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Reaction time and electromyographic activity during a sprint start

Antti Mero and Paavo V. Komi

Department of Biology of Physical Activity, University of Jyväskylä, SF-40100 Jyväskylä, Finland

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Summary. Eight male sprinters were filmed running three maximal starts over 3 m on a long force platform. The subjects were divided into two groups ($n=4$) according to the leg on which the electromyograph (EMG) electrodes were fixed. When in the set position one group had electrodes on the front leg (FLG) and the other group on the rear leg (RLG). The EMG activities of the gastrocnemius caput laterale muscle (GA), vastus lateralis muscle (VL), biceps femoris caput longum muscle (BF), rectus femoris muscle (RF) and gluteus maximus muscle (GM) were recorded telemetrically using surface electrodes. Total reaction time (TRT) was defined as the time from the gun signal until a horizontal force was produced with a value 10% above the base line. Pre-motor time was defined as the time from the gun signal until the onset of EMG activity and motor time (MT) as the time between the onset of EMG activity and that of force production. Reproducibility of the reaction time variables was satisfactory ($r=0.79$–0.89; coefficient of variation = 8.8%–11.6%). The TRT was 0.121 s, SD 0.014 in FLG and 0.119 s, SD 0.011 in RLG. The MT ranged from 0.008 s, SD 0.009 (GM) to 0.057 s, SD 0.050 (GA) in FLG and from 0.018 s, SD 0.029 (GA) to 0.045 s, SD 0.009 (GM) in RLG. In some individual cases there were no MT values before horizontal force production. Significant positive correlations were observed between MT and maximal horizontal force and the velocity of the centre of gravity during the last observable contact on the blocks ($P<0.05$–0.01). The EMG activities of the muscles analysed demonstrated large individual variations until the end of the first contact after the blocks. This resulted in non-observable MT in some individual cases. In general, however, despite the complex multijoint character of TRT, its fractions could be analysed during the early phases on the blocks. To optimize starting action it is desirable that all the important muscles should be activated before any force can be detected against the blocks.

Key words: Reaction time – Electromyographic activity – Sprinters

Introduction

A considerable amount of information exists on the biomechanics of the sprint start. The set position (Baumann 1976, 1979; Hoster and May 1978; Hoster 1981; Mero et al. 1983), reaction time (Henry 1952; Payne and Blader 1971; Baumann 1976; Dostal 1981; Mero and Artman 1984), force-time characteristics in the blocks (Henry 1952; Schnauber and Singer 1975; Baumann 1976, 1979; Hoster 1981; Mero et al. 1983; Vagenas and Hoshizaki 1986) and after the release (Mero et al. 1983, 1986; Mero 1988; Vagenas and Hoshizaki 1986) have been the most commonly investigated biomechanical parameters. Reaction time (RT) has been studied as the total reaction time (TRT) defined as the time from the gun signal until the production of force. No attempt has been made to separate the pre-motor time (PMT) and motor time (MT) components in the sprint start. The former is defined as the time from the gun signal until the onset of electromyographic (EMG) activity in skeletal muscle. The MT means the delay between the onset of electrical activity and the production of force by the muscle. The EMG activity of various

Table 1. Physical characteristics and running records of the subject groups

	FLG ($n=4$)		RLG ($n=4$)	
	mean	SD	mean	SD
Age (years)	24.8	1.9	25.9	2.0
Height (m)	1.79	0.04	1.82	0.04
Mass (kg)	74.8	3.6	73.1	3.9
100 m record (s)	10.76	0.19	10.82	0.23

FLG = front leg group; RLG = rear leg group

Offprint requests to: A. Mero

muscles in sprinting at constant speeds has been documented (Dietz et al. 1979; Mero and Komi 1987) but to our knowledge there is a lack of data on EMG activity during the sprint start.

Therefore, the purpose of this study was to separate PMT and MT of the front and rear leg in the block phase of the sprint start and to investigate EMG activity up to the end of the first contact after the blocks. As a result of these investigations it should be easier to understand the start mechanism and to develop training methods for starting.

