Musculotendinous stiffness: its relationship to eccentric, isometric, and concentric performance

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Wilson, Greg J., Aron J. Murphy, and John F. Pryor. Musculotendinous stiffness: its relationship to eccentric, isometric, and concentric performance. J. Appl. Physiol. 76(6): 2714-2719, 1994. The purpose of this study was to quantify the relationship between musculotendinous stiffness and performance in eccentric, isometric, and concentric activities. Thirteen trained subjects performed a series of maximal effort eccentric, concentric, and isometric muscular contractions in a bench press-type movement. Additionally, subjects performed a series of quasi-static muscular contractions in a bench press movement. A brief perturbation was applied to the bar while these isometric efforts were maintained, and the resulting damped oscillations provided data pertaining to each subject’s musculotendinous stiffness. Musculotendinous stiffness was significantly related to isometric and concentric performance (r = 0.57-0.78) but not to eccentric performance. These results are interpreted as demonstrating that the optimal musculotendinous stiffness for maximum concentric and isometric activities was toward the stiff end of the elasticity continuum. A stiffer musculotendinous unit may facilitate such performances by improving the force production capabilities of the contractile component, due to a combination of improved length and rate of shortening, and additionally by enhancing initial force transmission.

performance enhancement; muscle mechanics; muscle elasticity; stretch shortening cycle; muscular injuries

THE ELASTICITY of the muscle and tendons has been demonstrated to significantly effect performance in stretch shortening cycle (SSC) movements (20, 22) and implicated as an important factor in the occurrence of muscular injury (23). Previous research into the elastic properties of the musculotendinous system has revealed that a highly compliant elastic system increased the use of elastic strain energy in SSC movements, such as the bench press (22). Furthermore, it has been observed that increasing the compliance of the musculotendinous unit, through flexibility training, increased the contribution of elastic strain energy to movement, facilitating performance in an SSC movement (20).

However, a paucity of in vivo research data exists examining the relationship between the stiffness of the musculotendinous system and the performance of eccentric, isometric, or concentric movements. Wood et al. (24) performed a strength training study that resulted in a significant reduction in the compliance of the musculotendinous unit and an improvement in the rate of concentric torque development in a knee extension action. However, the relationship between these variables was not quantified. Wilson et al. (22) compared the concentric power time profiles of a purely concentric bench press movement between subjects who were very stiff and those who were compliant. They reported that the stiff subjects initially produced a faster rate of power production than the compliant subjects. This observation was rationalized by Wilson et al., who suggested that a compliant musculotendinous unit allowed a faster shortening of the contractile components than a stiffer musculotendinous unit, which served to depress force due to the force-velocity relationship. Presumably such a mechanism would also effect isometric force production.

During an isometric contraction the contractile component contracts as the musculotendinous unit extends. The extent and the rate of contractile component shortening are proportional to the magnitude of the muscular contraction and the stiffness of the musculotendinous unit. Conceptually a stiffer musculotendinous unit would enhance isometric or concentric force production compared with a more compliant system, not only due to a reduced contractile component shortening velocity but also to a relatively longer length of the contractile component throughout the contraction. Furthermore, the musculotendinous unit represents the link between the skeletal system and the contractile component of the muscles, and as such its stiffness will, to some extent, determine how effectively and rapidly internal forces generated by the contractile component are transmitted through to the skeletal system.

Although logical arguments can be developed that suggest a strong relationship between the stiffness of the musculotendinous unit and performance in concentric or isometric activities, limited research data are available on this subject. Consequently, the purpose of this research was to quantify the relationship between the stiffness of the musculotendinous system and performance in eccentric, isometric, and concentric contractions.

METHODS

Subjects

Thirteen male subjects, with a minimum of 1 yr of weight training experience and an ability to bench press a load at least equivalent to their own body mass, participated in this study. The subjects were all involved in recreational sports, and their age, height, body mass, years of training, and maximum bench press were 23.4 ± 4.1 yr, 178.4 ± 7.3 cm, 81.1 ± 9.1 kg, and 102.3 ± 14.8 kg, respectively. The study was approved by the Ethics Committee of the University of New England, Northern Rivers, and each subject signed a written consent form before participation in the project.

