 dólares, respectivamente; esto es, la potenciación contractil fue significativa bajo estas condiciones. Se especuló que la potenciación contractil, precomienzo, es un aspecto significativo del rendimiento esquelético en el movimiento isocinético. Sin embargo, también se sugirió que el alineamiento de la actividad muscular antes de la liberación sería significativamente mayor que aquello que permitiría a la musculatura alcanzar un estado activo más alto durante la fase inicial de la contracción concentrica (18).

Se estudiaron preparaciones musculares aisladas para aclarar los efectos de la estiramiento precodificado en las diferencias en el rendimiento de la contracción elástica, e incluso las contribuciones de otros procesos. Se ha reconocido que permitir a un músculo alcanzar un estado de activación más alto antes de la liberación permitiría un aumento significativamente mayor del rendimiento del trabajo muscular durante la fase inicial de la contracción concentrica (18).

Se encontró que la potenciación contractil es importante para el rendimiento de la contracción concentrica. Bobbert et al. (6) concluyeron que el rendimiento de la contracción concentrica se relaciona de manera más fuerte con el estado activo del músculo antes de la liberación, independientemente de las contribuciones de los procesos de potenciación previos. Se sugirió que la potenciación contractil que aparece durante la fase de potenciación contractil puede ser el resultado de la potenciación contractil, precomienzo, en el músculo durante la fase inicial de la contracción concentrica (18).

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METHODS

Subjects

Forty male subjects with a minimum of 12 mo of weight-training experience and an ability to squat a load of at least 1.5 times their body mass were recruited as subjects. All subjects were drawn from a variety of sporting backgrounds, which predominantly involved the lower body. Their mean age, height, and weight were 23 ± 1 yr, 179 ± 3 cm, and 77.2 ± 7.1 kg, respectively. Before testing, all subjects attended a familiarization session, which involved the performance of all test items. The study was approved by the Ethics Committee of Southern Cross University, and each subject signed a written consent form before participation in the project.

Overview of Testing Protocol

All tests were performed in a single session, and subjects were asked to refrain from all lower body training for the 3 days before testing. Before each session, a standardized warm-up was employed. It consisted of a 10-min stationary cycle at 60 W and then specific lower body stretches, followed by two sets of 10 repetitions of full squats with a 20-kg bar. To isolate any difference muscular contraction history may have on concentric work output, each subject was required to perform three separate isokinetic squats for which a common concentric movement pattern was employed. These were 1) a concentric-only (CO) squat, 2) a concentric-squat preceded by an isometric preload (IS), and 3) a stretch-shorten cycle (SSC) squat. The isokinetic modality allowed for an effective comparison among tests, by minimizing differences in muscle shortening velocity and thus muscle lengths over each specified time frame. For all subjects, surface electromyograms (EMGs) for vastus medialis, vastus lateralis, and biceps femoris were collected during all the squat tests. The choice of single-joint quadriceps muscles reflected the need to isolate those musculotendinous units (MTUs) with relatively large length changes and hence the greatest potential for stretch-induced myoelectric response. To assess the contribution of muscles crossing the hip and ankle, surface EMGs for gluteus maximus, rectus femoris, and medial gastrocnemius were also recorded for 10 subjects (30). To serve as control items for both subject performance and EMG analysis, subjects also performed a standard countermovement jump (CMJ) and a maximal voluntary isometric contraction (MVIC) of the muscles for which EMG was recorded. These data were collected immediately before the first squat test, and within 3 min after the last squat test was finished. All relevant kinetic and kinematic data were displayed and recorded in real time by using the AMLAB system (Amlab International, Sydney, Australia), and calibration of all equipment was performed before all testing sessions.

Test Items

Squat tests. All squats were performed on an isokinetic squat device (ISD), which was positioned directly over a force plate (type 9287, Kistler, Winterthur, Switzerland). At the start of each test, the charge amplifiers (type 9865A, Kistler) were reset to zero to negate the weight of the subject. The recording of force data commenced via a manual trigger before the start of each test. These data, sampled at a rate of 1,000 Hz, were collected for –3–5 s, and the amplified voltage signal was transferred to an AMLAB System and stored to disk for analysis. The force platform was calibrated for vertical forces by placing a series of known weights on the plate and adjusting the calibration factor accordingly.