Methods

Subjects. Eight experienced volunteer male sprinters who provided informed consent prior to participation performed a series of three maximal sprint starts on a long, Tartan mat covered, force platform (Komi 1985) in a hall using conventional starting blocks with the preferred antero-posterior hand and block spacing. They were divided into two groups ($n = 4$) according to the leg on which EMG electrodes were fixed. When in the "set" position the front leg group (FLG) had EMG electrodes on the leg to the fore and the rear leg group (RLG) on the leg to the rear. Physical characteristics and running records of the groups are given in Table 1.

Filming procedures and analysis. The start and the run up to 3 m were recorded perpendicular to the running direction with a Locam 51-0003 camera operating at a frame rate of 100 Hz. Step cycles covering the "set" position, force production in the blocks, flight phase after it, and the first contact were analysed using a Vanguard film analyser, Summagraphics 10, data tablet/digitizer and HP 21MX computer. Based on the segment parameters of Dempster (1955) the mechanical model of the runner was assumed to consist of 14 rigid body segments. The segmental landmarks were marked on the skin with black ink. In the analysis a ninth degree polynomial curve (Kuo 1965) was used to smooth the digitized data. Block velocity was determined from the velocity of the centre of gravity during the last observable contact on the blocks. After film analysis the fastest run of each subject (block velocity) was selected for further analysis.

RT measurements. The gun signal and the force-time curves of the horizontal and vertical ground reaction forces (Fig. 1a) were stored on magnetic tape (Racal Store 7) for further computerized analysis. The contact phase after the blocks was divided into braking and propulsion phases according to negative horizontal force (Miller 1983). The TRT was defined as the time from the gun signal until a force value of 10% above the baseline was produced. The force threshold of 10% from the maximal horizontal force was selected as a point of origin for force production. Average pretension (see Fig. 1a) was 6.4%, SD 4.6% measured also from the maximal horizontal force. The PMT was defined as the time from the gun signal until the onset of EMG activity (Weiss 1965) and MT as the time between the onset of EMG activity and the onset of production of the horizontal ground reaction force.

It would have been of interest to examine also the real electromechanical delays (EMD), but this was methodologically impossible, because EMD should always be referred to the specific muscle. Force and EMG analog signals (see below) were digitized with a sampling frequency of 1 kHz. The registered EMG signals were amplified 1000 times and full-wave rectified. The average pre-activity levels were 5.3%, SD 3.3% and they were measured from the maximal integrated-EMG (iEMG) activity of each muscle during force production in the blocks. The pre-activity level was used as zero for RT analysis.

EMG measurements. The EMG activity was recorded telemetrically (Medinik AB Model IC-600-G) simultaneously from the gastrocnemius caput laterale muscle (GA), vastus lateralis muscle (VL), biceps femoris caput longum muscle (BF), rectus femoris muscle (RF) and gluteus maximus muscle (GM). After standard skin preparation techniques (Basmajian 1974) bipolar surface electrodes (Beckman miniature skin electrodes) with a constant interelectrode distance of 20 mm were fixed over the muscle bellies on the same side of the body. They were placed longitudinally over the motor point areas determined by an electrical stimulator (DISA). The EMG signals were amplified with pre-amplifiers (1 Hz–1 kHz) and stored simultaneously with the force on magnetic tape. Off-line iEMG (for 1 s) of force production in the blocks, one flight phase (FP) and the succeeding contact phase was performed using a HP-1000-F computer system during several phases as shown in Fig. 2. The duration of the phases was usually 50 ms but it varied in several instances due to variation in the different phases as follows: RT_1 ranged from 69 ms to 71 ms, force production phase 7 from 40 ms to 49 ms, FP from 48 ms to 55 ms, braking phase (BP) from 22 ms to 23 ms, and propulsion phase 4 from 16 ms to 27 ms.