Testing Protocol

Before the initial testing, subjects participated in a familiarization session that involved the performance of all test items. Testing was performed on 2 separate days within a 1-wk period. Subjects were given a minimum of 72 h of rest between each
test day and were instructed to abstain from their normal upper body training for the duration of testing.

On the first testing occasion each subject’s maximum bench press was determined by using the procedures of Wilson et al. (20). This test involved the performance of the bench press exercise with progressively increasing loads until the maximum was achieved, and it was administered to allow other test items to be performed at loads relative to the maximum. Additionally, on the first testing day, the stiffness of the musculotendinous unit was determined with an oscillation technique for the following loads: 15, 30, 45, 60, and 70% of maximum.

On the second testing occasion the eccentric, isometric, and concentric performance tests were administered. These tests included 1) an eccentric test performed in a bench press movement with a load of 130% of the maximum bench press lift, 2) a maximal purely concentric bench press at a load of 30% of maximum, and 3) a maximal isometric test in a bench press position at an elbow angle of 120°. To control for possible order effects the order of the eccentric, concentric, and isometric tests was completely randomized.

All participants performed their normal warm-up and stretching before the commencement of each testing session. For the musculotendinous stiffness tests, three trials were performed at each load, and for the eccentric, isometric, and concentric performance tests, two trials were performed. In both cases the results were averaged. Only one trial was performed for the maximum bench press, as is standard for this test (6, 20). A 3-min rest period was imposed between repeat trials and tests.

Performance Tests

The eccentric, isometric, and concentric tests were performed in a bench press-type movement with the Plyometric Power System (Plyopower Technologies, Lismore, Australia), which was positioned over a bench that was secured into a force platform (model 9287, Kistler, Winterthur, Switzerland). The Plyometric Power System is a testing device that allows for the safe performance of bench press throws while recording relevant kinematic data (21). For all tests the subjects were instructed to keep their feet on the bench. Hand position on the bar was standardized as the distance between the elbows with the shoulder complex abducted to 90°.

Eccentric test. Subjects lay on a horizontal bench in a bench press position with the bar set at a height directly above the chest so that the elbow angle was 120°. The electromagnetic brake of the Plyometric Power System held the bar, loaded to 130% of the one repetition maximum, at this position. Subjects were instructed to make contact with the bar but not to exert force until they were given the auditory signal that the brake was to be released. Once the bar was released the subjects resisted the accelerating load as quickly and with as much force as possible. The load was prevented from descending past the subject’s 90° elbow angle by the mechanical stops of the Plyometric Power System.

Concentric test. Subjects lay in the bench press position with the 30% of maximum load held above the chest by the mechanical stops of the Plyometric Power System at a height that represented an elbow angle of 90°. Subjects were instructed to apply force as quickly as possible and throw the bar for maximum height. At maximum height the bar was halted by the electromagnetic braking mechanism of the Plyometric Power System. Isometric test. The isometric test was performed in the same manner as the eccentric and concentric tests with the exception that the bar was fixed at a height that represented an elbow angle of 120°. Subjects were instructed to apply force as quickly as possible (5) for ~3 s. The 120° elbow angle was chosen as it was within the ranges in which maximum force and maximum rate of force development occurred in the eccentric and concentric tests.

The force outputs throughout the eccentric, isometric, and concentric actions were recorded for each trial by use of a force platform. These data were used to determine the maximum force produced and the maximum rate of force development, using the procedures of Viitasalo et al. (19). During the concentric performance test, the maximum heights of the throws were recorded by the Plyometric Power System.

Determination of Musculotendinous Stiffness

The determination of the stiffness of the musculotendinous unit was achieved using the identical procedures recently outlined in detail by Wilson et al. (20, 22). Briefly, this procedure involved an oscillation technique whereby the subjects maintained a loaded bar in an isometric bench press action ~3 cm above the chest. The subjects held the bar steady in this position for ~0.6 s, after which an external force of ~100 N was briefly (150-200 ms) applied to the middle of the bar by a downward push of the experimenter’s hands. Such a procedure to perturbate the system has been used by Shorten (17) and Wilson et al. (20, 22). It does result in a slight variation in the magnitude of the perturbation between trials; however, this is not observed to vary the stiffness values obtained, as an elastic system will oscillate at its natural frequency independent of the magnitude of the applied perturbation. The resulting damped oscillations (Fig. 1) were recorded by a force plate and modeled by a second-order linear equation of the form