The ISD is a testing device that allows for standardized performance of the squat exercise by limiting movement to the frontal and sagittal plane while recording relevant kinetic data (Fig. 1). The ISD consisted of a Plyometric power system (PPS; Lismore, Australia; see Wilson et al. (33) for a full description), which was subsequently modified to allow it to function as a multijoint isokinetic dynamometer. The PPS was instrumented with a three-phase 4-kW motor, which was governed by an alternating current induction controller (PDL Electronic, Napier, New Zealand). A rotary encoder attached to the shaft of the motor provided the velocity feedback for the closed-loop system with the PDL controller. The response time of this system, i.e., zero to maximum torque, was achieved in under 10 ms. It provided standard bar acceleration of 2,200%/s² of the maximum motor speed of 1,440 revolutions/min such that the time to criterion bar velocity (~200 ms) was limited only by the subject’s individual performance. Bar-displacement data were provided by means of a rotational transducer (CelESCO) fixed to the shaft of the PPS. It was calibrated by moving the bar through a known distance and adjusting the calibration gain as necessary.

Bar speed was set at a constant 0.40 m/s during all tests, based on the mean bar speed of a typical squat movement (24). The isokinetic protocol was used in order that, for a given time, muscle length changes occurring as a result of the movement would be somewhat similar across tests and their influence on contractile performance thus controlled. However, as with all in vivo isokinetic evaluations, there is a period of acceleration before the onset of the criterion velocity, with some associated impact artifact that cannot be controlled without excessive ramping of the acceleration speed. Because the shortening speed of the musculature for the acceleration phase of the movement would be different across the tests, it would be reasonable to expect that the isokinetic evaluation was influenced by small differences in muscle lengths. To maintain consistency of hip, knee, and ankle angles for the starting position for the CO and IS tests, and for the turnaround point for the SSC test, foot position was standardized by means of a marker cemented to the surface of the force plate. Subjects were positioned on the marker with a corresponding knee angle of 90° as measured with a manual goniometer. This knee angle was chosen because it has been reported as typical of those used in other studies (8) designed to assess functional lower body performance. Additionally, pilot testing revealed that the ability to generate force in this position was somewhat compromised because of the mechanical disadvantage of this knee angle. This was seen as important because it reduced the stress placed on the lower back of the subjects and possibly reduced the risk of back injury. To eliminate any possible contribution from prior muscle action, as a consequence of unloading or excessive preforce, force traces were examined immediately after testing and the trial was rejected if force levels deviated by >80 N above or below the desired level. The order of testing was mixed for all subjects; however, because the IS squats required the transitional force data from SSC test, the IS squats were always performed after the SSC test. For all squat tests, subjects performed three trials with at least 3–5 min between trials and 5–8 min between tests.

CO SQUAT (CO). To determine the ability to generate force in a concentric movement, subjects performed an isokinetic squat for which only upward bar movement was allowed. Based on a technique previously described with respect to static jumps (32), the subject was restricted from utilizing any significant prestretch before the start of the tests by engaging the bottom stops of the ISD. This prevented downward movement of the bar. Subjects were instructed to exert
force as hard and fast as possible (4) in the vertical plane, and
the test was repeated if pretension due to pressure on the bar
exceeded 80 N in excess of subject's body weight. Thus the
protocol did require subjects to maintain an isometric contrac-
tion to a level equivalent to body mass for a brief period (<1.5
s) before the start of the test.

