Effects of Prestretching Velocities in Leg Extensors on Mechanical Efficiency and Myoelectrical Activities.

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Abstract

Six adult males were studied to examine the utilization of the stored elastic energy. The repetitive knee bending exercises were performed on a force platform (Kistler, Swiss) at various constant frequencies ranging from 20 to 80 cycles/min in two different amplitudes of knee angle (60° and 90°). The external mechanical work (W) was calculated from the ground reaction force recorded by force platform. The oxygen requirement (E) for three minutes exercise was determined by the Douglas bag methods. EMGs of leg extensor muscles (vastus medialis and rectus femoris) were recorded by bipolar surface electrodes and the mean amplitude of EMG (mEMG) was obtained. One cycle of knee bending was divided into the two work phases (knee extension phase: positive and flexion phase: negative) according to the electrogoniogram. Positive linear correlations were observed between W, E and mEMG in all the subjects. Mechanical net efficiency increased significantly with frequency (from 9.55% to 34.9%). MEMG during the negative work phase increased with frequency, while it remained almost the same in the positive work phase. The results suggest that 1) the higher the prestretching velocity of leg extensor muscles, the more elastic energy stored in the prestretching muscles and 2) the potentiation of myoelectrical activities is increased through prestretching.

Key words: Mechanical efficiency, Knee bending exercise, Muscle elasticity, Myoelectrical activity

Introduction

A more efficient dynamic muscle contraction can be performed when it follows immediately after active prestretching of that muscle. This advantage might result from the combined effects of muscle elasticity and myoelectrical potentiation.

Cavagna et al. (1964) reported that mechanical efficiency in running was higher than the conventionally reported value (about 25%) obtained from isolated muscle preparations. In kangaroo hopping, on the other hand, mechanical efficiency increased with hopping speed (Cavagna et al. 1977). These results suggest that the elastic energy stored in the muscle during prestretching (eccentric contraction) was released during shortening (concentric contraction), so that less energy would be needed to expend during the subsequent concentric contraction. The effect of prestretching on muscular performance has been confirmed from mechanical measurements obtained in vertical jumping (e.g. Asmussen and Bonde-Petersen 1974b; Bosco and Komi 1979; Bosco et al. 1981).

It is unclear, however, whether or not the increase of prestretching speed will improve mechanical efficiency and myoelectrical activity. In this study examining the utilization of stored elastic energy in man, mechanical efficiency and myoelectrical activity were measured by varying the prestretching speeds of the agonist leg extensor muscles.

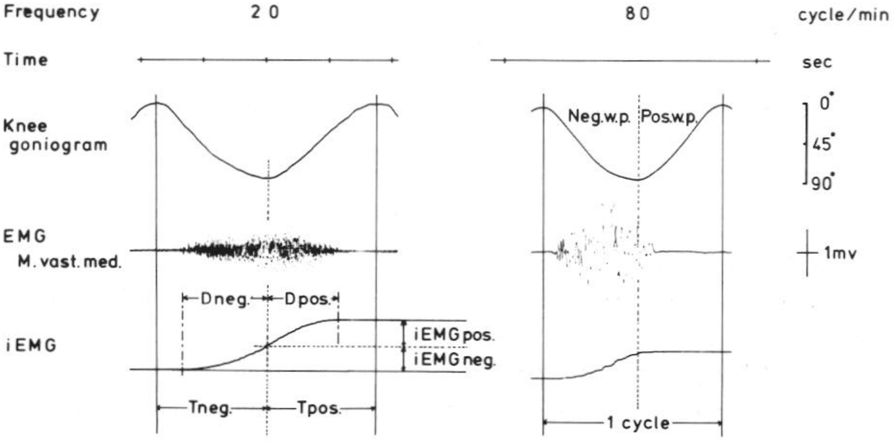
Methods

Subjects. Six healthy male students served as subject (age 24.0 ± 1.5 years, height 171.7 ± 2.9 cm and weight 65.8 ± 5.9 kg).

