Effect of an active pre-stretch on fatigue during repeated contractions

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Introduction

Experiments performed using in situ mammalian muscles demonstrated that reduction of power consequent upon fatigue was more pronounced than the loss of isometric force (De Haan et al. 1988, 1989a). In those experiments the shortenings were preceded by an isometric force-generating phase. However, in activities such as running, many muscles of the lower extremities appear to be actively stretched before they are allowed to shorten. For such stretch-shortening cycles increased work output and efficiency were reported (Edman et al.1978; Heglund and Cavagna 1987). Higher muscle efficiencies during exercise might have consequences for the higher resistance to fatigue. Thus, in the present study we investigated whether changes in work output during a series of repeated contractions were affected by an active pre-stretch. Muscle contractions were compared in which shortening was preceded either by an active isometric phase or by an active stretch.

Methods

Medial gastrocnemius muscles of anaesthetized male Wistar rats (pentobarbitone 60mg/kg; i.p.) were stimulated (pulse height 1mA; stimulation frequency 60Hz) via the severed sciatic nerve (temperature 25°C). Force and displacement signals were A/D converted and fed into a microcomputer.

The muscles performed 10 repeated contractions ($1.s^{-1}$; duration 0.45s). Each contraction consisted of a pre-phase (duration 150ms) followed by a shortening phase lasting for 300ms (Fig. 1). During the shortening phase the muscle-tendon complex was allowed to shorten at a constant velocity ($20mm.s^{-1}$) from L_o + 3mm to L_o - 3mm, at which length stimulation was stopped and the muscle relaxed.

Six muscles were passively stretched and held at L_o + 3mm. Stimulation was then begun and isometrically force developed for 150ms before the muscle was allowed to shorten (pre-isometric (PI) contractions). In the other six muscles activation was started while lengthening the muscle-tendon complex. The complex was actively stretched for 120ms (from L_o + 0.6mm to L_o + 3mm) with a velocity of $20mm.s^{-1}$, was subsequently remained isometric for 30ms, whereafter shortening was allowed (prestretch (PS) contractions; see Fig. 1).

Results and discussion

Force and work output

In the majority of previous studies on the effects of an active stretch, amphibian muscles have been stretched from an active isometric state (Katz 1939; Cavagna et al.1968; Edman et al.1978). However, as stated by Asmussen and Bonde-Petersen (1974) the onset of activation in vivo seems to take place in the last phase of the stretch. Moreover, Heglund and Cavagna (1987) reported that efficiency of rat EDL muscle was highest when the stretch commenced just before the onset of activation The present protocol showed that when stimulation was started during lengthening of the muscle-tendon complex a more than twofold enhancement in force could be achieved (see Fig.1). At L_o + 3mm in the PI experiments the isometric peak force was ~60% of the isometric force obtained at L_o (mean ± SD: 11.0 ± 0.8N; n=12); in contrast the peak force in the PS contraction was 150% of the isometric force at L_o (Fig. 1).

