DIRECTION OF ISOMETRIC BALLISTIC FORCE IS RELATED TO ANTAGONISTIC MUSCULE DISCHARGE

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The purpose of this study was to investigate the relationship between electromyographic (EMG) activities of human thigh muscles (vastus medialis, vastus lateralis, rectus femoris, biceps femoris and semitendinosus) and the direction of knee extension force during ramp and ballistic contractions. Four subjects exerted isometric knee extension forces at a target force level of 40% of maximum voluntary contraction (MVC) at various speeds. Variations of EMG amplitudes of all thigh muscles during ballistic contraction were much larger than those during ramp contractions. Only biceps femoris was related to the direction of force. These results suggest that EMG activity of biceps femoris muscle is an important factor for deciding direction of isometric ballistic knee extension force.

KEY WORDS: ballistic contraction, direction of force, electromyography, knee extension

INTRODUCTION

Force production performed as fast as possible, called ballistic contraction, is thought to be an important factor for high performance in various sports. Large variations in the amount of muscle discharges for human hand (adductor pollicis) and leg (tibialis anterior, vastus medialis, vastus lateralis rectus femoris) muscles have been reported during ballistic contraction (Yoneda et al. 1983; 1988, Mizumura et al. 2000; 2002). However variations have not been observed during ramp contraction (Yoneda et al, 1983; 1986, Mizumura et al. 2002). Furthermore, we have reported that the direction of the knee extension force was not constant during ballistic contraction (Mizumura et al. 1999; 2000). Although we investigated the relation between variation in agonist surface EMG activities on thigh extensor muscles (vastus medialis, vastus lateralis and rectus femoris) and direction of knee extension force, no significant correlations were observed between them (Mizumura et al. 2000). However, these previous studies did not examine the antagonistic EMG activity that may affect the agonist EMG activity during ballistic contraction. In the present study, in order to clarify whether the variation of thigh muscle is related to the direction of knee extension force, we examined the relationship between direction of knee extension force and the integrated EMG activities on thigh extensor and flexor muscles during ramp and ballistic contractions

METHODS

Subjects and tasks: Four healthy male volunteers participated in our experiments. We obtained informed consent before their participations. Subjects sat on an experimental chair with the right knee fixed at 90 degrees (Fig. 1A). The target force amplitude was set at a force level of 40% MVC. In order to examine the relationship between force rise time and variation of the integrated EMG activities, we instructed them to produce isometric forces at 5 different force rise times (2, 1, 0.5, 0.25s, and as short as possible) (Fig. 1B). The subjects exerted 10 or more trials at each condition.

Data Collection and analysis: Surface EMG signals were recorded from vastus medialis, vastus lateralis and rectus femoris muscle as agonists, and semitendinosus and biceps femoris muscles as antagonists from the subject's right thigh together with three components of force signals detected by a specially designed force transducer (Kyowa, LSM100) attached to a lever arm of the experimental chair (Fig. 1A). We defined the lateral-medial axis of knee extension force as the "x-component", the proximal/distal direction of lower leg as the "Y-component", and the direction of extension/flexion as the "z-component" (Kapandji 1977). The surface EMG activities and three components of forces were simultaneously recorded in a personal computer via A/D converter (Biopac, MP100) for the subsequent off-line analyses. We analyzed the relationship between the integrated EMG activities and direction of resultant force on the z-x plane.

RESULTS:

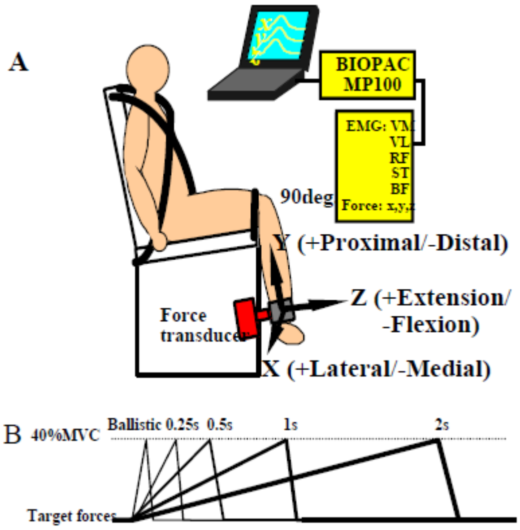

Figure 1. Schematic representation of experimental setup (A) and target force trajectories (B) in the present study

Table 1. Number of trials, mean, standard deviation and coefficient of variation in peak force amplitude at five different force rise times for one subject

Items	Ballistic	0.25s	0.5s	1s	2s	Total
n	17	4	9	12	10	52
Mean	40.1%	39.0%	39.5%	39.4%	40.0%	39.7%
SD	1.0%	1.3%	0.8%	1.2%	0.6%	1.0%
CV	2.6%	3.3%	2.0%	2.9%	1.5%	2.5%

