Effects of Rate of Force Development on EMG Amplitude and Frequency

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Abstract

The purpose of this study was to compare the amplitude and frequency of the gastrocnemius EMG during ramp and ballistic contractions in highly trained sprint athletes. Sixteen female sprinters performed ramp and ballistic isometric contractions on a Biodex dynamometer. RMS and median frequency of the gastrocnemius EMG signals were obtained at the following torque levels: 25 ± 5%, 50 ± 5%, 75 ± 5%, 100% MVC. The average rate of force development (RFD), was 610.2 ± 123.1 N·m/s and 212.3 ± 155.6 N·m/s for the ballistic and ramp contractions, respectively. In the ramp contractions the EMG amplitude increased as a function of torque. In the ballistic contractions the EMG amplitude decreased from 25% to 100% MVC. The highest RFD of 889.45 N·m/s was generated in ballistic contractions by a muscular activation pattern with high EMG amplitude (475.7 µV) and low frequency (116.7 Hz) at 25% MVC. The findings suggest that the CNS utilizes different muscular activation patterns to modulate RFD in ramp and ballistic contractions. In ramp contractions the EMG amplitude increased linearly with force. In ballistic contractions a high RFD is generated with a muscular activation pattern consisting of high amplitude and low frequency at the start of the contraction.

Key words
EMG · ballistic contraction · ramp contraction · isometric · isokinetic exercise

Introduction

Explosive movements such as sprinting may require a unique neuromuscular control pattern so that power production can be maximized. The neural drive required for the sprinter to generate maximal force-velocity production would theoretically involve the recruitment of all available motor units, with each unit firing at its maximal rate. When executing ballistic or explosive type movement, synchronization of motor units optimizes the rate of force generation via superposition of motor unit force twitches [6,22,24]. Neural and mechanical alterations in the neuromuscular system following dynamic training contribute to an increased rate of force development [22]. Dynamic training promotes higher initial discharge rates by motor units and increases motor unit synchronization during ballistic contractions, which enhances the rate of force development.

Synchronization of motor units has been shown to cause a reduction in the frequency spectrum and a concomitant increase in the amplitude of the surface EMG signal [13,29]. Moritani et al. [19]

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observed that short term power training utilizing resistance loads of 30% of maximal strength resulted in increased EMG amplitude and decreased mean power frequency. The authors suggested that these alterations in muscle activation were due to improved synchronization of motor units. Van Cutsem et al. [28] found that strength gains from low-load, high-velocity training resulted in: reductions in the recruitment threshold, increases in motor unit force and increased motor unit firing rates. These myoelectric changes increased the maximal rate of force development. Moritani et al. [20] also observed significant increases in the rate of force development following low-load high velocity training. They suggested that preferential recruitment of fast twitch motor units may have occurred to meet the demands of rapid, forceful movements. High discharge rates at recruitment, have been shown to optimize the speed and amount of force production [6,7,27].

Unlike ballistic contractions, in ramp contractions motor units are recruited in an orderly fashion, according to the size principle [10], beginning with slow twitch motor units and proceeding to fast twitch motor units. It is generally accepted that there is a linear relationship between the frequency spectrum of the myoelectric signal and the level of isometric force [5,21]. In ramp [2,4,18] and step contractions [2,4] the amplitude and frequency of the EMG signal have been observed to increase linearly with the isometric force.

Sprinters typically train to maximize power production by combining high intensity strength training with high velocity – low load training. Power training programs have been shown to shift the force-velocity curve to the right [19] and increase the rate of force development [22]. Since sprinters have high percentage of fast twitch fibers and high rate of force production they may be more prone to show increased amplitude and decreased median frequency of the surface EMG signal in ballistic contractions. This study was designed to answer the following question: How do ramp and ballistic contractions differ in amplitude and frequency of surface EMG?

Therefore, the purpose of this study was to compare the amplitude and median frequency of the surface EMG of the gastrocnemius muscle during ramp and ballistic contractions in highly trained sprint athletes.

Methods

Subjects

Sixteen female track athletes from a Division I University were recruited as subjects for this study. The mean (± SD) height, mass, and age for the subjects was 1.67 ± 0.04 cm, 61.68 ± 4.58 kg, and 20.21 ± 1.47 yr, respectively. Exclusionary criteria included any preexisting: peripheral nerve dysfunction, musculoskeletal disorders, and cardiopulmonary disorders. The experimental procedures were approved by the Human Subjects Institutional Review Board at Brigham Young University. All subjects were informed of the risks and benefits associated with the study and they signed a participant consent form.

