The Effect of Prestretch on Skeletal Muscle Behavior

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The article points out the controversial question related to the mechanical behavior of skeletal muscle during the stretch–shortening cycle (SSC) and its effective capacity in enhancing muscle efficiency. Though Ingen Schenau et al. analyzed a large spectrum of theories, suggestions, and reported findings, the present contribution is restricted solely to four observations.

First, the authors, comparing vertical jumps performed without and with counter-movement (CMJ), state that “this enhancement [of work output due to the stretch-shortening cycle] was attributed to the fact that the prestretch allows the muscles to develop a high level of active state and force before shortening begins” (p. 408). This is not a novel explanation, since this phenomenon was used to demonstrate the positive relationship found between mechanical delay (MD) and percentage of slow twitch fibers (Bosco, 1987). MD indicates the time spent by the contractile elements (CE) of the muscles for stretching the series elastic elements (SEE). In my 1987 study, I measured MD by calculating the differences between the time to perform a simple squat jump (SJ), in which the tension developed by the CE is transmitted through the muscle-tendon-bone linkage with some delay, and the corresponding time to perform positive (Tpos) work in the CMJ. In the latter case, the tension developed by CE is instantaneously transmitted to the bones. The relationship found between MD and ST fibers was not attributed to the different stiffnesses found in slow and fast muscles but was explained only through the differences in firing frequency between phasic and tonic motor units (Steg, 1964). In fact, the $T_{pos}$ for CMJ was similar for both slow and fast subjects, whereas in the latter subjects the $T_{pos}$ for SJ was shorter than for slow subjects ($p < .05$). In accordance, the results were explained through the fact that fast subjects required less time to reach the maximal neural firing frequency than slow subjects (Bosco, 1987). On the other hand, at the beginning of the positive work of CMJ, all of the $\alpha$-motoneurons should have been fully activated in all subjects studied (Bosco & Viitasalo, 1982), since the time for eccentric work was relatively long (128 ms on the average).

The biomechanical principles and benefits of accelerating a body in two different ways were presented by Hochmuth (1960). As shown in Figure 1, the acceleration will be small in the first part and high in the second part of no-rebound jumps (NRJ). In contrast, in rebound jumps (RJ) the greater acceleration will be experienced in the first part of the movement. Assuming there is a similar net impulse in the two jumping conditions, the acceleration time in RJ will be less than for NRJ conditions. Consequently, more work will be performed in RJ (Hochmuth & Marhold, 1978). According to these observations, the potentiation induced by the prestretch, in addition to the reuse of elastic energy, is also favored by the following conditions:
Figure 1 — Examples of ground reaction force recorded in rebound (RJ) and no-rebound (NRJ) jumps. Recordings in RJ and NRJ have been adjusted in time so that the time of zero vertical velocity in each case refers to the abscissa. In NRJ, the force rises slowly since a certain amount of time is required to stretch the SEE. On the other hand, in RJ the tension developed by the CE is already very high at the beginning of the positive work. From “The effect of pre-stretch on mechanical efficiency of human skeletal muscle” by C. Bosco et al., 1987, Acta Physiologica Scandinavica, 131, p. 326.

- The prestretch allows the muscles to build up a high level of active state at the beginning of the positive work (e.g., Bosco & Viitasalo, 1982).
- A high level of initial force allows the muscle to produce more work in the first part of the shortening distance (Hochmuth, 1960; Hochmuth & Marhold, 1978).

As for the second point, the authors write, “First of all, the amount of energy stored in series elastic elements at the start of the concentric phase is not determined by the amount of ‘negative work’ performed but solely by the force at the start of push-off” (p. 392). In 1982, Bosco et al. (1982b) pointed out that the “amount of elastic energy stored in the muscle during the eccentric work can be represented by the force developed at the end of the stretch (−Fi) which coincides with the force at the start of the push in CMJ” (p. 347).

The third point deals with the efficiency of negative work. Ingen Schenau et al. write that “Perhaps, as previously suggested (Ingen Schenau, 1984), the SSC helps to avoid a waste of ATP in taking up the slack of muscle fibers, which seems to occur in concentric contractions not preceded by an eccentric phase (Goldspink, 1978)” (p. 402). Cavagna (1977) and Bosco (1982) had already suggested, prior to Ingen Schenau (1984), that the increased efficiency in rebound jumps and generally in SSC exercises is also due to the fact that previous stretching decreases the time in which positive work is done during the subsequent shortening. It follows that to perform a given amount of work, the muscles remain active for a shorter time, as demonstrated by the negative relationship between mechanical efficiency and the time to perform positive work (Figure 2).

My fourth point is that higher mechanical efficiency observed during rebound jumps (27.8%) compared to simple positive work (17.2%) has been attributed not only to the reuse of elastic energy, which was calculated to be only 10% of the total extra work output, but also to other factors (Bosco et al., 1987). One of these factors might be the dif-