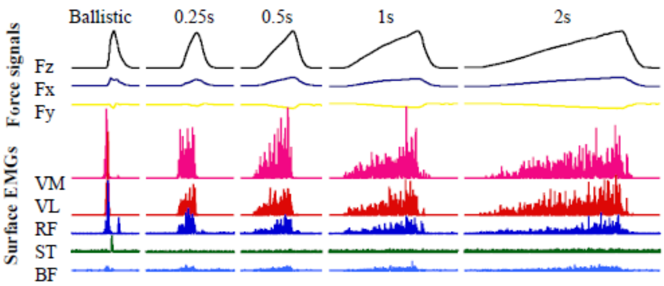

Fig. 2. Representative recordings of three components of force signals and surface EMG activities on thigh extensor and flexor muscles at five different force rise times

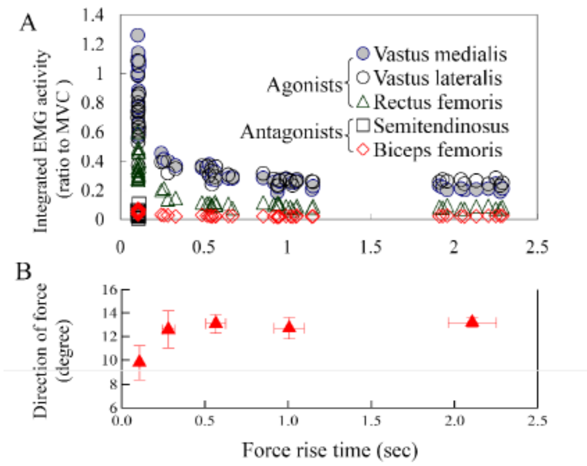

Fig. 3. Integrated EMG activity (A) and direction of resultant force on z-x plane (B) as a function of force rise time

A total of 240 trials from four subjects were analyzed. Values of mean peak force amplitude (%MVC), standard deviation (SD) and coefficient of variation (CV) at 5 different force rise time conditions for one subject are shown in Table 1. The values of mean force amplitudes were almost the same as the target force level. The values of CVs of force amplitudes were less than 5% at 5 conditions in all subjects examined, so that the force amplitudes analyzed were almost the same to the target force level. Representative recordings of three components of knee extension force and rectified EMGs of the three agonist and two antagonist muscles during ramp (0.25, 0.5, 1.0 and 2.0s) and ballistic contractions are depicted in Figure 2. In ballistic contraction large EMG amplitudes for the three agonist muscles were observed. The biceps femoris was activated at a similar time to the three agonist activities. On the other hand, the semitendinosus muscle only acted in a reciprocal timing to the activities of the agonist muscles during ballistic contraction.

EMG activities of three agonist and two antagonist muscles as a function of force rise time are shown in Figure 3A. Remarkably large variations in EMG activities were observed in the agonist muscles during ballistic contraction (Fig. 3A).

We measured the direction of resultant force on the z-x plane (see Fig. 1B). The direction of the resultant force in the ballistic contraction was smaller than the ramp and fast ramp contractions (Fig. 3B). Figure 4 shows values of mean and standard deviation of integrated EMG activity on the vastus medialis muscle for one subject. Shorter the force rise time, the greater the values of both mean and SD in integrated EMG activity (Fig. 4). A similar tendency was observed for the vastus lateralis, rectus femoris and biceps femoris muscles.

For the semitendinosus muscle the EMG activities were not observed in the 4 ramp conditions, but were observed at the ballistic condition (Fig. 2). Figure 5 depicts SDs in integrated EMG activities for 5 muscles at 4 ramp and ballistic conditions. In ballistic contraction, three agonist muscles showed remarkably large variations compared to the other 4 ramp conditions. The amounts of variation of the antagonist muscles were smaller than those of the agonist muscles in the ballistic condition (Fig. 5).

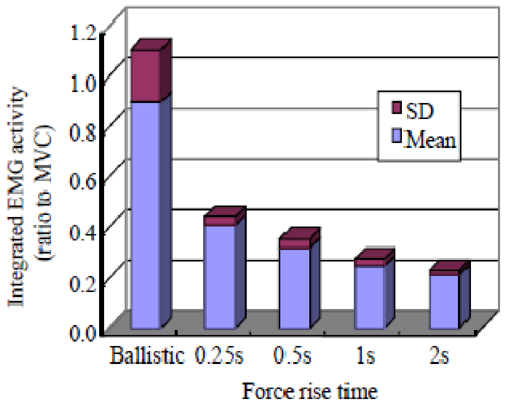

Fig. 4. Comparison of integrated EMG activity on vastus medialis muscle

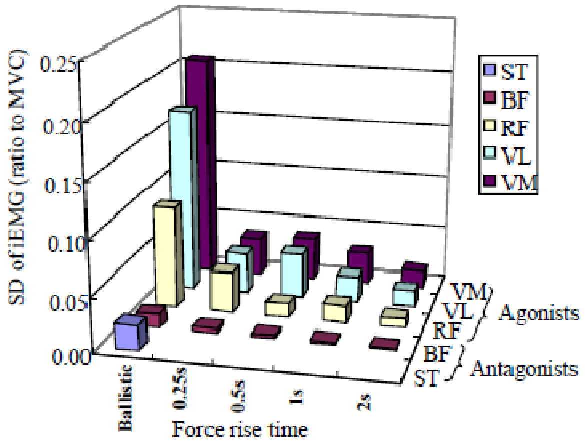

Fig. 5. Comparisons of SDs in integrated EMGs among 5 different muscles and conditions

