study sample included one female athlete (M. T.) whose specialty is 100-m hurdles (age: 23; body height: 167.0 cm; body mass: 56.1 kg; personal record in 100-m hurdles: 13.19 s).

Measurement procedure: The athlete executed eight starts which were included in the analysis and data-processing. A system consisting of nine CCD video cameras Smart – 600 (BTS Bioengineering, Padova) with a 60 Hz frequency and 768 x 576 pixel resolution was used for 3-D kinematic analysis. Kinematic parameters were processed by the BTS Smart Analyser programme. The dynamic model was defined, featuring a system of 17 infra-red sensitive markers (head, shoulders, forearm, upper arm, trunk, hips, thigh, shank, foot). The validity of the model was checked by the sequence of walking in the sagittal and frontal planes. The following was established by kinematic analysis: start velocity and block acceleration in the first two steps. Dynamic parameters of the sprint start were established by means of two independent tensiometric platforms – force plate (Kistler, Type 9286A) on which the standard start blocks were installed. The development of forces in horizontal- vertical (Fxy) directions was registered at the front and rear blocks. A 16-channel electromyograph (BTS Pocket EMG, Myolab) was used to analyse electromyographic activity (EMG). It consisted of two units: a mobile unit (HP Ipaq 4700), capturing all EMG signals and transmitting them to a stationary unit by wireless technology (Wi-Fi) – Fig. 1. The EMG activation of six muscles on the left and six muscles on the right leg (m. gluteus maximus, m. rectus femoris, m. vastus medialis, m. vastus lateralis, m. biceps femoris, m. gastrocnemius – medialis) as well as one trunk extensor muscle (m. erector spinae) was monitored. Superficial electromyographic muscle activity was detected by means of bipolar surface electrodes Ag-AgCl (FIAB S.p.A, Florence, Italy), which were fastened to the specific location of motor unit of muscles, following thorough skin preparation. The electrodes were fastened by a highly qualified person. In the continuation of the experiment the recorded signals were filtered and smoothed. First, a Hamming high-pass filter was used at a 30 Hz frequency to eliminate the artefacts. Then, the signal was integrated with the RMS algorithm with the time base of 20 ms. A Hamming low-pass filter was used for further smoothing at a 10 Hz frequency. The statistical analysis of results was processed with the SPSS statistical software.

Fig. 1
EMG measurement procedure – block velocity

Results

Table 1
Dynamic parameters in a sprint start

PARAMETER	Unit	N	Result
Block velocity	$m.s^{-1}$	8	2.84±0.21
Running velocity – first step	$m.s^{-1}$	8	4.02±0.24
Running velocity – second step	$m.s^{-1}$	8	4.78±0.27
Flight phase after blocks	ms	8	82±10
First contact after blocks	ms	8	168±17
Second flight phase after blocks	ms	8	101±20
Second contact after blocks	ms	8	139±22
Maximal force of rear blocks	N	8	628±34
Maximal force of front blocks	N	8	1023±30
Force impulse of rear blocks	Ns	8	72±7
Force impulse of front blocks	Ns	8	138±6
Total force impulse	Ns	8	210±11

Our study subject's maximal force on the rear starting block was 628±34 N and on the front starting block 1023±30 N (Table 1). The rear leg thus produced only 61.1% of the maximal force in the pushing phase of the start. Impulse i.e. impelling force (impulse = F x t), which is determined as the integral of the area under the force-time curve (Fig. 2), is one of the most significant criteria of an efficient start. Our athlete developed a force impulse of 72±7 Ns on the rear starting block and 138±6 Ns on the front starting block. In view of the total impulse (210±11 Ns) the force production/time ratio in the rear and front blocks was 34%:66%. It may be established that the contribution of the rear foot to the production of force was too small. The reason lies in the relatively large distance between the front block and the starting line (0.65 m), which resulted in a slight shift in the sprinter's centre of gravity towards her arms.

The sprinter's velocity at the moment of losing contact with the front starting block is defined as the block velocity; our subject's block velocity was 2.84±0.21 $m.s^{-1}$. The quality of the transition from the start to block acceleration is manifested in an increase in velocity in the first two steps (Table 1, Fig. 3). At the end of the first step the velocity of the body's centre of gravity of our athlete was 4.02±0.24 $m.s^{-1}$ and at the end of the second step 4.78±0.27 $m.s^{-1}$. In the first two steps, the velocity increased by 1.94 $m.s^{-1}$.