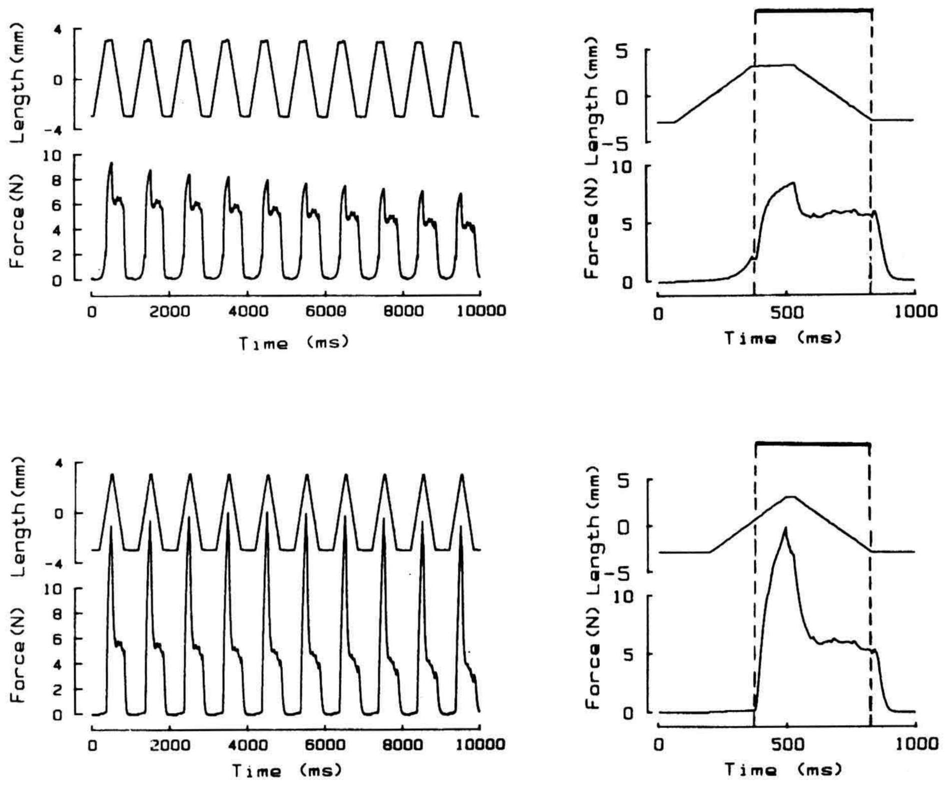

Figure 1. Examples of force and length traces obtained during series of pre-isometric contractions (top diagrams) and prestretch contractions (bottom diagrams).
Left: series of 10 successive contractions.
Right: enlarged diagrams of the first contraction of the series. The upper black bars indicate the time of stimulation.
Length is given relative to muscle optimum length (L_o).

Taken over the whole 10 contractions, the total work output during the shortening phase of the PS group was ~40% higher compared to the PI group (354 ± 36 vs. 254 ± 49mJ). The *extra* total work output of the PS group was predominantly (~70%) produced during the first 100ms of the shortening, while only 7% of the extra work was produced in the last 100ms of the shortening. This indicates that recoil of series-elastic elements had a large contribution in this *extra* work output.

Fatigue
The absolute difference in work output between the first and tenth contraction was not different for the PI and PS groups (9.53 ± 2.73 and 9.55 ± 1.93 mJ), respectively). This could imply that the contribution of the active contractile component (i.e. cross-bridge cycling) to work output in the shortening phase, and thus the time course of fatigue, was not affected by prestretch. All the extra work output performed after an active stretch would then originate from sources other than cross-bridge cycling and these sources would be hardly or not at all sensitive to fatigue. The findings that energy utilization was not affected by prestretch (De Haan et al.1989b, 1991) is in keeping with this hypothesis.

The changes in forces immediately prior to shortening were quite different for the PI and PS contractions (Fig.2). Whereas the force during the series of PI contractions decreased by 2-3% per contraction, the force after an active stretch (in the PS group) increased by ~8% in the first

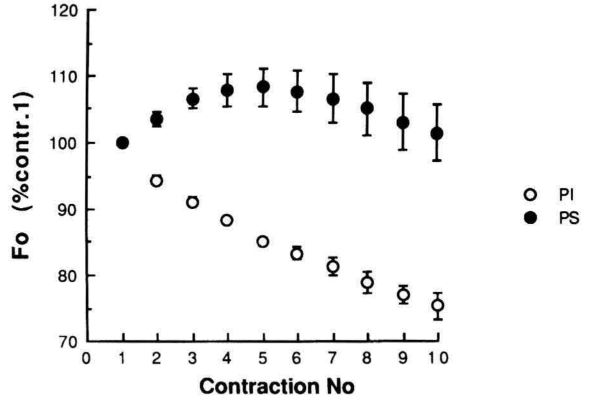

Figure 2. Relative changes in the force immediately prior to shortening for the series of 10 pre-isometric (PI) and prestretch (PS) contractions.
Mean (SD; n=6) for force (Fo) is given relative to the force of the first contraction of the series (=100%).

4 contractions before declining by ~1% per contraction. This is consistent with the observation of Curtin and Edman (1989) who noted a relatively smaller fatigue effect on force during active stretching of single fibres.

As a consequence of the similar absolute reductions in work output with the number of PI and PS contractions, the relative reduction (which is how fatigue is often expressed in human physiology) was less after a prestretch (26% vs 32%). Thus prestretch gives the impression of apparently protecting against fatigue.

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