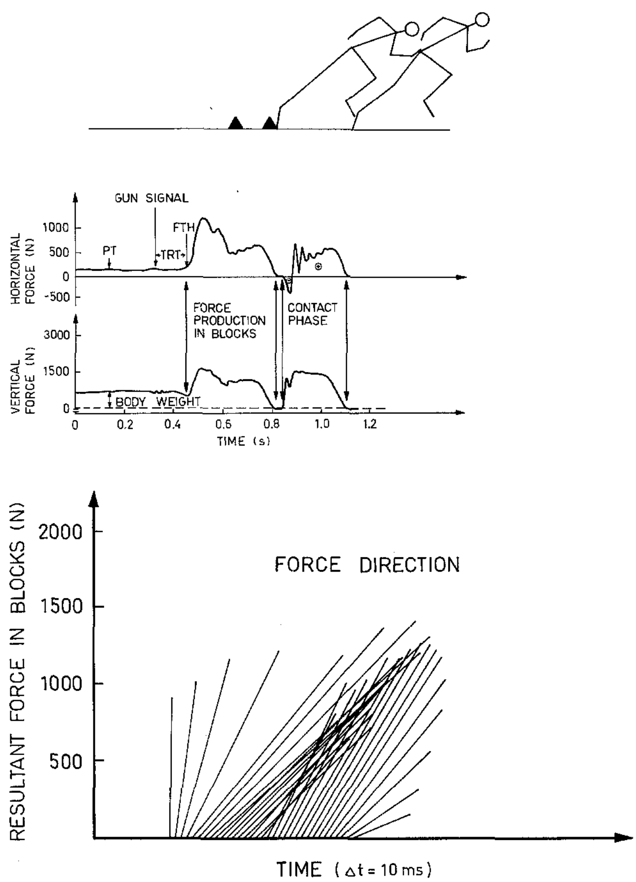

Fig. 1. *Upper panel,* Gun signal and force-time curves of ground reaction forces (*PT,* pretension; *TRT,* total reaction time; *FTH,* force threshold; ⊖, braking phase; ⊕ propulsion phase). *Lower panel,* An example of resultant force production and its direction in the block phase for one subject

Statistical analysis. Data were analysed using means, standard deviations, dependent and independent Student's *t*-tests, linear correlation coefficients, and the coefficients of variation (CV). Differences were considered statistically significant at *P*-values of < 0.05. Reproducibility of RT measurements was determined with duplicate measurements (the two fastest runs): it was higher in TRT ($r = 0.89$, CV = 8.8%) than in PMT and MT ($r = 0.79$, CV = 11.6%). Reproducibility of EMG measurements was determined with duplicate measurements of iEMG from the five leg

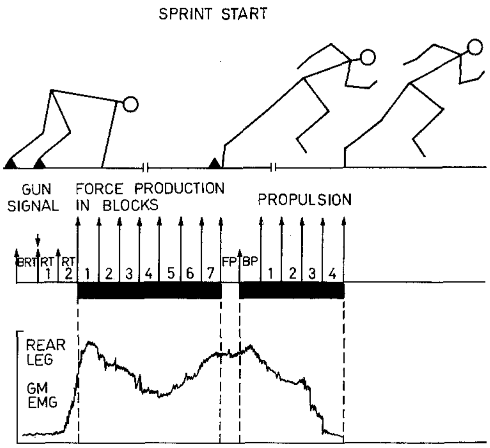

Fig. 2. Electromyographic (*EMG*) analysis (*BRT*, before reaction time; *RT*, reaction time; $RT_1 + RT_2$, total reaction time; *FP*, flight phase; *BP*, braking phase; *GM*, gluteus maximus muscle). The time over which *EMG* was integrated was usually 50 ms (variation, see Methods): it was measured backwards and forwards from the beginning of force production in the blocks

muscles (GA, RF, VL, GM and BF): during measured stride cycles the reproducibility ($r = 0.90$, CV = 7.0%) was of the same order as reported earlier by Mero and Komi (1987).

Results and discussion

Set position

The structure of the set position was similar in the two groups as indicated by the various position variables determined from the film (Table 2, Fig. 3).

