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Time Frequency Wavelet Analyses of Sprint Start in Young Elite Sprinters

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Abstract

Surface electromyography is the method commonly used to evaluate the muscle activity in movements. A time frequency analysis based on wavelets is hereby an appropriate tool to study patterns of muscle fiber recruitment during the sprint start. The aim of this study was to identify muscle fiber activity based on the wavelet technique during the sprint start. Also, the influence of age, gender and anthropometric parameters was investigated. Sixty young elite sprinters volunteered for this study. Bilateral electromyographic activity was recorded from the Gastrocnemius medialis (GAS), Rectus femoris (RF), Biceps femoris (BF) and Gluteus maximus (GLU) for both rear and front legs. For statistical analysis Kolmogorov-Smirnov normality test and one-way ANOVA with Scheffé post hoc test was used. During all phases of sprint start, the GAS muscles of rear and front legs showed significantly higher frequencies while the GLU muscles presented lower frequencies than any other muscles. No significant differences were observed between boys and girls, however, the results showed that the older sprinters, the ones with a higher percentage of thigh and calf circumference and skeletal muscle mass have a better capability to recruit more fast twitch fibers, for instance in the GAS. The results indicate that the recruitment of high frequency muscle fibres during the sprint start may be explained by the explosive nature of these movements.

KeyWords: Sprint Athletes, Wavelet Analysis, Anthropometrical Parameters, Sprint Start.

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Introduction

Surface electromyography is the method commonly used to evaluate the muscle activity in movements. A time frequency analysis based on wavelets is hereby an appropriate tool to study patterns of muscle fiber recruitment during the sprint start. From childhood to adulthood an increased recruitment pattern of fast twitch muscle fibres is noticed [1]. Traditional understanding of muscle fibers recruitment believes that slower fibers were used for all contraction. However, new studies reported that some movement can better be performed by faster muscle fibers [2-3, 4]. In other words, the myoelectric signals that are recorded from an active muscle contain information about the muscle fibre types that generated the signal [2, 4]. Slow and fast muscle fiber types generate a respectively low and high myoeletric frequency. Therefore, “to obtain insight into muscle recruitment patterns for a given activity, the myoelectric signals must be resolved simultaneously into time and frequency space using wavelet techniques” [2]. Moreover, as slow and fast muscle fibres have different frequency spectra, wavelet analysis of an EMG signal allows in vivo differentiation between fibre types during specific movements [2-3, 5].

The mechanical benefits of using faster motor units for faster activities should be investigated for different dynamic activity from slow to fast. The wavelet method as described by von Tscharner (2000) provides a suitable analysis tool that will enable us to provide greater insight into the patterns of motor unit recruitment during a sprint start [2]. On the other hand, this method is the only method that analyzes the contribution of the fast and slow muscle fiber types during a specific movement. Although, little data are available with respect to the wavelet muscle fiber recruitment during sprint running. However, the influence of the ground reaction forces on muscle activity was investigated during running [3]. In the study above, the myoelectric signals were registered and then resolved into the time/frequency space for four groups of lower extremity muscles. Some researchers found significant differences in the myoelectric activity patterns during the stride phases of running. In this way, myoelectric activity for the lower extremity muscles during running displayed more intensity (154%) for the 50 ms before heel impact (pre activity) than the 50 ms after impact (post activity). In this study, the intensity of the low-frequency signals decreased, while the high-frequency intensity increased during the 30-min running trails. In other words, increase in intensity of the high-frequency content occurred with a decrease in intensity of the low-frequency content of muscle activity [2-6, 10]. In another study, Wakeling (2006) identified the motor recruitment pattern using the spectral properties of the myoelectric signals during walking and running at different speeds. He reported that the muscle fibers recruitment patterns can change for each stride. An increase in myoelectrical intensity was displayed when the running velocity increased [4].

As the same, Wakeling et. al (2002) and von Tscharner (2000) also identified the muscle fiber recruitment from four groups of the lower extremity muscle using wavelet technique. The results again showed the motor units to be recruited in an orderly fashion from slow to fast, whereas the recruiting of the faster muscle fibers produced the higher frequency components. [2, 6].