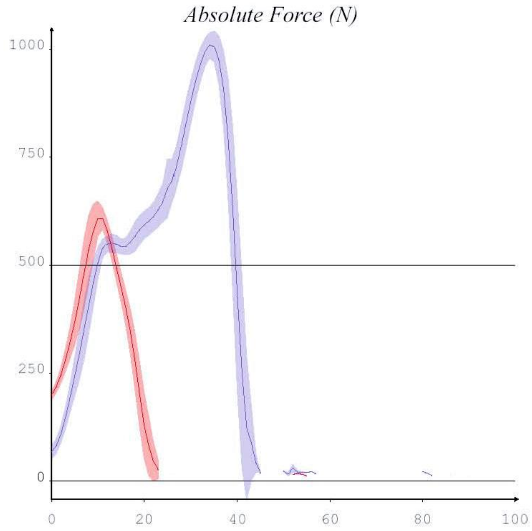

Fig. 2
Starting forces analyses - rear and front block

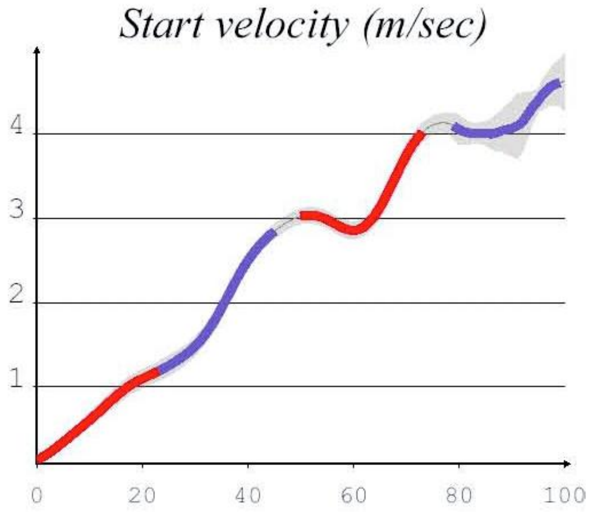

Fig. 3
Start velocity : block velocity – rear block- front block, first step, second step