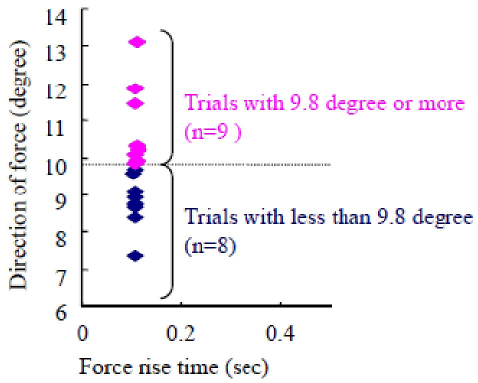

Fig. 6. Classification of ballistic trials according to value of direction of resultant force

Table 2. Comparison of integrated EMG activities between the two groups classified by direction of force

Muscles		Direction of resultant forces		
		Less than 9.8 degree (n=9)	9.8 degree or more (n=8)	
		Mean ± SD	Mean ± SD	
Agonists	VM	0.849 ± 0.226	0.958 ± 0.180	ns
	VL	0.780 ± 0.178	0.654 ± 0.143	ns
	RF	0.368 ± 0.105	0.387 ± 0.086	ns
Antagonists	ST	0.037 ± 0.016	0.038 ± 0.030	ns
	BF	0.048 ± 0.013	0.060 ± 0.010	*

Values were ratio to MVC, * $p<0.05$

In order to clarify whether direction of knee extension force is related to the integrated EMG activity during ballistic condition, we divided the trials in the ballistic condition into two groups based on a value of the direction of resultant force as depicted in figure 6. Integrated EMG activities in the three agonist and semitendinosus muscles in the ballistic condition were not related to the direction of resultant force, however, biceps femoris muscle activity was related to the direction of force (Table 2).

DISCUSSION:

We examined the relationship between the direction of knee extension force and the integrated EMG activities on thigh extensor and flexor muscles during ramp and ballistic contractions. Our main findings were that large variations of integrated EMG activities during isometric ballistic knee extension force exertion were observed in both agonist and antagonist muscles, and that the integrated EMG activity of the biceps femoris was related to the direction of knee extension force. The following discussion identifies possible mechanisms for the large variation in EMG activities and the functional role of the biceps femoris muscle during isomtric ballistic knee extension force exertion.

Surface EMG signal consists of superimposed motor unit action potentials from several active motor units. Therefore, the large variation of the surface EMG activity in the ballistic contraction could be related to firing behaviors of the active motor units. The recruitment threshold forces of the motor units during ballistic contraction were much lower than those during slow and fast ramp contractions (Yoneda et al. 1986; Masakado et al. 1995). Furthermore, remarkably high firing frequencies and large variation of the frequencies of motor units were observed during ballistic contraction (Oishi et al. 1988). Therefore, we believe that the large variation in surface EMG activity during ballistic contraction is mainly due to the diversification of the firing frequencies of motor units.

The biceps femoris muscle has two heads of origin (long and short heads). In this study we recorded the surface EMG from the long head of the biceps femoris muscle. The long head acts as both a knee flexor and hip extensor. In this study the EMG activity of the biceps femoris muscle was activated at a similar time to the vastus medialis, vastus lateralis and rectus femoris muscles at various force rise times. Since the long head of the biceps femoris muscle is activated during hip extension, the head may act like a agonist muscle when subjects exert an isometric force for both knee and hip extension.

The integrated EMG activity of the biceps femoris muscle was related to the direction of knee extension force during ballistic contraction. The larger the direction of the force outward, the larger the amplitude of the EMG activity of the biceps femoris muscle. When a knee is semi flexed, the biceps femoris rotates the lower leg slightly outward due to its oblique direction. Our results suggest that EMG activity of biceps femoris muscle is an important factor for deciding direction of isometric ballistic knee extension force.

CONCLUSION:

We examined the relation between direction of knee extension force and the integrated EMG activities on thigh extensor and flexor muscles during ramp and ballistic contractions. The direction of the knee extension force was related to the integrated EMG activity on biceps femoris muscle during ballistic contraction. Our results suggest that antagonistic EMG activity should be taken into account for variation in the direction of force when subjects produce ballistic knee extension.

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