Based on the research, it was the purpose of this study to identify muscle fiber using wavelet during sprint start. Because, the wavelet method as described by von Tscharner (2000) is actually the only method that can analyze the contribution of the fast and slow muscle fiber types during a certain movement. Therefore, to identify the fast and slow contribution of lower extremity muscles during the sprint start, the myoelectric signals will be resolved into their time–frequency space using wavelet techniques [2]. So, the purpose of this study was to analyze the electromyographic activity of the lower extremity muscle with respect to fast and slow muscle fiber recruitment. Also of interest in this study was the influence of several anthropometric parameters on this recruitment pattern

Method

Sixty (30 boys and 30 girls) young elite sprint athletes (from 11 to 18 years old with a mean age of 14.7 ± 1.8 years and 14.8±1.5 years for boys and girls respectively) volunteered. Informed written consent was obtained from all subjects prior to testing. Anthropometrical measurements were used to calculate corrected thigh girth (CTG), corrected calf girth (CCG) and total body skeletal muscle mass (SMM) (7). Bilateral EMG signals of the Gastrocnemius medialis (GAS), Rectus femoris (RF), Biceps femoris (BF) and Gluteus maximus (Glu) were recorded with a Varioport datalogger (Becker Meditec) at 2000Hz during a sprint start and two subsequent steps.

Electromyography of these muscles was recorded using disposable, self-adhesive, and ready-to-use surface electrodes (22 mm by 14 mm; Ambu Blue Sensor, NF-SO-K/EU).

The surface electrodes were fixed along the longitudinal axis of the muscle belly, close to the motor point. In order to enhance electric conductance, the skin was cleaned and rubbed with alcohol before the electrodes were attached. Wavelet analysis of the EMG signals was performed with software from Biomechanics Research Corp (Canada). Moreover, Following the literature [2], in this study low frequencies between 40 -80 Hz were attributed to slow muscles and frequencies over 140 Hz to fast muscle fibers.

Data Analysis: All sprinters were successively divided into three equal subpopulations according to their age, thigh girth circumference, calf girth circumference and skeletal muscle mass (Table 1). After applying the Kolmogorov-Smirnov test for normal distribution, one-way ANOVA with

Scheffé post hoc test was used. All statistics were carried out using SPSS 15.0. The significance level was set at α=0.05.

Results

Table 1- Anthropometrical parameters according to the three Groups (Mean ± SD)

Parameters	Group 1 (n = 20)	Group 2 (n = 20)	Group 3 (n = 20)
Age (years)	12.9 ± 0.9	14.9 ± 0.5	16.6 ± 0.6
SMM (kg)	16.9 ± 2.0	21.6 ± 1.1	26.9 ± 3.0
CTG (cm)	45.7 ± 2.3	50.1 ± 0.7	53.2 ± 1.9
CCG (cm)	30.9 ± 1.5	33.5 ± 0.7	36.1 ± 1.2

The present study examined the frequency content in order to identify muscle fiber recruitment patterns during the sprint start including the set position and the two subsequent steps (the first and second contact after leaving the blocks respectively).