SSC SQUAT. To assess the relative contribution of prestretch
to dynamic movement, subjects performed an isokinetic squat
preceded by a ballistic countermovement. With respect to
concentric bar speed, this test was identical to the CO and IS
tests and differed only in that subjects commenced the
movement with the addition of an active stretch of the lower
body musculature. To achieve this, software was used to
disable the isokinetic mode of the ISD during the eccentric
phase of the tests. As soon as the subject commenced upward
movement, the isokinetic mode was automatically reengaged.
A dynamic prestretch was a prerequisite for the validity of
this test. To achieve this, subjects were instructed to perform
the eccentric movement as fast as possible. To maintain the
accuracy of the 90° knee joint angle turnaround point (±3°),
an auditory pretrigger controlled via software signaled to the
subject to cease downward movement and immediately com-
mence the concentric phase of the squat. If the subject did not
satisfy these criteria, the test was repeated. Specific to each
subject, the offset for the pretrigger was determined during
the familiarization sessions and was used to account for the
delay in turnaround resulting from individual reaction times and system momentum.

IS SQUAT. To address the issue of the effect of pretension
subsequent to muscle shortening, an isokinetic concentric
squat was preceded by an isometric contraction. This was
accomplished by using software to switch the ISD from
isometric to isokinetic mode and was solely dependent on the
subject achieving a preset level of force as measured via the
force plate. Subjects were asked to exert force as hard and fast
as possible (4) against the bar, which remained stationary
(typically between 100–200 ms), until it automatically
switched to isokinetic mode. At this point, subjects continued
exerting maximal force for the duration of the concentric
movement. The release force was individually determined
from the mean transitional force at the 90° knee joint angle
turnaround point during the three SSC tests.

At this point it must be noted that isokinetic bar speed does
not necessarily imply isokinetic muscle shortening. The influ-
ence of muscle and skeletal architecture in multijoint move-
ments will result in angular accelerations and decelerations
of the hip, knee, and ankle joints with corresponding muscletendon length changes. Particularly at the onset of concentric
movement of the bar, it is unlikely that all muscles will begin
to shorten at the same time. However, such effects on testing
were reduced by attempting to normalize body position at the
start of the concentric phase.

Control Items

CMJ. To determine the extent of localized muscular fatigue
as a consequence of the rigorous lower body testing protocol
employed, all subjects were required to perform a standard
CMJ before and after testing (31). For the CMJ, all subjects
were required to perform three trials with 3 min of rest
between trials. Maximum jump height was recorded by using
a VerTec gauge (Questec, Northridge, CA). Starting position
for the CMJ required the subjects to place their hands on their hips and to retain this position until the end of the concentric phase of the jump. At this point they were allowed to raise their hand to displace the sliding bars of the VerTec. This procedure ensured that the contribution to performance from arm swing was negligible. For all jumping trials, subjects were instructed to jump for maximum height. MVIC. MVIC of the muscles chosen for EMG analysis was also used to assess the integrity of the subjects' muscular condition and electrode-skin interface during testing. MVICs were conducted before and after the squat testing sessions, and subjects were required to perform a series of MVICs with as much effort as physically possible. They maintained each individual contraction for at least 4 s, during which time a 500-ms segment of maximal muscular activation was randomly recorded for further analysis.

EMG

Before application of the electrodes, the surfaces were shaved, cleansed with alcohol, and mildly abraded, and a small amount of conductive gel was applied onto the electrode contact face. Pairs of silver-plated surface electrodes with a bipolar configuration were positioned parallel to the muscle fibers over the apparent belly of the muscles. The electrodes were taped and bandaged in position, to limit movement artifact, and remained untouched throughout the testing session. The EMG signal was fed directly into the alternating current-coupled input channels of the AMLAB system, which converted the analog signal to digital at 1,000 Hz. Software within AMLAB was used for the filtering of the EMG data. All signals were fed through a band-pass second-order Butterworth filter with high- and low-pass filters set at 3 and 500 Hz, respectively. The attenuation above the high-frequency corner and below the low-frequency corner was 12 dB/octave (40 dB/decade).

Posttest Processing of Data

Data were averaged for all trials and subsequently normalized to the 100-, 200-, 300-, and 500-ms time frames after the start of the concentric movement across all test conditions. For the IS and CO tests, onset of concentric movement was defined as bar displacement of 3 mm. For the SSC test, it was 3 mm above the turnaround point at the end of the eccentric phase. Bar-displacement data were filtered by using a fourth-order Butterworth [cut-off frequency 39 Hz determined according to the methods of Yu and Hay (37)] and used in conjunction with force data to determine mechanical work for all tests. To allow comparisons among conditions and over time frames, EMG data were rectified, integrated, and normalized (i.e., expressed as a percent) to the corresponding period for the CO test (NIEMG). To account for possible influence due to electromechanical delay, a 30-ms offset before concentric bar movement was introduced to the EMG analysis. This epoch was chosen because in all three conditions the muscle-tendon complex was already under tension before shortening (35). All posttest processing was performed on an IBM-compatible Pentium (100 MHz) by using software developed within the Visual Basic 3.0 programming language (Microsoft).