$$m \frac{d^2x}{dt^2} + c \frac{dx}{dt} + kx = mg$$

where \(x\) is the position, \(g\) is the gravitational acceleration, and \(m\) is the mass of the bar-weights system. The stiffness \(k\) of the system is determined by

$$k = 4m\omega^2 + c^2/4m$$

The damped natural frequency \(\omega\) was quantified as the inverse of the period between successive force peaks (Fig. 1). The damping ratio \(\zeta\) was determined by plotting the natural log of peak forces against time and obtaining the slope of the line. The damping coefficient \(c\) was then calculated by

$$c = 4\pi f_0 \zeta$$

where the natural frequency \(f_0 = (\sqrt{1/\zeta})^{-1}\).

The subjects were instructed to maintain a constant level of muscular activity and not to respond to the perturbation during the oscillation of the bar. This “do not intervene” strategy has been used previously in an attempt to limit the neural re-
various performance measurements with a factorial design who possessed the stiffest musculotendinous units and the five-duct-moment correlations were performed. The five subjects accepted at an a level of 0.05.

most compliant subjects were compared for differences in stiffness and the performance measurements, Pearson product-moment correlations and the various performance tests through a rigid bench served to hold the bar in a stationary position at any point in the 2.8-m range of motion. The system was calibrated before use by measuring the total number of pulses produced as the bar was moved through its full vertical range (2.8 m). The system also incorporates an electromagnetic braking unit that when engaged prevents attenuation of the developed forces. At the start of each test the force plate was reset to zero to negate the weight of the subject and the bench. This allowed for a more sensitive recording of the force produced during the tests. The recording software calculates the height thrown and the work done (m \times g \times height). The system was calibrated before use by measuring the total number of pulses produced as the bar was moved through its full vertical range (2.8 m). The system also incorporates an electromagnetic braking unit that when engaged prevents attenuation of the developed forces. At the start of each test the force plate was reset to zero to negate the weight of the subject and the bench. This allowed for a more sensitive recording of the force produced during the tests. The recording software calculates the height thrown and the work done (m \times g \times height).

Equipment

Plyometric Power System. The isometric, eccentric, and concentric performance tests involved the use of the Plyometric Power System. This device enables subjects to safely perform dynamic throws with a loaded bar while relevant kinematic data are recorded at -3,000 Hz (21). The machine only allows vertical movements of the bar, and mechanical stops permit the maximum and minimum height of the bar to be controlled with an accuracy of 0.02 m. The use of linear bearings, which are attached to either end of the bar, allows the bar to slide about two hardened axle steel shafts with low friction. A rotary encoder attached to the machine produces pulses indicating the displacement of the bar. One pulse is generated for each 0.00106 m of bar movement. Each pulse is recorded by a counter timer board installed in a 386DX IBM-compatible computer that is capable of measuring pulse frequencies up to 1 MHz. The above information is recorded by the computer, and software calculates the height thrown and the work done (m \times g \times height). The system was calibrated before use by measuring the total number of pulses produced as the bar was moved through its full vertical range (2.8 m). The system also incorporates an electromagnetic braking unit that when engaged serves to hold the bar in a stationary position at any point in the 2.8-m range of motion.

Force platform. Vertical force was recorded during the oscillations and the various performance tests through a rigid bench that was secured by four bolts directly into a force platform. The surface of the bench was solid, with negligible padding, to prevent attenuation of the developed forces. At the start of each test the force plate was reset to zero to negate the weight of the subject and the bench. This allowed for a more sensitive recording of the force produced during the tests. The recording of force commenced via a manual trigger before the start of each test. Force data, sampled at a rate of 500 Hz, were collected for 3 s by a DAS16 analog-to-digital card installed in a 386DX IBM compatible computer. The force platform was calibrated before and after each testing session. The kinetic data from the force platform and kinematic data from the Plyometric Power System were simultaneously recorded.

Statistical Methods

Intraclass correlations were used to examine the intraclass reliability of the eccentric, concentric, and isometric tests. To quantify relationships between maximal musculotendinous stiffness and the performance measurements, Pearson product-moment correlations were performed. The five subjects who possessed the stiffest musculotendinous units and the five most compliant subjects were compared for differences in various performance measurements with a factorial design one-way analysis of variance. Statistical significance was accepted at an a level of 0.05.