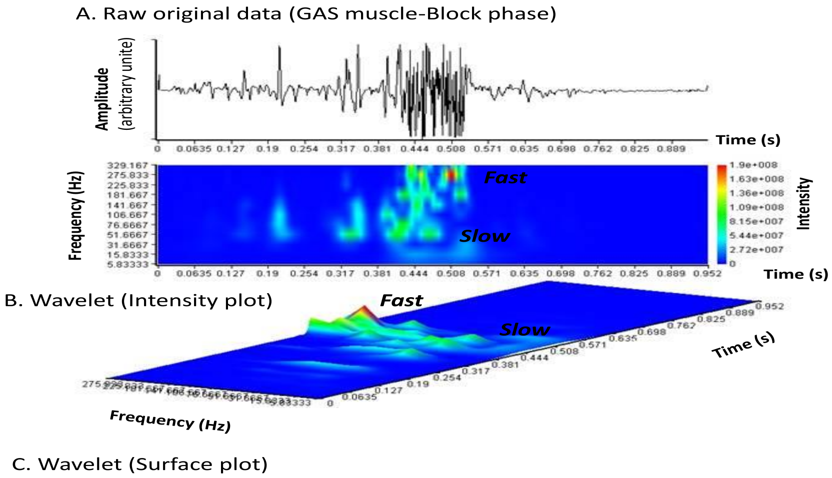
As a first result, the peak frequencies for four groups of muscles were observed during the block phase (including the set position) and the two subsequent steps after leaving the blocks (Table 2). As revealed in Table 2, during block, first and second step phases, the GAS muscles of rear and front legs (GAS) for all sprinters showed significantly higher frequencies as compared to the other muscles. On the other hand, the gluteus (GLU) muscles significantly presented lower frequencies than any other muscles during all start phases.

Table 2- Overview of peak frequencies (showing maximal intensity) for all subjects (n = 60, mean ± SD)

Muscle	High &low frequency (Hz)	Block Phase (B) (or set position)		First step (S1)		Second step (S2)		Significant [*#P<0.05]
		Rear foot	Front foot	Rear foot	Front foot	Rear foot	Front foot	
GAS	High	189±25*#	191±25*#	184±31	183±28	177±21	180±23	*GAS/All muscles #B/S1 and S2
	Low	79±16	77±19	71±20	74±22	68±20	66±17	
RF	High	159±33	179±27	166±25	174±43	176±35	180±27	*Front/Rear
	Low	63±15	76±18*	66±15	64±15	66±13	64±15	
BF	High	176±32	180±39	172±31	176±31	174±32	172±34	
	Low	58±12	64±14	65±8	67±16	66±14	69±26	
GLU	High	163±41	158±33	151±41	145±31	161±29	145±19	
	Low	48±14	50±15	47±14	46±13	47±6*	51±17*	*GLU/All muscles

Moreover, the BF and RF muscles of both rear and front legs also generated significantly higher frequencies than GLU during the block phase, with the front leg continuing to do so during the first and second steps also (Figure 2).

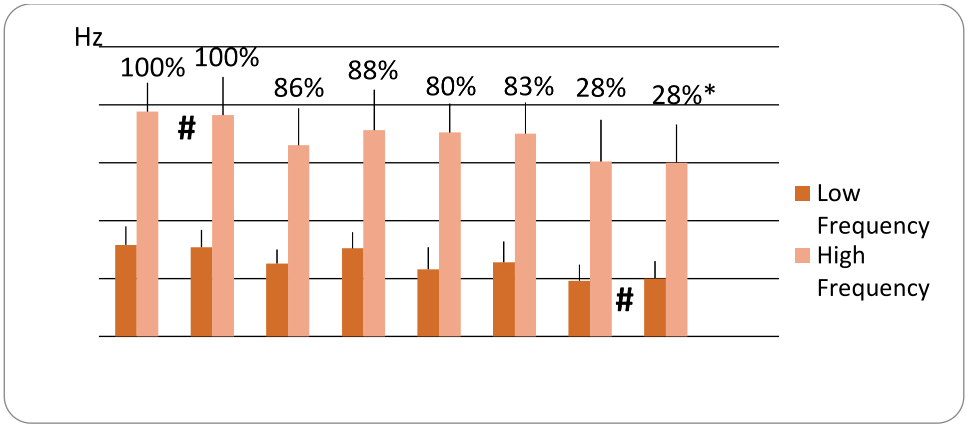
The influence of anthropometrical variables on the frequency content of the muscle activity was investigated for all three start phases. The results indicated that the GAS muscle produced higher frequencies in the second and third group for all sprint phases. However, in the block phase the higher GAS frequency came mainly from the rear leg.