Torque measurement

Subjects reported to the lab for familiarization and testing. An isokinetic dynamometer (Biodex System 3, Biomedical Systems, Newark, CA, USA) was used to measure the torque of the plantar flexor muscles. Subjects were seated in a straight leg position trying to isolate the gastrocnemius muscle as the primary torque generator. Their chests and hips were strapped and the arms crossed at the chest's height to avoid accessory movements and additional moment generation. The center of the ankle joint was aligned with the dynamometer center of rotation at an angle of 90° (zero degrees of plantar flexion). The familiarization was composed of 3 sets of 5 repetitions of isometric ballistic plantar flexion and 4 isometric ramp contractions. A 3-min rest interval was allowed between contractions and a 5-min interval between sets. None of the subjects reported fatigue during the familiarization.

Following familiarization, the subjects performed 3 ramp contractions and 3 ballistic contractions. A 3-min rest interval was allowed between contractions. In the ramp isometric contraction the subjects were instructed to gradually build up the torque, taking 2 – 3 sec to reach peak torque and then holding the maximal torque for 2 – 3 seconds. In the ballistic isometric contractions they were instructed to generate peak torque as rapidly as possible and also hold it at maximal force for 2 – 3 seconds. Real time visual feedback of the torque signal was provided to the subject using a computer monitor.

Electromyography

A telemetric EMG unit (Telemyo system, Noraxon USA Inc., Scottsdale, AZ, USA) and Ag/AgCl circular electrode pairs, with an interelectrode distance of 2 cm, were used to capture the EMG signal. The electrodes were attached to the belly of the lateral head of the gastrocnemius muscle, aligned in parallel to muscle fiber orientation. In addition, a ground electrode was positioned at the mid-tibia on its medial side. Before electrode placement the skin area was shaved, abraded, and cleaned with an isopropyl alcohol pad to reduce skin impedance. The EMG signals were differentially amplified with a gain of 1000 and a bandwidth of 16 – 500 Hz at – 3 dB. The EMG amplifiers have an input noise below 1 µV RMS and an effective common mode rejection of 85 dB.

Data collection and analysis

EMG and torque data were recorded using a Dell P III 400 computer interfaced with a Keithley-Metrabyte KPCMCIA-16 AI-C, 16 channel, 16 bit A/D converter. The EMG and torque data were collected at frequency of 1000 Hz. The RMS and MF of the EMG signals were calculated at the following torque levels: 25 ± 5%, 50 ± 5%, 75 ± 5%, 100% of MVC (see Fig. **1**). The MF was computed from the raw EMG signals using short-term Fast Fourier Transform [15] with variable length time windows of 104.6 ± 5.5 ms and 51.6 ± 1.5 ms for the ramp and ballistic contractions, respectively. The short-term Fast Fourier Transform algorithm has been shown to average out non-stationarities in dynamic contractions [15] and ramp contractions [3]. Each EMG segment was multiplied by a Blackman taper window and zero padded to obtain a frequency resolution of 2 Hz for each interval.

The Median Frequency (MF), which is the frequency value that bisects the power spectrum into two regions of equal power was defined as follows:

$$\mathrm{MF} = \int_0^{f_{med}} P(f)df = \int_{f_{med}}^{\infty} P(f)df = \frac{1}{2}\int_0^{\infty} P(f)df$$

where *P(f)* is the power spectrum density of the EMG signal.

The average rate of force development was defined as the slope of the torque-time curve, between 20 and 80% of the maximal torque level. In addition, the rate of force development was calculated at each at the following torque levels: 25 ± 5%, 50 ± 5%, 75 ± 5% of MVC.

Statistical analysis

The comparisons of the RMS, MF, rate of force development, and torque between conditions (ramp and ballistic) and force levels (25%, 50%, 75%, and 100%) were done with a SAS® Proc Mixed. Type of contraction (ballistic and ramp) and force level (25% ± 5, 50% ± 5, 75% ± 5, and 100%) were considered as fixed effects and subjects as a repeated, random factor. The correlation within subject's measurements was modeled with an unstructured covariance structure. This procedure allows a better fit of the statistical model, producing more accurate F- and, consequently, p-values [8,14,23]. Significance level was set at 0.05 and post hoc p-values for multiple comparisons were adjusted with Tukey-Kraemer.