Reaction time

The TRT was 0.121 s, SD 0.014 in FLG and 0.119 s, SD 0.011 in RLG (Table 3). The values are smaller than those measured at major championships (Moravec et al. 1988). If RT are to be compared, uniform conditions for measuring must be laid down. This is not the case at present. The minimal RT for a valid start has changed and, for example, in Rome (World Championships) it was 0.120 s (Moravec et al. 1988). The PMT of GA and VL were slightly shorter and those of RF and GM

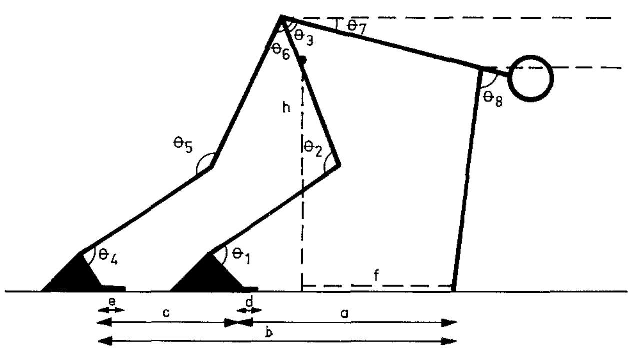

Fig. 3. Diagram of the set position and its various parameters determined from film (see in conjunction with Table 2 for definitions)

Table 2. Kinematics in the set position (for illustration of the definitions, see Fig. 3)

	FLG		RLG	
	mean (m)	SD	mean (m)	SD
Horizontal distance from the front block to starting line (a)	0.53	0.06	0.49	0.04
Horizontal distance from the rear block to starting line (b)	0.85	0.08	0.81	0.06
Horizontal distance between the blocks (c)	0.32	0.03	0.32	0.07
Part of the front foot on track (d)	0.08	0.02	0.07	0.02
Part of the rear foot on track (e)	0.02	0.01	0.03	0.02
Height of centre of gravity (h)	0.59	0.04	0.55	0.04
Horizontal distance of centre of gravity from starting line (f)	0.28	0.04	0.31	0.06
Angles of the front leg	(degrees)		(degrees)	
Ankle (Θ_1)	94	3	95	6
Knee (Θ_2)	101	15	97	7
Hip (Θ_3)	43	5	44	6
Angles of the rear leg				
Ankle (Θ_4)	99	10	95	6
Knee (Θ_5)	136	14	136	13
Hip (Θ_6)	80	11	75	8
Angle of trunk (Θ_7)	24	9	18	6
Angle of arms (Θ_8)	103	5	104	11

FLG = front leg group; RLG = rear leg group

Table 3. Reaction times of the subject groups

	FLG		RLG	
	mean (s)	SD	mean (s)	SD
Total reaction time	0.121	0.114	0.119	0.011
Pre-motor time				
GA	0.064	0.048	0.101	0.042
VL	0.079	0.036	0.090	0.014
BF	0.097	0.024	0.096	0.002
RF	0.110	0.019	0.099	0.040
GM	0.113	0.018	0.074	0.016
Motor time				
GA	0.057	0.050	0.018	0.029
VL	0.042	0.049	0.029	0.004
BF	0.024	0.010	0.023	0.003
RF	0.011	0.019	0.020	0.028
GM	0.008	0.009	0.045	0.009

FLG = front leg group; RLG = rear leg group; GA = gastrocnemins caput laterale muscle; VL = vastus lateralis muscle; BF = biceps femoris caput longum muscle; RF = rectus femoris muscle; GM = gluteus maximus muscle