*Original picture has been captured from wavlelet package

Figure 1- Raw EMG analysed into time and frequency for one subject (Block phase- Gastrocnemius muscle).

Comparing the frequencies of all muscle in between the three phases of the sprint start, both GAS muscles of rear and front legs showed significantly higher frequencies during the block phase than during the second step phase**.** Moreover, the peak frequencies for four groups of muscles were compared in between rear and front legs during the block phase and the two subsequent steps. In this way, for the whole population during block phase, only the RF muscle generated higher frequencies in the front leg compared to the rear leg.



* The percentage of subjects showing high frequencies (for the low frequencies this is 100%).
# P < 0.05

Figure 2- Frequencies in rear and front legs of four muscles during the block phase for the entire subject population.

The influence of the gender on the frequency content of the muscles was also identified during the three phases of sprint. In this way, although, for the whole subject population, no significant differences were observed between boys and girls, however, comparison between boys and girls in every age group showed significant differences between the boys and girls, only in the third group. In this way, the rear and front muscles of the gluteus muscles in the boys recruited significantly more low frequency fibers than girls.

Discussion

The present study examined the frequency content in order to identify muscle fiber recruitment patterns during the sprint start including the set position and two subsequent steps.

A key observation in our study was that, statistically significant differences were noted for all 4 muscles during the sprint start. In this way, during the block phase and subsequent first and second step phase, the GAS muscles for all sprinters showed significantly higher frequencies as compared with the other muscles. On the other hand, GLU muscles presented significantly lower frequencies than any other muscles during all start phases. The muscles of the lower extremities selected in this study differ in both their structure and function. Among the lower extremities muscles, the BF, GAS and RF muscles are two joint muscles where the BF flexes the knee but also extends the hip joint, the GAS is a knee flexor but also an ankle plantar flexor and the RF stretching across knee and hip. The vasti are mono-articular knee extensors. Therefore, regarding the diversity in between these muscles and also the difference between muscle fiber types, it is expected that some muscles with a high percentage of FT fibers would be more active during explosive exercise such as the sprint start. In this way some studies reported that sprinters develop more fast twitch fibers and fewer slow twitch ones [8-9, 10].

The results indicate that the motor unit recruitment patterns change through each sprint phase and between muscles. Significantly higher frequencies were generated in the GAS muscle which delivers a short and powerful contribution to the push-off phase of these movements and especially during the block phase. This indicated the recruitment of high frequency muscle fibres during the sprint start due to the explosive nature of these movements in which a rapid and maximal force exertion needs to be delivered. In this way, Mero and Komi 1990 reported that among the five lower extremity muscles (gastrocnemius (GAS), vastus lateralis (VL), biceps femoris (BF), rectus femoris (RF), and gluteus maximus (GM) muscles), the GAS was the most important muscle during early force production on the rear block. Moreover, among those muscles the GAS was the first muscle starting EMG activity during the block phase (6). Mero's study emphasized the importance of the knee flexors during starting blocks phase. Moreover, Wakeling (2004) reported that different frequencies content indicates that different populations of motor units are being recruited. The importance of muscle fiber distribution for sprinting has been documented in the several studies [8, 9]. Based on this research, the basic biochemical reasons for a high fast twitch (FT) fiber distribution in the leg extensor muscles of sprinters are related to the metabolic characteristics of these fibers. It is well documented that the FT type motor unit and its respective muscle fibers have a higher rate of force production [8-11, 12]. In response to force, motor units are typically recruited in a set order from slow to fast twitch. Both slow and fast muscle fibers of any muscle generate distinct low and high myoeletric frequency bands which correspond, respectively, to slow and fast motor unit recruitment [2]. According to the size principle of motor unit recruitment [13], a weak stimulus results in the slowest muscle fibers being recruited, and consequently the faster motor units are sequentially recruited as the stimulus strength increases.

In other words, the slow-twitch motor units, with the lowest threshold for activation, are selectively recruited during a lighter effort. These slow-twitch fibers are activated during sustained activities. For more rapid and powerful movements, there is a progressive activation of the more powerful fast-twitch fatigue-resistant (type IIa) fibers up through the fast-twitch fatigable (type IIb) when peak force is required.