Results

There were no differences in the mean torque generated during the ramp and ballistic contractions at the 25%, 50%, 75%, and 100% force levels ($p < 0.05$) (see Table **1**). Since the torque generated at each force level was the same, it was assumed that any differences in the EMG variables were due to a different strategy in the activation of motor units to modulate the rate of force production.

The rate of force development was significantly different between the contractions at each force level ($p < 0.05$) (see Fig. **2**). The highest RFD of 889.45 N · m/s occurred in the ballistic contraction at the 25% MVC force level. The average rate of force development, which was defined as the slope of the torque as a function of time curve, between 20 and 80% of the maximal torque level was 610.18 ± 123.13 N · m/s and 212.25 ± 155.60 N · m/s for the ballistic and ramp contractions, respectively.

The means and standard deviations of the amplitude and frequency of the EMG signal as a function of force for the ramp and ballistic contractions are shown in Table **2**. In the ballistic contractions the amplitude of the myoelectric signal decreased from 25% to 100% (Fig. **3**). The RMS at 25% MVC (475.50 ± 259.28 µV) was significantly higher than at 100% MVC (330.22 ± 148.83 µV). Unlike the ballistic contraction, the amplitude of the EMG in the ramp contraction increased as a function of torque from 187.98 ± 165.99 µV at 25% to 399.75 ± 142.61 µV at 100% (Fig. **3**). When comparing the RMS values between contractions, the RMS at 25, 50, and 75% in the ballistic contraction were significantly higher than the RMS in the ramp contractions at 25, 50, and 75%, $p < 0.05$ (Table **2** and Fig. **3**).

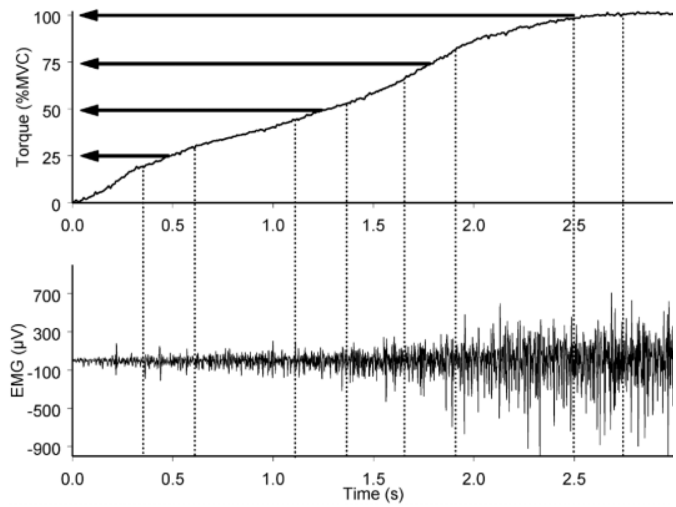

Fig. **1** Torque (N · m) and EMG (µV) in a ramp isometric plantar flexion contraction. The EMG amplitude and median frequency variables were computed at the following normalized torque levels: 25 ± 5, 50 ± 5, 75 ± 5, 100% of MVC.

Table **1** Mean and standard deviation for torque (N · m) in ballistic and ramp contractions

Torque (N · m)	*Ballistic*	*Ramp*
25% MVC	49.4 ± 9.9	52.0 ± 9.8
50% MVC	96.5 ± 19.8	102.4 ± 18.8
75% MVC	144.6 ± 28.5	154.1 ± 29.6
100% MVC	198.3 ± 37.7	203.3 ± 38.0

* Indicates significant difference between ballistic and ramp contractions ($p < 0.05$)