RESULTS

The reliability of the performance measurements was assessed by an intraclass correlation between the two trials for each test. The coefficients achieved for the various isometric and concentric force variables were between 0.85 and 0.87, which were similar to those previously reported (19, 21). The coefficient for the maximum eccentric force was 0.91, whereas for the eccentric rate of force development the intertrial correlation was only 0.65. The low reliability of the eccentric rate of force development test may be explained, in part, by the novelty of dynamic eccentric tests of upper body muscular function. The intertrial reliability of the height thrown in the concentric test was 0.85, which was similar to that previously reported by Wilson et al. (21) for maximal vertical jumps performed on the Plyometric Power System.

The results of the maximal musculotendinous stiffness and the various performance measurements are outlined for all subjects in Table 1. The maximal musculotendinous stiffness was 10,431.3 \pm 2,832.3 N/m. This value is below that recently outlined by Wilson et al. (20, 22) of \sim 17,000 \pm 4,000 N/m, who used an identical procedure. This disparity is due to the differences in the subjects. The current subjects were substantially weaker and of reduced training experience compared with those of the previous studies. Both the maximum load lifted and the number of training years have been reported to be significantly related with the maximal stiffness of the musculotendinous unit (22). Furthermore, research by Wood et al. (24) and Pousson et al. (14) have demonstrated that the strength training process increased the stiffness of the musculotendinous unit.

The relationships between the maximal stiffness of the musculotendinous unit and the various isometric, eccentric, and concentric performance measurements are outlined in Table 2. The stiffness of the musculotendinous system was significantly related to all of the isometric and most of the concentric performance measurements. In all cases, the relationship between musculotendinous stiffness and concentric and isometric performance was greater for the rate of force development than for the other performance indicators. The stiffness of the musculotendinous unit was not significantly related to eccentric muscular performance.

To examine the effect of stiffness on concentric, eccentric, and isometric performance, the subjects were divided into two groups of five on the basis of their maximal musculotendinous stiffness values. The five stiffest subjects possessed musculotendinous units that were sig-

<table>
<thead>
<tr>
<th>Performance Variable</th>
<th>Value</th>
</tr>
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<tbody>
<tr>
<td>Maximal musculotendinous stiffness, N/m</td>
<td>10,431.3 \pm 2,832.3</td>
</tr>
<tr>
<td>Maximum concentric force, N</td>
<td>893.3 \pm 142.6</td>
</tr>
<tr>
<td>Maximum eccentric force, N</td>
<td>1,200.6 \pm 151.1</td>
</tr>
<tr>
<td>Maximum eccentric RFD, N/s</td>
<td>14,652.5 \pm 3,546.2</td>
</tr>
<tr>
<td>Maximum isometric force, N</td>
<td>1,333.5 \pm 287.2</td>
</tr>
<tr>
<td>Maximum isometric RFD, N/s</td>
<td>12,149.0 \pm 4,734.9</td>
</tr>
</tbody>
</table>

Values are means \pm SD; n = 13 men. RFD, rate of force development.
The stiffness of the musculotendinous unit is significantly related to isometric and concentric performance. This result is contrary to research that has reported higher eccentric forces in comparison to isometric forces (7, 16) or no differences in the eccentric and isometric force levels (1). However, it is similar to the research of Singh and Karpovich (18), who reported that certain angles of elbow extension the maximum isometric force was significantly greater than the maximum eccentric force. To some extent the results of the present analysis probably reflect the fact that the isometric contraction was performed in a higher and more mechanically advantageous force-producing position (elbow angle 120°) than the location in which maximal eccentric force was produced (elbow angle ~100–110°).

TABLE 2. Relationship between maximal musculotendinous stiffness and isometric, eccentric, and concentric performance

<table>
<thead>
<tr>
<th>Performance Variable</th>
<th>Maximal Musculotendinous Stiffness</th>
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<tbody>
<tr>
<td>Maximum concentric force</td>
<td>0.38</td>
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<tr>
<td>Maximum concentric RFD</td>
<td>0.65*</td>
</tr>
<tr>
<td>Work done concentric bench press throw</td>
<td>0.57*</td>
</tr>
<tr>
<td>Maximum eccentric force</td>
<td>0.27</td>
</tr>
<tr>
<td>Maximum eccentric RFD</td>
<td>0.15</td>
</tr>
<tr>
<td>Maximum isometric force</td>
<td>0.63*</td>
</tr>
<tr>
<td>Maximum isometric RFD</td>
<td>0.78†</td>
</tr>
</tbody>
</table>