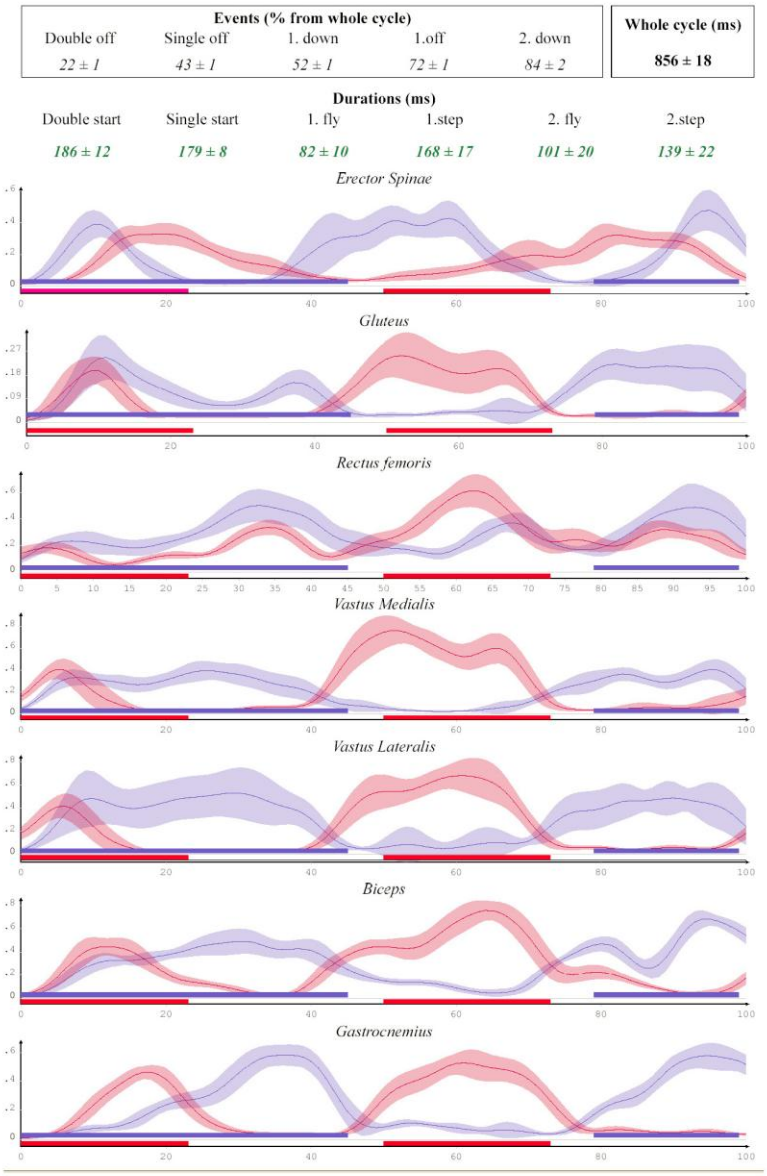

Fig. 4
Integrated electromyographic muscle activation (iEMG) – start action (rear block-front block), first step - second step

We analysed the EMG activation of six muscles of the right leg, six of the left leg and one trunk extensor muscle in the start phase and the execution of the first two steps. The cycle lasted for 856±18 ms. Hence, the following phase durations were established: the push from the rear starting block 186±12 ms, the push from the front starting block 179±8 ms, the flight after the push from the starting blocks 82±10 ms, the contact phase of the first step 168±17 ms, the second flight phase 101±20 ms and the contact phase of the second step 139±22 ms. (Table 1, Fig. 4). The block velocity is largely generated by the EMG activation of m. erector spinae, m. vastus lateralis and m. gastrocnemius–medialis. The velocity of the block acceleration (the execution of the first two steps) was generated by the EMG activation of m. gluteus maximus, m. rectus femoris, m. vastus medialis, m. vastus lateralis, m. biceps femoris and m. gastrocnemius–medialis.

Discussion and Conclusion

The results of the study clearly reveal the importance of the force produced in the starting blocks. In the set position, the athlete produced force on the rear block for 186±12 ms and on the front block for 365±21 ms. Electromyography enables the identification of the participating muscles and the sequence in which they generate force. Muscle force production in a start depends on many factors. The main ones are the maximal number of motor units recruited during contraction, motoneuron excitability and the type of recruited motor units [26]. The performance of a start involves concentric, eccentric and isometric muscle action.

One of the most important extensor muscles is erector spinae (ES), whose key role in the starting phase is to lift the trunk. Based on the results (Fig. 4) it may be established that the largest activation of this muscle (left–right) is in the phase of clearing the starting blocks. The second activation peak of ES (left) was recorded in the braking phase of the first step and the third activation peak (right) in the braking phase of the second step. The average degree of activation of ES during the start and the start acceleration in the first two steps was higher in the erector spinae muscle (left).

The one-joint gluteus maximus muscle (GM) showed the highest EMG activation values at the beginning of producing force in the start blocks. Nevertheless, the activation degree was slightly higher in the front (left) leg. The gluteus maximus of the front leg achieved the second activation peak at the end of the push from the starting block. The GM of both legs shows a constantly high activation during the entire contact phase of the first and second steps. Activation of GM is minimal in the first and second flight phases.

The double-joint rectus femoris muscle (RF) showed a relatively low activation at the beginning of the starting action. This was particularly true of the RF of the right leg. The EMG activation of the RF of the right and left legs achieved its peak in the last third of the starting action. The second peak activation of the RF was recorded towards the end of the propulsion phase in the first and second steps. Throughout the cycle (start – first step – second step), the RF of the left leg was slightly more active than the RF of the right leg.

The EMG activation of the one-joint vastus medialis muscle (VM) and vastus lateralis muscle (VL) of the right leg is seen only at the beginning of the pushing action from the rear starting block. The vastus medialis muscle (VM) and the vastus lateralis muscle (VL) of the left leg were active throughout the starting phase. A slightly higher degree of activation throughout the starting phase (365 ms) was seen in the vastus lateralis muscle (VL). In this muscle, different degrees of activation can be established during repeated starts.

The vastus medialis muscle (VM) of the rear leg recorded the maximal degree of activation when it touched the ground in the first step after the push from the rear block. Pre-activation of this muscle started already during the first flight phase, which lasted for 82±10 ms. Pre-activation of the vastus medialis muscle plays an extremely important role in ensuring the rigidity of those muscles that enable the transfer of elastic energy from the eccentric to the concentric contraction. The vastus medialis muscle achieves the second activation peak in the propulsion phase of the first step. In the braking phase of the first step (eccentric phase) the vastus medialis muscle (VM) is more active, whereas in the propulsion phase (concentric phase), the vastus lateralis muscle (VL) is substantially more active. The execution of the second step is related to the slightly lower activation of the vastus medialis muscle (VM) and the vastus lateralis muscle (VL) in the braking phase and in the propulsion phase.