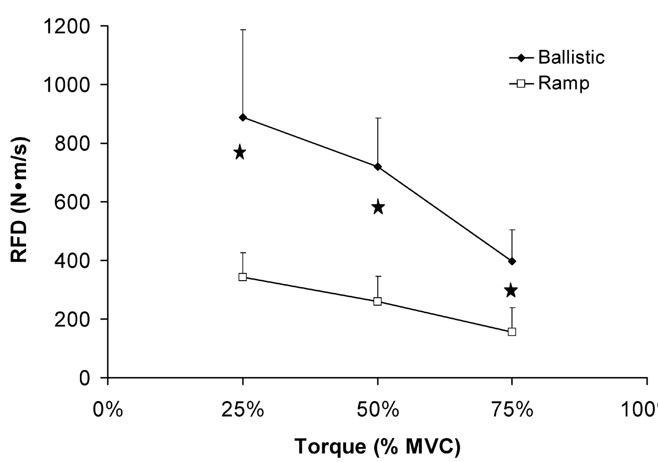

Fig. **2** Rate of force development (RFD) and standard deviation in the ballistic and ramp isometric contractions at each force interval (★ $p < 0.05$, ballistic greater than ramp).

Table 2 Mean and standard deviation for RMS and MF in ballistic and ramp contractions by level of torque

Torque	*Ballistic*		*Ramp*	
	RMS (μV)	*MF (Hz)*	*RMS (μV)*	*MF (Hz)*
25%	475.50 ± 259.28 [3,4]	116.75 ± 36.89	187.98 ± 165.99 [8]	119.61 ± 35.78
50%	397.30 ± 158.83 [5]	151.30 ± 33.38 [2]	254.47 ± 155.08 [9]	123.33 ± 19.85
75%	393.12 ± 146.34 [6]	148.11 ± 41.25	318.28 ± 121.40 [10]	146.13 ± 30.79
100%	330.22 ± 148.83 [7]	148.22 ± 28.92 [1]	399.77 ± 142.61	138.47 ± 20.73

[1] MF ballistic 25% lower than ballistic 100%; [2] MF ballistic 50% greater than ramp 25 and 50%; [3] RMS ballistic 25% greater than ballistic 100%; [4] RMS ballistic 25% greater than ramp 25 and 50%; [5] RMS ballistic 50% greater than ramp 25 and 50%; [6] RMS ballistic 75% greater than ramp 25, 50, and 75%; [7] RMS ballistic 100% greater than ramp 25%; [8] RMS ramp 25% smaller than ramp 50, 75, and 100%; [9] RMS ramp 50% smaller than ramp 100%; [10] RMS ramp 75% smaller than ramp 100%

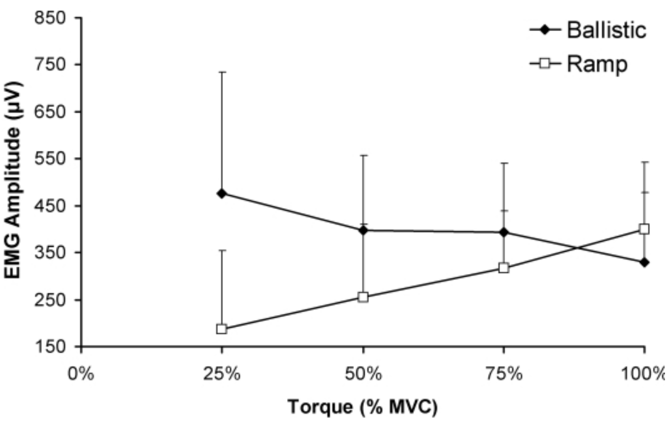

Fig. 3 Relationship between EMG amplitude and isometric torque in ballistic and ramp contractions.

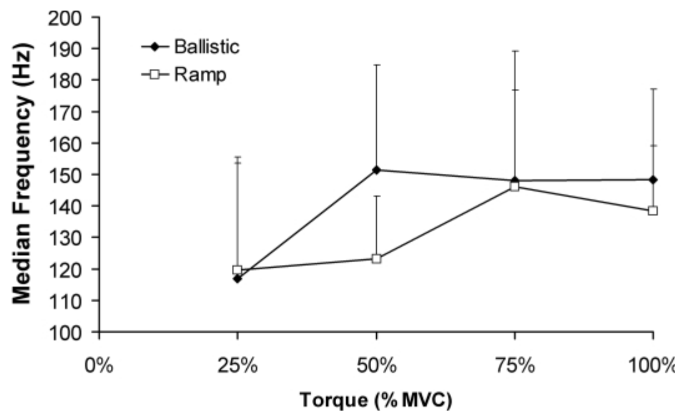

Fig. 4 Relationship between EMG median frequency and isometric torque in ballistic and ramp contractions.