Experimental Procedures. Each subject performed ten repetitive knee bending exercises on a force platform (Kistler, Switzerland) with varying frequencies and knee angles of movement. Frequency was controlled by an auditory metronome at 20, 35, 50, 65 and 80 cycles/min. A constant range of knee angle was set on the oscilloscope which was put in front of the subjects so that they could visually control the angle of their knee at either 60° or 90°. Each subject performed five bouts one day with differing frequency at one knee angle and five bouts at the other angle on the next day. During exercise, the subject kept his hand at his waist, his body in an upright position and placed his heels on the force platform to limit front-back and right-left movements and to make the quadriceps act as the agonist muscle group.

Oxygen requirement. Each exercise was performed for three minutes. Using the Douglas bag methods, oxygen requirement was determined during last 5 minutes of a 20-minute rest period, 3 minutes of exercise and 25 minutes of recovery. Expired air volumes were measured using a dry gas meter. The O_2 and CO_2 gas fractions were determined with a gas analyzer (1H06, SANEI Inc., Tokyo) which had been periodically calibrated using the micro-Scholander technique. To obtain mean metabolic power, net oxygen requirement per second (as expressed by the caloric equivalent) was calculated.

Electromyography. EMGs were continuously recorded from the rectus femoris and vastus medialis



mEMG : Neg. w.p. = iEMGneg. / Dneg.
Pos. w.p. = iEMGpos. / Dpos.
1 cycle = (iEMGpos. + iEMGneg.) / (Dpos. + Dneg.)

Neg. w.p. : Negative work phase
Pos. w.p. : Positive work phase

Fig. 1. Examples of recordings of the knee goniogram (upper), EMG from vastus medialis (middle) and its integrated EMG (lower) during knee bending at a frequency of 20 cycles/min (left) and 80 cycles/min (right). Determination of iEMG and calculation of mEMG are also presented.

during exercise. Bipolar surface electrodes made of a silver plate 10 mm in diameter were attached 4 cm apart on the belly of muscle. EMG signals obtained during the last 30 seconds of each 3-minute exercise period were amplified, rectified and integrated (iEMG). As shown in Fig. 1, the iEMG during one cycle of knee bending was divided into two phases: during knee flexion or the negative work phase (iEMGneg) and during knee extension or the positive work phase (iEMGpos). These phases respectively correspond to eccentric and concentric contractions of the quadriceps. Mean amplitudes of the EMG (mEMGneg and mEMGpos) were calculated from dividing iEMGneg and iEMGpos by the duration of muscle activity during negative (Dneg) and positive (Dpos) work phases, respectively.

Mechanical work. Potential external energy was determined by the double electrical integration of the vertical acceleration which was recorded on the force platform. Mean mechanical power was calculated as external energy divided by duration of positive work phase. Net mechanical efficiency was determined from the ratio of mean mechanical power to mean metabolic power.

Results

Oxygen requirement increased with the frequency of contraction (Fig. 2). The requirement at 90° was higher than that at 60° in each subject. On the other hand, oxygen requirement per cycle of knee bending had a tendency to decrease with frequency.

Although the potential external energy per cycle of knee bending was essentially the same at the five frequencies because each subject adjusted his movement to a desired knee angle, mean mechanical power increased with frequency. Fig. 3 shows a significant linear correlation between mean mechanical power and mean metabolic power. As seen in this figure, each plot was scattered across many iso-efficiency levels.

Mechanical efficiency increased linearly with increasing frequency (Fig. 4) but mechanical efficiencies at 60° of the nee joint amplitude were not significantly different from those at the 90°.

Figure 5 shows comparison of iEMG and mEMG changes relative to the frequency of movement for all subjects. IEMGs and mEMGs obtained with each subject at the frequency of 20 c/min was assumed to be 100%. IEMGneg and iEMGpos showed almost the same values at the frequency of 20 c/min. At higher frequencies (e.g., 80 c/m), however, iEMGpos decreased to 6–10% in spite of an unchanged iEMGneg similar to that obtained at 20 c/m. As a result, the reduction in iEMG during one cycle that occurred with increasing frequency was mainly due to the decrease in iEMGpos. On the other hand, mEMGneg increased with frequency, i.e., the value obtained at the frequency of 80 c/min was 3.7–4.4 times greater than that at a frequency of 20 c/min. MEMGpos showed less change, and consequently mEMG during one cycle increased with frequency.