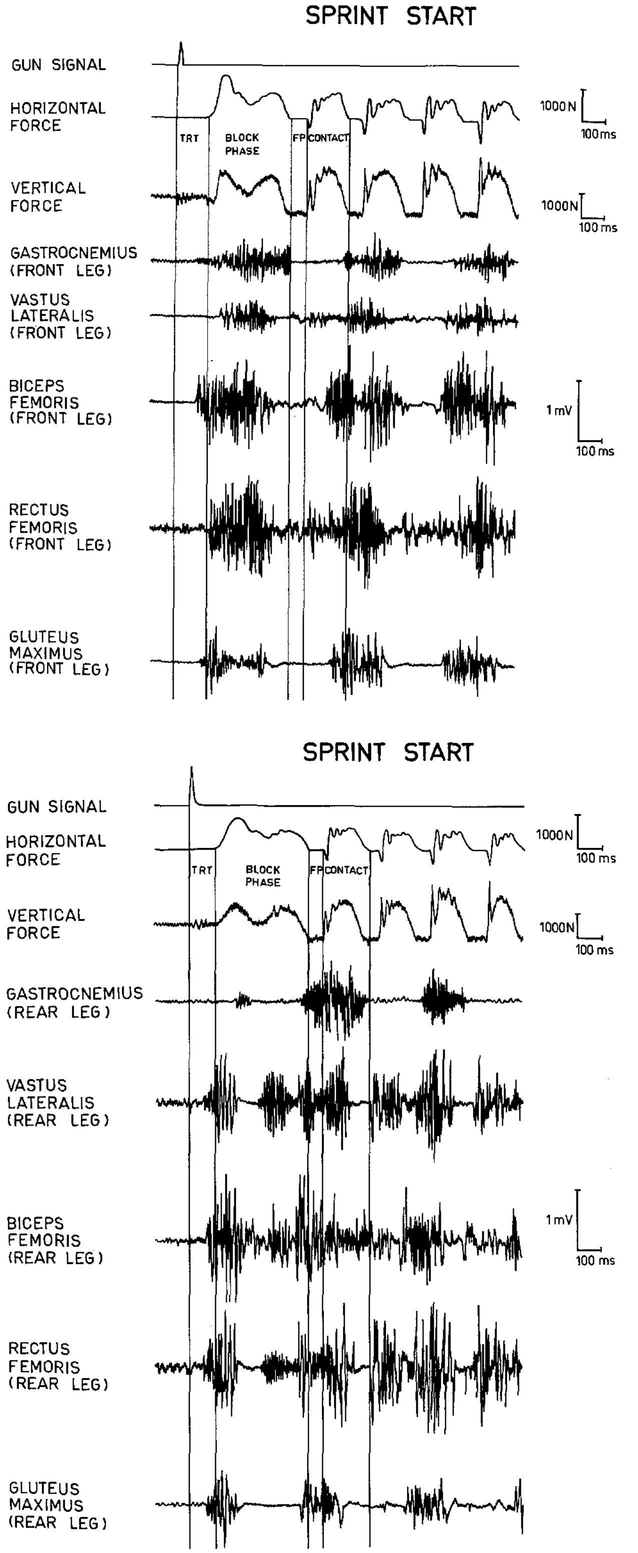

Fig. 4. Examples of raw electromyographs in a sprint start for muscles of the front leg (*upper panel*) and rear leg (*lower panel*) of one subject

slightly longer in FLG than in RLG. On average PMT ranged from 0.064 s, SD 0.048 to 0.113 s, SD 0.018. The MT ranged from 0.008 s, SD 0.009 to 0.057 s, SD 0.050. Muscle activation varied considerably between individuals, and in two subjects of FLG some of the muscles were almost silent during TRT. For example, in the example given in Fig. 4 VL became active only after TRT. Similar patterns were observed also in RLG for GA and RF. Figure 4 gives an example of the low activation of GA.

These results showed that TRT can be divided into PMT and MT during sprint starts. However, there were examples in which electrical activity in some muscles started to increase after TRT due to the multi-joint character of the sprint start movement. Muscle force production during a maximal voluntary contraction such as in a sprint start is dependent on many factors. These include the proportion of the available total motor unit pool which is recruited during contraction (Milner-Brown et al. 1973), motoneuron excitability (Sale et al. 1983), the type of motor unit recruited during contraction (Burke and Edgerton 1975), and the cross-sectional area of the contracting muscle (Ikai and Fukunaga 1970). During the course of muscle contraction and force production there are several time delays, such as PMT and MT. In the present study, TRT was measured with a horizontal force impulse of both legs. Earlier Payne and Blader (1971) found no difference but Henry (1952) and Baumann (1979) found a significant difference between TRT of the rear leg and that of the front leg. The rear leg reacted about 0.02 s faster than the front leg. This difference could not be examined in the present study because the front and rear blocks did not have separate force plates.