\( n = 13 \text{ men. Statistically significant: } * P < 0.05; \dagger P < 0.01. \)

The third proposed mechanism that may underlie the strong relationship between musculotendinous stiffness and concentric and isometric performance relates to the fact that the stiffness of the musculotendinous unit will, at least partially, determine the effectiveness of initial force development. The musculotendinous unit represents the link between the skeletal system and the contractile component of the muscles, and as such its stiffness will, to some extent, determine how effectively and rapidly internal forces generated by the contractile component are transmitted through to the skeletal system. A stiffer musculotendinous system should conceivably improve the initial transmission of force, facilitating the initial rate of force development.

Of all the isometric and concentric performance parameters assessed, musculotendinous stiffness most dramatically affected the initial rate of force development (Fig. 2, Tables 2 and 3). Such an occurrence is clearly depicted in Fig. 2 and supports previous research by Wood et al. (24), who reported that strength training resulted in an increase in musculotendinous stiffness and an improvement in the concentric rate of torque development in a leg extension movement. Furthermore, it also supports research by Wilson et al. (22), who observed that subjects with stiffer musculotendinous systems had a greater rate of initial power production in a concentric movement than did more compliant subjects. The three proposed mechanisms through which musculotendinous stiffness may enhance isometric or concentric performance would all assist the initial development of force. However, with a greater initial development of force, over time the contractile component length and contraction velocity advantages associated with a stiffer musculotendinous unit would be reduced as the magnitude of force development decreases.

<table>
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<tr>
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<th>Stiff Subjects</th>
<th>Compliant Subjects</th>
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<tbody>
<tr>
<td>Musculotendinous stiffness, N/m</td>
<td>12,848.8±2,607.0</td>
<td>8,302.3±1,035.0*</td>
</tr>
<tr>
<td>Concentric force, N</td>
<td>981±33.3</td>
<td>872.4±140.2</td>
</tr>
<tr>
<td>Concentric RFD, N/s</td>
<td>14,478.8±1,299.2</td>
<td>11,028.8±2,896.2*</td>
</tr>
<tr>
<td>Work done bench press throw, J</td>
<td>230.9±20.3</td>
<td>179.2±25.1*</td>
</tr>
<tr>
<td>Eccentric force, N</td>
<td>1,367.7±157.1</td>
<td>1,110.9±238.5</td>
</tr>
<tr>
<td>Eccentric RFD, N/s</td>
<td>16,871.0±5,405.0</td>
<td>13,814.1±1,273.4</td>
</tr>
<tr>
<td>Isometric force, N</td>
<td>1,535.4±66.6</td>
<td>1,152.4±179.0f</td>
</tr>
<tr>
<td>Isometric RFD, N/s</td>
<td>16,091.6±4,372.3</td>
<td>8,207.6±1,524.4f</td>
</tr>
</tbody>
</table>

Values are means ± SD; \( n = 5 \) men for each. Statistically significant; \( * P < 0.05; \dagger P < 0.01. \)
tude of the contraction became greater for a stiffer musculotendinous system compared with a more compliant system. Furthermore, once a maximal level of tension was achieved in the isometric contraction, the musculotendinous unit may no longer extend and thus the contractile component may no longer shorten. Hence the enhanced force production associated with a stiffer musculotendinous unit due to a reduced velocity of contractile component shortening may no longer apply.

Although the three proposed mechanisms underlying the relationship between musculotendinous stiffness and performance should operate in both isometric and concentric conditions, they appear to have a greater influence on the isometric performance (Fig. 2, Tables 2 and 3). During the concentric activity, the contractile component is shortening dominantly due to the actual movement. In contrast, during an isometric activity, the shortening of the contractile component occurs dominantly due to the extension of the musculotendinous unit. Consequently, even though a stiffer musculotendinous unit may serve to reduce the overall length and rate of contractile component shortening, its effect should be less pronounced in concentric compared with isometric activities.