Statistical Methods

The intertrial reliability of all test items was assessed by using two different statistical methodologies: intraclass correlations and the SE of means. The method error was expressed as the coefficient of variation, i.e., equal to the SD of the mean difference in scores, expressed as a percentage of the combined means. Comparisons among the three squat conditions were initially assessed by using a repeated-measures multivariate analysis of variance on all values for the 100-, 200-, 300-, and 500-ms periods after the concentric start. If a significant difference was found, post hoc comparisons were made by using a series of one-way repeated measures analysis of variance, with Helmert contrasts performed with SPSS (version 6.1) statistical analysis software. Statistical significance was accepted for an alpha level of 0.05.

RESULTS

Reliability of Test and Control Items

The intertrial reliability of both the control items and work values are depicted in Table 1. It is evident from these values that all measures show a high degree of repeatability within trials. The coefficient of variation for all of the tests is well within the 15% value recommended for biological measurement (1). On the basis of the similarity between the CMJ and NIEMG values for the MVICs before and after testing, it was assumed that the testing protocol undertaken did not adversely affect the subjects’ performance and that it was reasonable to discount the effects of muscular fatigue on test performance.

Comparison of Isokinetic Squat Tests

Figure 2 depicts the typical force-displacement curves produced by a subject performing the three tests. Bar position at the onset of concentric movement for the CO and IS tests was identical yet was on average 3 ± 3.7 cm lower for the SSC test. Mean force at the start of concentric bar movement for the CO test was 489 ± 131 N, which was significantly (P < 0.001) lower than for the IS and SSC conditions. Comparison of the SSC and IS tests was contingent on the equality of the starting forces. It was subsequently shown that the mean force at the onset of shortening for the SSC and IS tests was 1,193 ± 222 (SD) and 1,169 ± 216 N, respectively, and

<table>
<thead>
<tr>
<th>Test Items</th>
<th>Control Items</th>
</tr>
</thead>
<tbody>
<tr>
<td>CMJ height</td>
<td>2.83 (0.91)</td>
</tr>
<tr>
<td>NIEMG GM</td>
<td>5.2 (0.89)</td>
</tr>
<tr>
<td>BF</td>
<td>8.8 (0.76)</td>
</tr>
<tr>
<td>VM</td>
<td>6.9 (0.80)</td>
</tr>
<tr>
<td>VL</td>
<td>10.1 (0.79)</td>
</tr>
<tr>
<td>RF</td>
<td>6.3 (0.83)</td>
</tr>
<tr>
<td>MG</td>
<td>5.7 (0.88)</td>
</tr>
<tr>
<td>Work</td>
<td></td>
</tr>
<tr>
<td>0–100 ms</td>
<td>9.7 (0.76)</td>
</tr>
<tr>
<td>0–200 ms</td>
<td>6.0 (0.85)</td>
</tr>
<tr>
<td>0–300 ms</td>
<td>5.3 (0.89)</td>
</tr>
<tr>
<td>0–500 ms</td>
<td>5.1 (0.88)</td>
</tr>
<tr>
<td>100–200 ms</td>
<td>8.8 (0.70)</td>
</tr>
<tr>
<td>200–300 ms</td>
<td>5.4 (0.83)</td>
</tr>
<tr>
<td>300–500 ms</td>
<td>5.0 (0.66)</td>
</tr>
<tr>
<td>500–600 ms</td>
<td>4.3 (0.92)</td>
</tr>
<tr>
<td>600–700 ms</td>
<td>5.9 (0.86)</td>
</tr>
</tbody>
</table>