In the present study GM had the shortest PMT (0.074 s, SD 0.016) in RLG being thus the first rear leg muscle to increase EMG activity. The GA and RF had the longest PMT and in both muscles there was no increase in EMG activity during TRT in two subjects. This suggests inefficient use of the rear leg during the early stages of force production in the blocks. In FLG the shortest PMT (0.064 s, SD 0.048) was observed in GA and the longest (0.113 s, SD 0.018) in GM. The BF was the only muscle in which MT could be measured for all subjects. Thus the variations in PMT and MT were large although TRT were similar in both groups.

In earlier studies (Weiss 1965; Schmidt and Stull 1970; Kroll 1974; Surburg 1977; Clarkson 1978; Cavanagh and Komi 1979; Viitasalo and Komi 1981; Bell and Jacobs 1986) MT has ranged from 29.3 ms to 87.0 ms. Movements have been over one joint (arm or leg), contractions concentric, eccentric or isometric and stimulus sound or light. In the present study MT were fairly short, the mean value being 27.7 ms. Multi-joint movement partly explains the difference, because work is done by many muscles and one muscle can be complemented by others. Also muscle contraction patterns varied between individuals. After the start signal, the knee and hip angles of both legs began to increase when producing force, while the angle of the ankle decreased in both legs at the beginning of the force production. Such an action means that there is eccentric contraction in GA before the concentric phase. According to film analysis VL and GM contracted concentrically but the situation of the two-joint muscles BF and

RF is complex and it is difficult to evaluate the precise change of muscle length.

Significant positive correlations (Table 5) between MT and maximal horizontal force in the blocks and block velocity (see also Table 4) emphasize fast activation of the nervous system in the sprint start. The chemical and electrical events of MT include the depolarization of muscle fibres involved and the propagation of the action potential. These processes have a median duration of approximately 9 ms (Basmajian 1978). The rest of MT has been associated with mechanical events, which include the increase of tension between actin and myosin and a limited shortening of the sarcomeres. A considerable proportion of MT has been associated with the time necessary for the elastic elements in series with the contractile elements to attain their load-dependent length (Cavanagh and Komi 1979; Viitasalo and Komi 1981). This must occur before muscular tension can be transmitted across joints. In the sprint start it is clear that after the gun signal every leg extensor muscle must contribute maximally to the production of force and finally to the running velocity. Therefore, the faster the electrical activity begins in every muscle, the faster the neuromuscular performance is maximized. The TRT does not necessarily indicate these aspects and, therefore, it was not a surprise to see that TRT did not correlate with the block velocity in the present study. Similar non-significant correlations have been observed earlier with race time (Dostal 1981). The TRT found in the present study was similar to the findings of Baumann (1976, 1979), Dostal (1981) and Mero and Artman (1984).

Table 4. Contact and flight times, force production and running velocity

	FLG		RLG	
	mean	SD	mean	SD
Duration of force production in blocks				
total (s)	0.340	0.057	0.349	0.029
rear leg (s)	0.152	0.041	0.155	0.030
Maximal horizontal force (N)	1202	132	1246	214
Block velocity ($m \cdot s^{-1}$)	3.42	0.38	3.50	0.22
Flight phase after blocks (s)	0.055	0.017	0.048	0.010
First contact after blocks				
braking phase (s)	0.022	0.002	0.023	0.002
propulsion phase (s)	0.166	0.014	0.177	0.017
running velocity at the end of the contact ($m \cdot s^{-1}$)	4.60	0.24	4.70	0.29

FLG = front leg group; RLG = rear leg group

Table 5. Correlation coefficients between reaction time parameters and starting performance ($n = 8$)

	Maximal horizontal force in blocks (N)	Block velocity ($m \cdot s^{-1}$)
Motor time (s)		
GA	0.59	0.61
VL	0.67	0.72*
BF	0.87**	0.83**
RF	0.60	0.56
GM	0.80*	0.90**
Total reaction time (s)	−0.09	−0.48

* $P<0.05$, ** $P<0.01$; for other definitions see Table 3

EMG activity in rear leg muscles

As can be seen from Figs. 4 and 5, the structure of the set position was similar in both groups and can be called a medium starting stance (Menely and Rosemier 1969; Hoster 1981). In this position the rear leg produced force with a median time of 0.154 s. The one-joint GM achieved its maximal iEMG during the first 50-ms period and thereafter the activity level decreased but began to increase markedly before the next contact phase. The peak value after the blocks occurred in BP. These results further support (see discussion of MT) the concept that GM of the rear leg is a very active muscle at the beginning of force production during a sprint start.

