Effects of cutaneous and joint receptors on the in vivo quadriceps femoris torque-velocity relationship

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Abstract:

The influence of cutaneous and joint receptors on the quadriceps femoris torque-velocity relationship was assessed with the Kin-Com (Chattecx, Inc., Hixson, TN) isokinetic dynamometer. Twenty-four females (age = 21 ± 1.4 years, ht = 163 + 6.0 cm, wt = 60 ± 7.6 kg) were divided into two groups and tested with the force pad placed either proximally or distally on the leg. Three concentric and eccentric contractions were performed at 25, 50, 75, 100, 125, 150, 175 and 200's-1 on 2 separate days with an anesthetic applied to the skin under the force pad on 1 of the 2 days. An ANOVA was performed on peak torque with trend analyses performed on velocity factors. The results indicate the cutaneous and knee joint receptors do not affect the quadriceps femoris concentric or eccentric torque-velocity relationships, F(7,154) — 1.61. Furthermore, the results revealed significant linear, F(1,154) - 161.14, and quadratic trends, F(1,154) = 25.85, for concentric and eccentric peak torque, respectively. Thus, the concentric torque-velocity relationship is best described by a linear relationship rather than the classic curvilinear relationship. Conversely, the eccentric relationship is best described by the classic curvilinear relationship. These results suggest that adequate assessment of muscular torque production requires testing at multiple velocities.

Article:

I. INTRODUCTION

In 1927, Levin and Wyman [13] used the jaw muscle of the dogfish to determine the concentric and eccentric force-velocity relationship of muscle. They established that as the concentric velocity increased the force of contraction decreased in a curvilinear fashion, and conversely, that, as the eccentric velocity increased, the force of contraction increased in a curvilinear fashion. Hill [8], using isolated frog muscle, confirmed the concentric results of Levin and Wyman [13], demonstrating that as the load in- ceased, the velocity of contraction decreased in a curvilinear fashion.

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More recently, the results of various investigations [17,24] have suggested that these relationships do not adequately describe the in vivo torque-velocity relationship. Perrin and Edgerton [17] used the Cybex II (Lumex, Inc., Ronkonkoma, NY) to study the human in vivo concentric torque-velocity relationship at velocities ranging from 0.00 to 288's^{-1} and reported the relationship as being similar to Hill's [8] relationship except at slow velocities, at which the curvilinear relationship reversed its upward trend and plateaued. Westing et al. [24], using a device constructed in their laboratory (SPARK system) and velocities ranging from 0.00 to 360° s $^{-1}$, reported the concentric torque-velocity relationship as being more linear without a plateau. Additionally, they demonstrated the eccentric torque—velocity relationship did not differ across velocities. Both of these studies determined the shape of the curves with visual analysis rather than the statistical method of trend analysis.

To explain the differences between the in vitro studies [8,13] and the in vivo studies [17,24], Nisell et al. [16] and Wickiewicz et al. [26] argued that neural control from a variety of receptors may be responsible. The existance of a neural inhibition has been demonstrated by Westing et al. [25]. Nisell et al. [16] specifically proposed periosteal and cutaneous receptors as being responsible.

The suggestion that cutaneous receptors may effect muscle function is supported by Johnson's [10] mechanical analysis of resisted knee extension. Johnson pointed out that the compressive forces of the contact pad increase as resistance (torque) increases. Thus, the increase in concentric torque as velocity decreases and the increase in eccentric torque as velocity increases would result in increased pad contact force. These increases in pad contact force could possibly stimulate the cutaneous receptors beyond a threshold value and thus produce an inhibition of the contracting muscle, resulting in the plateaus described above.

A study by Hagbarth [7] supports the above possibility. Using spinalized cats, Hagbarth demonstrated an inhibition of the quadriceps femoris as the result of cutaneous stimulation of the leg and thigh. More specifically, Lundberg et al. [14] demonstrated in low spinal cats that stimulation of cutaneous nerves produced facilitation of the autogenetic lb inhibitory pathway. They suggested that 'cutaneous impulses evoke excitatory action in lb inhibitory interneurones (sic) projecting directly to motomeurones (sic).' Furthermore, they demonstrated that simultaneous stimulation of cutaneous nerves and lb neurons of extensors stimulated antagonist flexor motor neurons.

In addition to cutaneous receptors, Westing et al. [22] suggested that stress on the joint tissues may stimulate the joint receptors, producing the plateaus in the torque—velocity relationship. Johnson [10] demonstrated that as the resistance force increases, the anterior shear force of the knee also increases, thus producing stress on the anterior cruciate ligament (ACL) and the joint capsule. In a study using 21 cadaver knees with Hall effect force transducers implanted in the ACL, Arms et al. [3] demonstrated significant increases in tension in the ligament during quadriceps loading through a range of 0-45° of flexion. Furthermore, Nisell et al. [16] demonstrated that when the contact pad of the Cybex was moved proximally, the shear force of the knee decreased significantly.