Values are coefficients of variation with intraclass correlation in parentheses. CO, concentric-only squat; IS, isometric squat; SSC, stretch-shorten cycle squat; CMJ, countermovement jump; NIEMG, normalized integrated EMG; GM, gluteus maximus; BF, biceps femoris; VM, vastus medialis; VL, vastus lateralis; RF, rectus femoris; MG, medial gastrocnemius.
there was no significant difference (P = 0.37) between these values. When the mechanical work output for the three conditions was compared, it was observed that both the IS and SSC conditions resulted in significantly greater muscular performance for the first 300 ms of the concentric phase compared with the CO squat (Table 2). Analysis also revealed that, if the squat was preceded by an active stretch rather than an isometric contraction, the subjects were initially able to produce more work, and these effects were seen over the first 300 ms of the concentric movement. Furthermore, if the mechanical work transients for each condition are examined (Fig. 3), it is clearly evident that, as a relative percentage of the total work, any early benefits from the active stretch and/or isometric preload are greatly reduced after the first 200–300 ms of the concentric action.

**Table 2. Work for all tests over respective time frames**

<table>
<thead>
<tr>
<th></th>
<th>CO Test</th>
<th>IS Test</th>
<th>SSC Test</th>
</tr>
</thead>
<tbody>
<tr>
<td>Work 0–100 ms post*†‡</td>
<td>20.2 ± 6.5</td>
<td>31.8 ± 7.9</td>
<td>39.6 ± 13.3</td>
</tr>
<tr>
<td>Work 0–200 ms post*†‡</td>
<td>69.9 ± 18.8</td>
<td>87.0 ± 20.2</td>
<td>97.9 ± 23.1</td>
</tr>
<tr>
<td>Work 0–300 ms post*†§</td>
<td>129.7 ± 34.4</td>
<td>147.9 ± 34.7</td>
<td>154.8 ± 39.8</td>
</tr>
<tr>
<td>Work 0–500 ms post</td>
<td>268.9 ± 72.9</td>
<td>282.1 ± 73.6</td>
<td>280.2 ± 76.6</td>
</tr>
</tbody>
</table>

Values are means ± SD given in J. Post, after start of concentric movement. *CO significantly different vs. IS, P < 0.001. †CO significantly different vs. SSC, P < 0.001. ‡IS significantly different vs. SSC, P < 0.001. §IS significantly different vs. SSC, P < 0.05.

**DISCUSSION**

The importance of pretension, before muscle shortening during in vivo research, has been repeatedly demon-
Regardless of contraction history, if the concentric movement begins from a relatively higher level of force, our results show that this will add to the mechanical work of the muscles measured during the first 300 ms of shortening. This finding is supported by earlier research in isokinetic assessment (21, 28). These studies reported that concentric movements that were immediately preceded by either isometric or eccentric contractions led to greater concentric torque output than did purely concentric actions and that this effect was greatest early in the range of motion of the muscle(s) being tested. With regard to the present movement pattern, it has been suggested that higher levels of muscle activation earlier in the movement will allow the muscles to produce greater force over a range of joint angles considered more favorable in terms of optimizing performance during these types of actions (6, 14).

However, our results also reveal that, whereas the level of force before the concentric phase of a multijoint movement is an important factor in determining subsequent performance, the manner in which this force is achieved must also be considered. An eccentric loading of the musculature resulted in significantly greater gains in performance than was evident as a consequence of preforce alone. Comparison of the SSC and IS tests shows that, for at least the first 200 ms of the squat, mechanical work was also dependent on the type of contraction preceding concentric bar movement. The following discussion will focus on the interpretation of these findings in relation to current theories on work enhancement due to active stretch of the musculature.

Intermuscular Coordination

For multijoint tasks, optimal performance is not merely constrained by the net force released by the MTUs, which are used to generate the movement. A specific pattern of intermuscular coordination is also necessary to effectively utilize the work capacity of the

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**Fig. 4.** Power-time curves from 1 representative subject for SSC squat test, IS squat test, and CO squat test.