The two-joint BF of the rear leg had the first peak iEMG at the end of the block contact of that leg. During the next 0.1 s the activity decreased but then began to increase and achieved the highest iEMG at the end of the propulsion phase. The iEMG curve of this muscle in the FP occurred in association with the muscle lengthening in the forward swinging phase.

The EMG activity of the one-joint VL was increasing after the first peak which occurred at the beginning of force production in the blocks. The second peak was in the propulsion phase of the first contact and was the highest one. The extension of the rear shank in FP seemed to achieve two small peaks in the iEMG curve of this muscle.

The activity of the two-joint muscles GA and RF started late during the reaction phase. The GA had high activation during the first third of the block phase, but its highest peak occurred in BP of the first contact after the blocks. Figure 4 shows an example of the performance where GA is only slightly active at the end of the rear leg contact. In most of our subjects the rear foot was placed on the track (in FLG 0.02 m, SD 0.01) but in the example of Fig. 4, the shoe only touched the surface. This might have prevented GA from lengthening (pre-stretching) and its function may not have been optimal for the fast production of force.

The RF of the rear leg had an increasing iEMG activity with three small peaks. The first was at the beginning of force production in the blocks (leg extension), the second after the block when flexing the rear thigh, and the third at the beginning of the propulsion phase during ipsilateral contact (leg extension).

In general, the rear leg muscles had a high preactivity before the ipsilateral contact which supports the findings of Mero and Komi (1987) in the phase of