The activation modality of the functioning of the two-joint biceps femoris muscle (BF) of the right leg is reflected in maximal EMG activity in the first half of the push from the rear starting block. The activation is of a short duration and is related to the time of producing force in the rear block, lasting only for 186±12 ms. The activation of the biceps femoris muscle (BF) of the front leg is at its peak in the second third, and lasts until the last contact of the foot with the front starting block. The peak activation of the biceps femoris muscle (BF) of the right leg can be established in the propulsion phase of the first step. The muscle's function is to actively position the foot on the ground and thus decrease the negative ground reaction force. From a biomechanical point of view, execution of the first step is a very demanding task for a sprinter, bearing a decisive impact on an efficient transition from start to block acceleration [14,22]. At the end of the first step the athlete developed 1.8 m.s^{-1} higher velocity compared to that recorded during the push from the front starting block. The activation of the biceps femoris muscle (BF) of the left foot in the second step is similar, reaching its peak in the second third of the contact phase.

In view of the EMG analysis results, the gastrocnemius–medialis muscle (GA) is one of the most important muscles generating the efficiency of start and block acceleration. The activity of the gastrocnemius muscle of the rear leg begins slightly later. This depends, in particular, on the position of the foot of the rear leg in the starting block. If the tip of the sprinter's foot barely touches the ground, pre-activation does not occur and, consequently, the muscle activation is delayed [21]. The peak activation of the gastrocnemius muscle of the rear and front legs can be identified in the final phase of the push off from the blocks. The peak activation was achieved by the gastrocnemius muscle of the front leg, directly influencing the block velocity. The substantially lower activation of the gastrocnemius muscle (GA) of the rear leg is manifested in a relatively low force impulse on the rear starting block, accounting for only 52% of the force impulse of the front leg. It may be concluded that the athlete's ability to develop force on the rear block is poor or her movement stereotype start technique is inadequate. Biomechanical studies [9,10,11,21] showed that the gastrocnemius muscle is one of the key extensors of the feet and thus a generator of force production on the starting blocks.

The start and transition to start acceleration is a very complex sequence, requiring high muscle activation. The EMG activity of the gastrocnemius muscle of the right leg is present throughout the contact phase of the first step, which lasts for 168±17 ms. Maximal EMG activation is recorded at the point of transition from the braking phase to the propulsion phase of the first step. The execution of the first step is related to a strong force impulse and a specifically high position of the foot, as a consequence of a greater inclination of the trunk in the direction of the sprint. Adequate pre-activation of muscles is important for the efficient execution of the contact phase as it ensures that the muscles are properly rigid to overcome the ground reaction forces. The higher rigidity of the muscles results in better use of the elastic force stored in the serial elastic elements of the muscle [10,23]. It is the sprinter's task to execute the contact phase of the first step within the shortest time possible. Insufficient rigidity of muscles, especially of the gastrocnemius medialis muscle, gastrocnemius lateralis muscle and soleus muscle, results in a lowering of the heel, thereby prolonging the contact time and decreasing the block velocity.

The execution of the second step is similar from the point of view of the EMG activation of the gastrocnemius muscle of the left leg. The time of the contact phase is 17% shorter than that of the first step. The degree of activation starts already rising before the foot touches the ground. It peaks in the medium zone of the contact phase. The maximal degree of activation of the gastrocnemius muscle of the left leg is slightly higher than that of the right leg. Throughout the time cycle, which lasts for 856±18 ms and includes the start and execution of two steps, a generally high degree of muscle activation of the gastrocnemius muscle of the left and the right legs can be established in all three phases of the motor task, which is important for the production of force in the start and in the block acceleration.

Some of the most important dynamic, kinematic and electromyographic parameters, which generate the efficiency of the start action, were established using a biomechanical analysis. We used state-of-the-art integrated measurement technology. As only one elite female sprinter participated in our study, the results cannot be absolutely generalised. However, this kind of research provides us with certain valuable information which is important for the sport science as well as for the athletics as a professional discipline and the athletic training. The study results must be analysed critically and should be combined with those produced by further similar studies using larger samples of elite male and female sprinters.

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