**Fig. 5.** Normalized integrated EMG for each muscle group, for respective time frames, before (pre) and after (post) start of concentric bar movement. (see METHODS for full explanation and subject numbers). Values are means ± SD expressed as percentage of corresponding value for CO condition. A: gluteus maximus; B: biceps femoris; C: rectus femoris; D: vastus medialis; E: vastus lateralis; F: medial gastrocnemius.
muscles under these conditions (30). For the concentric portion of the tests, examination of the NIEMG data presented in Fig. 5, A–F, reveals that there was no significant difference among either the SSC, IS, or CO conditions. Figure 5 also shows that all muscles maintained a consistently high level of muscle activation for the duration of the assessment. The observed similarity of the concentric phase of the three tests presumably reflects the specific demands of the task.

In trained jumpers, a temporally ordered, proximal-to-distal sequence of muscle activation for the lower extremity musculature has been observed. This firing pattern coincides with the coactivation of mono- and biarticular muscles, which provides an effective mechanical framework for the transportation of energy delivered by this recruitment strategy. The end result is a coupling of joint powers such that vertical jumping performance is optimized and inappropriate acceleration of hip and knee joints is minimized (30). In this test, even though a similar posture to jumping was used, the movement speed of the bar was strictly controlled. This would effectively limit the angular acceleration of hip, knee, and ankle joints, a restriction that permitted simultaneous and near-maximal activation for all the muscles tested, regardless of the type of action that preceded the concentric movement. While small differences in activation patterns among the tests cannot be discounted, there is no evidence to support the notion that the enhanced performance of the SSC squat was due to changes in activation patterns for any of the muscles assessed.

Myoelectric Contributions

When jumps with and without prior stretch are compared, the greater jump height that is often observed in the prestretch jump may be accompanied by enhanced muscle activation, attributable to the rapid stretch of intrafusal muscle fibers and the resultant α-afferent activation (8). The latency of the reflex response determines whether the augmentation to improved jump height is the result of direct contributions to the motorneuron pool or of increases in extrinsic muscular stiffness leading to an improved capacity to benefit from storage of potential elastic energy (8, 22). In some cases, it has been suggested that the myoelectric responses account for up to 85% of the increase in jump height after a countermovement (22).

Some doubts as to the importance of the stretch reflex have been raised by similar studies that report no difference in EMG recordings attributable to active stretch of the musculature (9, 27, 36). Such studies discount the effects of the stretch reflex on the basis of a saturation phenomenon, whereby, at maximal levels of contraction, the muscles become less responsive to brief increases in neural output (27, 36). Specifically, when comparing EMG activity for isokinetic knee extension tests across concentric, isometric preload and maximal eccentric contraction conditions, Svantesson et al. (28) reported unchanged or lower values when the movement was preceded by a muscle action. In the present study, the lack of significant differences among NIEMG values among the tests would tend to suggest that, for the muscle groups tested, the contribution from myoelectric mechanisms to the superior work output for the SSC test was minimal.

Restitution of Elastic Strain Energy

The contribution of elastic strain energy to the improved muscular performance of the IS and SSC tests, relative to the CO test, cannot be discounted on the basis of the present findings. The attainment of forces in excess of 1,000 N before shortening for these experiments, which was over twice that measured for the CO squat, would result in significantly greater extension of the series elastic elements (SEEs) (2, 17). At the onset of shortening, elastic recoil of these elements would presumably add to the work output of the muscle-tendon complexes involved in these actions. However, it is impossible to determine its relative contribution for the different conditions.

Cavagna et al. (9, 10) and Bergel et al. (5) reported cases in which they were able to obtain equivalent forces before muscle shortening after both active stretch and isometric contractions. They claimed that this would invoke identical extension of the SEEs and thus the amount of energy stored within these components would be the same. Accordingly, in this series of experiments, the observed differences between the SSC and IS conditions cannot be explained by enhanced elastic energy release attributable to differences in force. With <2% separating the mean transitional forces for these tests, the effects of elastic recoil would be effectively limited between the conditions.