A significant positive linear correlations were observed between metabolic power and mEMG of the quadriceps (Fig. 6). The correlation coefficient for all subjects ranged from 0.78 to 0.99.

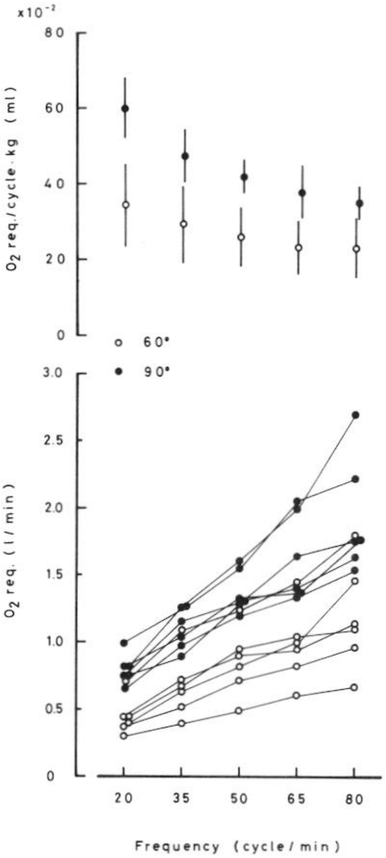


Fig. 2. Changes in oxygen requirement per min in each subject (lower) and oxygen requirement per cycle of knee bending (upper, means ± SD).

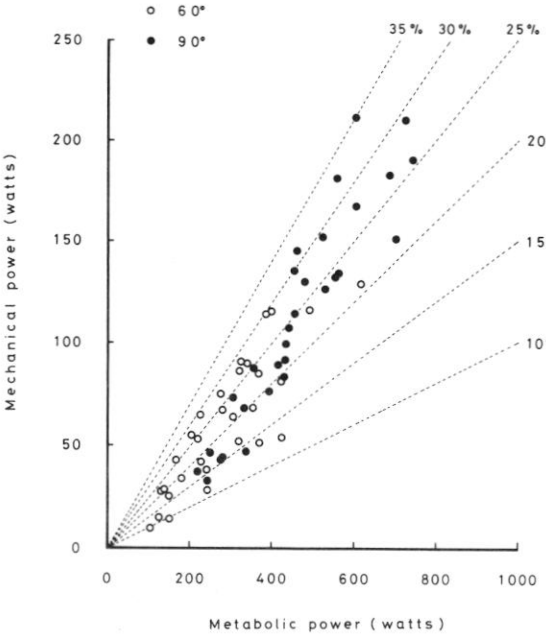


Fig. 3. Relationship between metabolic power and mechanical power. Dotted lines denote iso-efficiency levels.
60°: $Y = 17.3 + 0.92X, r = 0.66, p < 0.001$
90°: $Y = 32.7 + 1.42X, r = 0.87, p < 0.001$

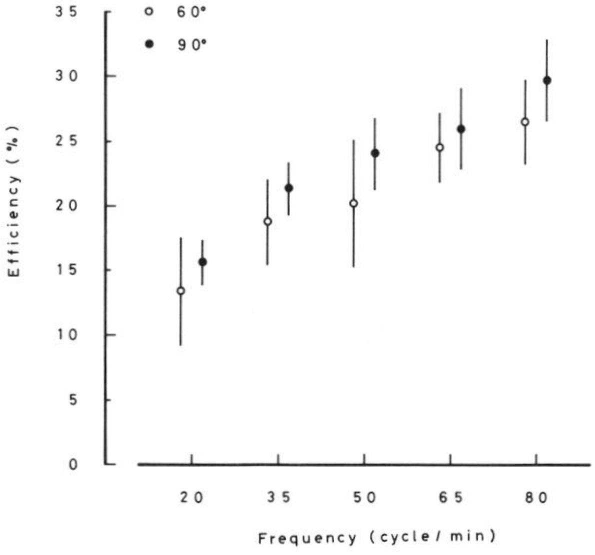


Fig. 4. Relationship between mechanical efficiency and frequency of movement.
$Y = 11.23 + 0.22X, r = 0.78, p < 0.001$