Therefore, it seems that the faster fibers of GAS muscle has been recruited during the powerful starting block, since frequencies in this muscle were significantly higher as compared to other muscles. On the other hand, the GLU muscle seems to contribute to a lesser extend to the power development in the sprint start since frequencies in this muscle were significantly lower as compared to other muscles. In other words, different frequencies content indicates that different populations of motor units are being recruited [4, 14].

These results, indicating the recruitment of high myoelectrical intensity of GAS and RF muscles during 30-min running, were agreement with the results of Wakeling and coworkers (2001). They also demonstrated that the low-frequency components decreased in intensity and the high-frequency components increased in intensity during 30-min running trials. They concluded that the increase in intensity of the high-frequency content occurred with a decrease in intensity of the low-frequency content of muscle activity. Besides the fact that in this study significantly higher frequencies were generated by the GAS muscle, results also indicated that the intensity of GAS muscles increased and the intensity of GLU muscles decreased during the starting block phase and two subsequent strides [4]. Moreover, this preferential recruitment of faster fibers (GAS muscle) for faster tasks (sprint start) indicates that in some circumstances motor unit recruitment during movement can match the contractile properties of the muscle fibers to the mechanical demands of the contraction [4, 15]. In this way, one of the most mechanical demands in sprint start is the explosive nature of these movements in which a rapid and maximal force exertion needs to be delivered [8-9, 11]. Moreover, it is well known that the greater percentage of FT fibers in sprinters enables them to produce greater muscle force and power than their ST -fibered counterparts [8-9, 15]. Hence, according to some studies [6, 7, 14] it seems that the GAS with high percentage of fast twitch fibers can be the most important muscle during early force production. Additionally, Wakeling et al. (2006) also reported that a selective recruitment of the faster motor units occurred in response to increasing muscle activity [4].

In general, as revealed in the results for all anthropometrical variables the GAS muscle of the rear or front legs presented significantly higher frequencies than other muscles, especially the GLU muscles. It has been suggested that some anthropometrical variables may be beneficial for good athletic performance in various sports such as sprint running [17]. However, there are no studies to show influences of anthropometrical variables on muscle frequencies, especially during sprint performance. However, the results in this study indicated that the GAS muscle produced higher frequency in the second and third groups for all phases. However, during the block phase higher GAS frequencies came mainly from the rear leg.

The results of the present study also revealed that the older sprinters and also the sprinters with a higher percentage of thigh and calf circumference and skeletal muscle mass have a better capability to recruit more fast twitch fibers as for instance in the GAS muscles. These results, besides indicating the importance of the fast twitch muscle fibers, especially of the GAS during sprint running, also showed that athletes with low skeletal muscle mass and also low thigh and calf circumstances couldn’t recruit as much fast fibers as the other sprinters. This is in agreement with the theory that children and adolescents have a lower ability in recruiting fast muscle fibres than adults [18]. Moreover, the higher frequencies of GAS muscles, especially of the rear block, show the importance of applying forces with the rear leg during block phase. This result is in agreement with Mero & Komi (1990) and ilbeigi (2012) reporting that skilled sprinters during starting are applying more peak force on the rear block compared with front block. Moreover, some authors indicated that the rear leg muscles have a high pre-activity during the set position, before the ipsilateral contact phase. So, the role of the muscle activity during the block phase, especially in the rear leg, is very important to get more pretension to produce efficient force during the starting phase [6, 12]. Finally, the higher recruited of the gluteus muscles of both rear and front legs in the older boys indicate that this group seem to have a greater ability to produce more low frequencies of the gluteus muscle as compared to the girls.

Conclusion

The results indicate that the motor unit recruitment patterns change through each sprint phase and between muscles. Also, the recruitment of high frequency muscle fibres during the sprint start may be explained by the explosive nature of these movements in which a rapid and maximal force exertion needs to be delivered.

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