Nonetheless, a potential difference in the use of elastic strain energy may be explained by the concept of resonance. A number of authors have reported that maximal use of elastic strain energy occurs when the natural frequency of the MTU is equal to the movement frequency of the SSC action and hence the system is in resonance (3, 34). In essence, the concept of resonance suggests that elastic systems have a preferred rate of stretch in which optimal use of strain energy is achieved. This may contribute to both force output and/or the efficiency of energy consumption (3). Thus the use of elastic strain energy in a dynamic system is dependent not only on the extension of the SEE but also on the rate at which this extension occurs. The duration of the eccentric phase of the SSC test ranged between 500 and 800 ms, much longer than the 100–300 ms typically required to achieve the desired transition force for the IS test. Because this was an aspect of testing that was not controlled between the IS and SSC conditions, it is conceivable that the difference in the initial concentric performance enhancement may be explained, to some extent, by the SSC action involving a rate of SEE extension that was closer to achieving resonance compared with the IS condition.

Interaction Effects of Tendinous Recoil on Contractile Dynamics

It has been shown that the contribution of the contractile element to work production during SSC move-
ments is influenced by the effects of tendinous recoil 
(16, 17, 20). Higher forces at the onset of shortening for 
the IS and SSC squats relative to the CO test would 
introduce differences in both fiber length and fiber 
shortening velocity during the subsequent contraction 
(12, 16). Assuming that the similarity in the concentric 
starting point across the tests resulted in compar- 
atively equal MTU lengths, the additional force present 
at the start of the IS and SSC tests would mean 
relatively greater tendinous extension with less myofi-
brillar displacement (2). Thus there exists the potential 
for the fibers in the SSC and IS squats to have been 
displaced less and thus be operating closer to an 
optimal length.

A similar argument is also feasible with respect to 
muscle force-velocity characteristics. The recoil of tendi-
nous structure, associated with the release of elastic 
energy for the IS and SSC squats, would suggest that 
the velocity of CE shortening would be relatively lower 
with corresponding enhancement to force production. 
This contrasts with the situation during the CO test, in 
which a higher velocity of CE element shortening may 
have occurred initially to extend the elastic elements of 
the SEE. Hence the force-velocity relationship would 
dictate that force production of the CE would be com-
promised. In comparison, the SSC and IS squats com-
mented with similar transitional forces. Assuming that 
a constant bar velocity also translated to similar CE 
shortening velocities across the SSC and IS conditions, 
it is difficult to explain the SSC-IS difference solely on 
the basis of different CE velocities.

Potentiation of the Contractile Element

The nature of the differences between the SSC and IS 
tests led to the hypothesis that the improved capacity 
for mechanical work, as a result of the stretch, was 
primarily due to the enhanced performance of the CE. 
These findings support earlier experiments conducted 
on intact muscle-tendon complexes (9, 12), isolated 
amphibian and rat muscles (9, 16, 17), and single 
muscle fibers (15, 26). This interpretation is based on 
the regulation of force levels across the present tests, 
which is thought to rule out any discussion based on 
difference in elastic potential energy (5) as well as 
differences due to the interaction of SEE and CE at the 
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The results of this study clearly reinforce the importance of contraction history before muscle shortening. When distinguishing between the concentric and pre-force (SSC and IS) tests, it was not possible to delineate the contribution of force alone from those mechanisms that arise as a direct result of the applied force. Therefore, it was concluded that higher transitional force at the commencement of the concentric movement in the preforce conditions may have elicited greater positive work due to a combination of several factors. These included a relatively greater active muscle state, the restitution of elastic strain energy, and the effects of tendon recoil on muscle-tendon interaction. There appeared to be minimal influence from stretch-induced reflex activity. Nevertheless, the importance of pretension does present the opportunity for more discriminate assessment of athletic function, with a view to improving both the performance and training of these movements.

The present findings also suggest that CE potentiation may contribute significantly to stretch-induced work enhancement during multijoint SSC movements, particularly if the duration of the concentric phase of these contractions is under 300 ms. While these results provide functional evidence in support of those findings previously described with respect to in vitro research, there is a need for a more detailed investigation into the practical relevance of such mechanisms. In particular, it would be worthwhile to examine the response of CE potentiation to training stimuli as well as examine its relationship to eccentric muscle length in vivo.

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