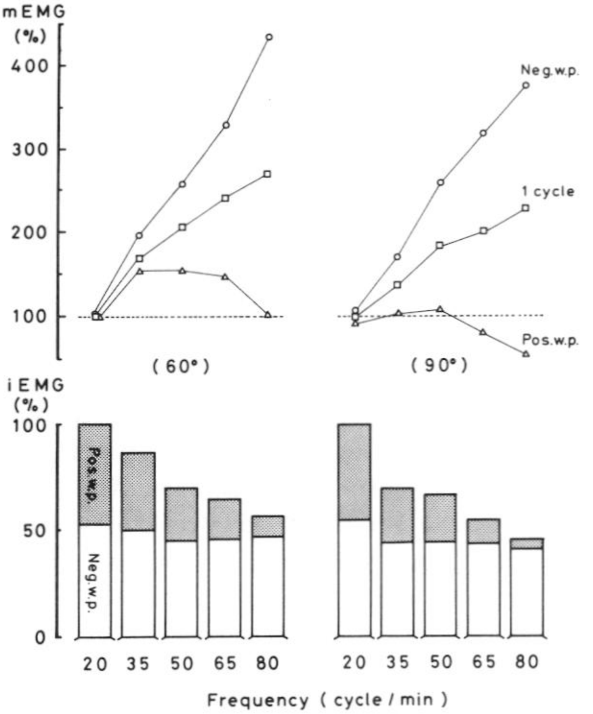


Fig. 5. Relative comparison of iEMG (lower) and mEMG (upper) with frequency of movement. Each value indicates mean of all the subjects.

Table 1. Correlation coefficients between mEMG and metabolic power for all the subjects.

Sujb.	M. rectus femoris	M. vastus medialis
H.H.	0.96 ***	0.95 ***
K.S.	0.99 ***	0.97 ***
K.I.	0.91 ***	0.93 ***
K.F.	0.98 ***	0.97 ***
M.W.	0.92 ***	0.93 ***
N.Y.	0.80 **	0.78 **

*** P<0.001
** 0.001<P<0.01

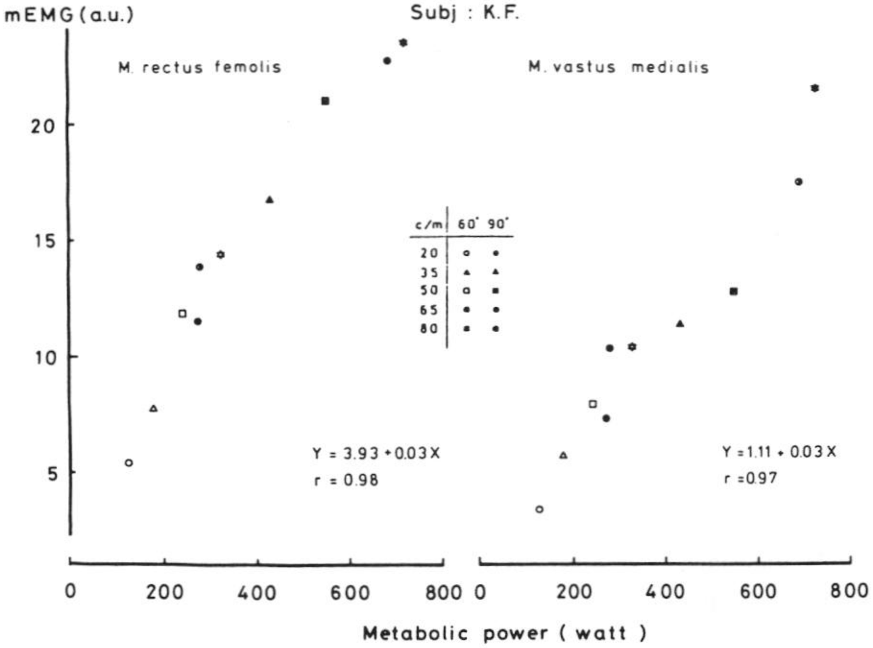


Fig. 6. Relationship between mEMG and metabolic power for rectus femoris (left) and vastus medialis (right).