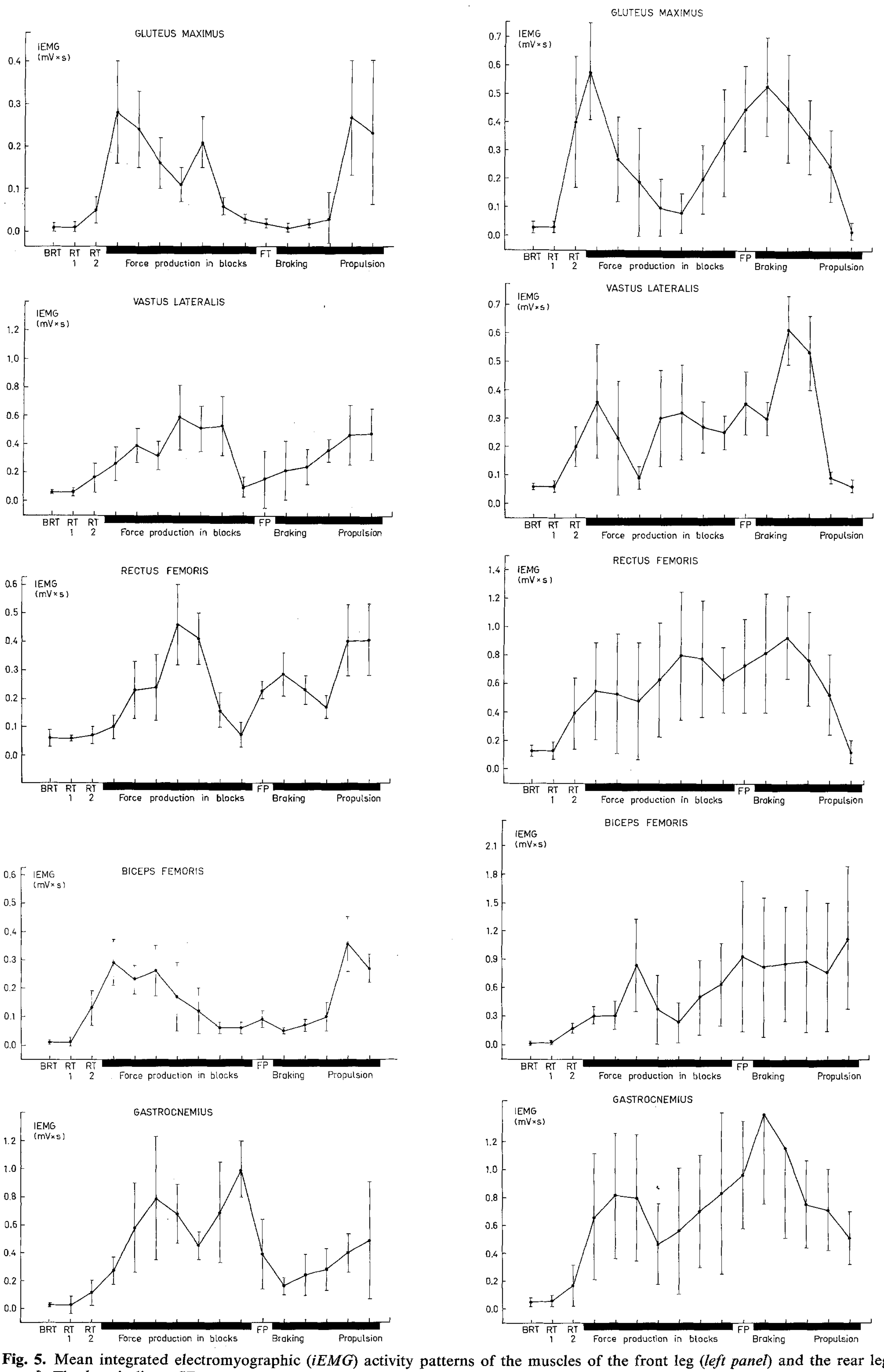

Fig. 5. Mean integrated electromyographic (*iEMG*) activity patterns of the muscles of the front leg (*left panel*) and the rear leg (*right panel*). The *bars* indicate SD

maximal constant speed. The maximal activity was observed during ipsilateral one-leg contact, except for GM. Minimal activity of the one-joint muscles was small but that of the two-joint muscles was somewhat greater.

EMG activity in front leg muscles

As can also be seen from Figs. 4 and 5, the duration of the force production by the front leg was the same as the total block phase. The GA was the first one to begin EMG activity because MT of the muscle was 0.057 s, SD 0.050. The two-peak activities were observed during the block phase and the highest one was at the end of the phase. The peaks occurred at the end of both the rear leg and the front leg contact. During the contralateral contact the activity was generally low but increased towards the end of the phase. Because the front foot was also positioned so that the first spikes were in the track, the GA activity phase was long. This enabled efficient force production.

The VL of the front leg increased EMG activity during the block phase and thereafter it decreased, but slightly increased during the contralateral contact. It seems that this muscle as well as GA, RF and GM of the front leg were not maximally utilized by all subjects because their primary activation occurred after the onset of the force record.

The activity model of BF in the front leg consisted of two peaks, the first at the beginning of force production and the second at the end of the phases analysed. In this muscle MT could be measured in the case of every subject which emphasizes the importance of BF in the early stages of the sprint start.

The RF as a two-joint muscle had increasing activity in the block phase until the last stages when it decreased. During the contralateral contact the EMG activity again increased, modelling the hip flexion of the leg.

The GM of the front leg has the maximal iEMG value at the beginning of force production in the blocks and the second peak was 0.2 s later. After the block phase, the muscle was very silent until the end of the propulsion phase when the activity increased sharply. This supports the suggestion by Ito et al. (1983) that the beginning of the stretch-shortening cycle of GM, which is a typical one-joint muscle, can be identified as occurring at the end of the forward swing phase.

In conclusion, TRT in the sprint start could be separated into PMT and MT but, due to the multi-joint character of the movement, the horizontal ground reaction force could be recorded prior to activation of some muscles. This may not be desirable for optimal and efficient force production during the sprint start. However, great interindividual variation in the pattern of muscle activation emphasizes the complexity of the sprint start.

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