Interestingly there was no relationship between musculotendinous stiffness and eccentric force production (Table 2). During an eccentric movement the musculature lengthens, and thus the mechanisms underlying the relationship between musculotendinous stiffness and isometric and concentric performance do not apply. In fact, conceivably a stiff musculotendinous unit could be considered detrimental to eccentric force production as it would serve to increase the extension of the contractile component to a greater extent than a compliant musculotendinous unit. This would result in an extended muscle length that may involve a reduced overlap between the actin and myosin protein filaments. However, a stiffer musculotendinous system would also involve a greater contractile component extension velocity, which has been reported to enhance the production of eccentric force (10, 15). Consequently the musculotendinous stiffness was not significantly related to eccentric force production.

The strong relationship between the stiffness of the musculotendinous unit and isometric and concentric performance would appear to have tremendous application to the exercise science field. Many physical pursuits such as swimming, cycling, wrestling, and boxing involve the rapid development of force in an isometric or concentric muscular contraction, and it would appear that such performances could be enhanced through an increase in musculotendinous stiffness. The stiffness of the musculotendinous system has been reported to be modified through flexibility or strength training. Flexibility training has been demonstrated to reduce the stiffness of the musculotendinous system (20), whereas strength training has been reported to increase musculotendinous stiffness (14, 24).

Interestingly, the stiffness of the musculotendinous unit has also been implicated as an important factor in the occurrence of muscular injuries (23). Wilson et al. (23) stated that “the musculotendinous unit represents the link between the skeletal system and muscle structures. As an external force is imposed on the musculature, a compliant system will extend to a greater extent allowing the applied force to be absorbed over a larger distance and greater time as compared to a stiff system. As such, the cushioning effect of a compliant system reduces the trauma on the muscle fibres decreasing the incidence of muscular injury as compared to a stiff musculotendinous system.” Thus athletes involved in activities that require the rapid production of isometric or concentric force may be in a dilemma in their quest to maximize competitive performance while minimizing the occurrence of muscular injuries. Indeed, in developing their musculature for optimal performance, some athletes may inadvertently enhance their likelihood of the occurrence of muscular injury.

**Relationship Between Musculotendinous Stiffness and SSC Performance**

The proposed mechanisms underlying the strong relationship between musculotendinous stiffness and isometric and concentric performance will also be operative during the concentric phase of an SSC activity. However, in such movements the elastic characteristics of the musculotendinous unit will also have a large effect on the use of elastic strain energy. For example, a highly compliant elastic system has been shown to maximize the use of elastic energy in a heavily loaded bench press movement (22), and reducing musculotendinous stiffness has been
observed to enhance SSC performance in a heavily loaded bench press movement (20). These findings indicate that the enhancement in the use of elastic energy from reducing musculotendinous stiffness outweighs the performance augmentation to the concentric phase of movement associated with a stiff musculotendinous unit, in at least some SSC movements. However, a heavily loaded bench press movement is a relatively slow performance task in which the concentric phase lasts ~2 s (8). In SSC movements such as sprint running, where the contact phase is within 100 ms (13), the rapid development of force becomes of paramount importance and thus a stiffer musculotendinous unit may be more advantageous.

Many authors have suggested that a stiff musculotendinous system is optimal for the performance of SSC activities (2, 4, 11, 12). Although the support given to these claims could be described as speculative at best, they may in fact be accurate if the increase in musculotendinous stiffness facilitates concentric force production to a greater extent than any resulting loss in the use of elastic strain energy. Certainly the whole area of optimal musculotendinous stiffness in SSC movements requires further research, and it is likely that the results obtained from such investigations may be highly specific to the individual movement analyzed.

Conclusions

The stiffness of the musculotendinous system, which maximizes isometric and concentric performance, appears to be toward the stiff end of the elasticity continuum. A stiff musculotendinous unit appears to enhance the force production capacity of the contractile component through a combination of an improved contractile component length and rate of shortening. Furthermore, a stiffer musculotendinous unit may serve to facilitate the initial transmission of force from the contractile component to the skeletal structures. These proposed mechanisms do not apply to eccentric movements, and thus there was no relationship between eccentric force production and the elasticity of the musculotendinous unit. The augmentations of concentric and isometric performance associated with a stiff musculotendinous unit were most notable over the first 100 ms of the contractions and were more pronounced during the isometric action compared with the concentric movement. The strong relationship observed between musculotendinous stiffness and concentric and isometric performance has great relevance to many physical activities and is of particular interest, as musculotendinous stiffness has been demonstrated to be readily modified by flexibility or strength training.

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