Comparisons of median frequency for ballistic and ramp contractions by torque are shown in Fig. **4**. In the ballistic contraction, the median frequency was significantly lower at 25% MVC than at 100% MVC (Table **2**). While the median frequency increased from 116.75 Hz at 25% MVC to 151.30 Hz at 50% MVC, this increase was not significant ($p = 0.068$). The median frequency remained elevated in the ballistic contractions from 50% to 100% MVC (see Fig. **4**). In the ramp contractions, the median frequency increased slightly as a function of force level up to 75% and then decreased at 100% (Fig. **4**). However, these differences were not significant, $p < 0.05$ (Table **2**).

Discussion

The main findings of the study are that different muscular activation patterns were utilized to modulate the rate of force development in ramp and ballistic contractions. In ramp contractions, the amplitude of the EMG increased linearly with force (Fig. **3**), contributing to an average rate of force development of 212.25 N·m/s. The highest rate of force development (343.03 N·m/s) in the ramp contractions occurred at 25% MVC. Although the median frequency in the ramp contractions appeared to increase from 25 – 75% MVC (Fig. **4**), these differences were not statistically significant, suggesting that median frequency did not change with increasing force. In ballistic contractions, a different activation pattern was observed. At the onset of the ballistic contractions, a high rate of force development of 889.45 N·m/s was generated by a muscular activation pattern consisting of higher amplitude, than that observed at the onset of ramp contractions; see Fig. **3** (25% MVC). After this initial burst of activation in the ballistic contractions, the amplitude decreased from 25 – 100% MVC, while the median frequency increased to approximately 150 Hz and remained at that level from 50 – 100% MVC. The median frequency at the onset of the ballistic contraction was significantly lower at 25% MVC (116.75 Hz) than at 100% MVC (148.22 Hz). These results suggest that the CNS utilizes a different activation pattern in ballistic and ramp contractions.

Asynchronous firing of motor units facilitates the smooth production of force in ramp contractions. This activation pattern results in a linear increase in the amplitude with isometric force (Fig. **3**). These results are consistent with both ramp [2,4,18] and step contractions [2,4], where the amplitude of the EMG signal have been observed to increase linearly with the isometric force. Fig. **4** shows a decline in median frequency upon attaining 100%MVC, in the ramp contraction. Two factors have been used to explain this decrement in the MF at maximum force level. De Luca et al. [9] suggested that it might be partially due to muscle force potentiation, while Bigland-Ritchie [1] related it to the muscle wisdom phenomenon.

In contrast to ramp contractions, in ballistic contractions synchronous firing of motor units enhances the rate of force production. Synchronization of motor unit activation has been shown to decrease the amplitude and increase the frequency of the surface EMG signal [11,12,29]. Semmler [25] suggested that motor unit synchronization represents a deliberate neural strategy, which enhances the rate of force production in ballistic contractions. In ballistic contractions, motor units discharge with higher initial frequencies (80 – 100 Hz) and subsequently reach their peak firing rates sooner [17]. The likelihood of motor unit synchronization increases in ballistic contractions and the mechanical effect of motor unit synchronization is a non-linear muscle force augmentation [6,7,27]. It is likely that the neural drive in ballistic contractions elicits higher initial discharge rates by motor units, which enhances the rate of force development, resulting in the muscular activation observed in this study, consisting of a significantly higher EMG amplitude (475 µV) and lower EMG frequency (116 Hz) at the start of the contraction, 25% MVC, than at 100% MVC (see Figs. **3** and **4**, respectively).

Training characteristics can influence both the neural control of muscle and the mechanical response of the muscle to this neural drive. In the present study, we selected sprint-trained athletes to identify the effects of the rate of force development on the surface EMG signal. High velocity strength training increases the rate of force development [28] and the amount of motor unit synchronization [16,19,20,26,28]. The results of this study suggest that the CNS utilizes different muscular activation patterns to modulate the rate of force development in ramp and ballistic contractions. In ramp contractions the EMG amplitude increases linearly with force. In ballistic contractions a high rate of force development is generated with a muscular activation pattern consisting of high amplitude and low frequency at the start of the contraction.

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