The possibility that these mechanical stresses may have an inhibitory effect on motorneurons is sup= ported by a study conducted by Lundberg et al. [15]. Using low spinal cats, they demonstrated that stimulation of the knee joint's articular nerve combined with stimulation of the Ib afferent of the quadriceps produced a post-synaptic inhibitory potential of the quadriceps motor neuron. As with the cutaneous nerves, they suggested that input from joint receptors stimulated inhibitory intemeurons acting on the lb inhibitory pathway. Additionally, they demonstrated that stimulation of the articular nerve produced an excitatory post-synaptic potential in the posterior biceps femoris and semitendinosus motor neurons. Thus, as with the cutaneous nerves, stimulation of the joint nerve has two potential mechanisms for decreasing quadriceps muscular torque.

Therefore, it is the purpose of this study to determine if anesthetizing the skin under the contact pad to decrease cutaneous neural feedback will alter the concentric and eccentric torque—velocity relationship. Furthermore, it is the purpose of this study to determine if decreasing joint structure neural feedback by using a proximal pad placement to reduce anterior shear of the knee will alter the concentric and eccentric torque—velocity relationships.

2. METHODS

2.1. *Subjects and experimental design*

Twenty-four females (age = 21 ± 1.4 years, ht = 163 ± 6.0 cm, wt = 60 ± 7.6 kg) with no training experience or history of knee pathology gave informed consent to participate in the study. This study was approved by the university's human subjects review board. Each subject was randomly assigned to either a proximal pad placement group or a distal pad placement group. Additionally, each subject performed isokinetic tests on 2 days separated by a minimum of 18 h, with the skin anesthetized on 1 of the 2 days. The order of the testing days was counterbalanced with half of the subjects in each group performing the anesthesia tests on day 1 and the other half performing the anesthesia tests on day 2. Ten grams of 2.5% lidocaine and 2.5% prilocaine in a cream base (EMLA® Cream, Astra USA, Inc., Westborough, MA) was applied to the approximately 100 cm^2 of skin beneath the dynamometer's contact pad. After application of the cream, the skin patch was covered with a bioclusive dressing for 1 h before testing was begun.

2.2. *Dynamometer set-up*

Each subject sat on the Kin-Com II isokinetic dynamometer (Chattecx Corp., Hixson, TN) with the lateral epicondyle of the knee aligned with the axis of the dynamometer. Velcro straps were placed across the hips, thigh and ankle of each subject for stabilization. For the distal force pad position, the inferior edge of the force pad was aligned directly superior to the malleoli. For the proximal force pad position, the superior edge of the force pad was aligned directly inferior to the tibial tuberosity. Finally, the seat position was noted and the vertical and horizontal positions of the dynamometer head were measured. These positions were used on the second day of testing to improve reliability of measurement.

2.3. *Test protocol*

To prevent testing of dominant and non-dominant legs, the opposite leg of the one used to kick a tennis ball was used for testing. Concentric and eccentric isokinetic tests of the quadriceps femoris were performed at 25, 50, 75, 100, 125, 150, 175 and 20005- with the maximum velocity determined by the limitations of the dymamometer. Velocities were rotated within each group to

reduce the impact of fatigue (Table 1). For the second day of testing, subjects were randomly reassigned to the velocity orders.

Prior to testing, each subject performed a 5-min warm up on a stationary bicycle. Additionally, each subject performed two submaximal familiarization contractions followed by one maximal familiarization contraction at each test velocity prior to performing the test contractions. To reduce the effects of fatigue, a 1-min rest was given between the warm up contractions and test contractions and between the test contractions and the next velocity's warm up contractions. For testing, each subject performed three eccentric and three concentric contractions at each velocity through a range 10-100° of flexion. The eccentric test contraction at a given velocity immediately followed the concentric test contraction at the same velocity with a brief rest between the contractions. Gravity correction was performed with the knee at 0° of flexion. The dynamometer's preload and minimal force values were set at 50 and 20 N, respectively.

2.4. *Data extraction and analysis*

To reduce measurement error, peak torque was extracted from the torque curve produced as the mean of the three contractions completed at each velocity. Initially, a mixed design ANOVA with three fully crossed within variables (anesthesia, contraction type, and velocity) and one between variable (pad placement) was completed. A trend analysis for velocity was then performed on the highest order interaction, involving both the velocity and contraction type factors. In addition to calculating the *F* values for each trend component, the η^2 value (the ANOVA equivalent of R^2 for each component was also calculated. The alpha level for all statistical tests was set at 0.05.

3. RESULTS

The means and standard deviations for peak torque at each velocity for the distal and proximal pad placement are presented in Tables 2 and 3, respectively. The ANOVA revealed non-significant anesthesia, $F(1, 22) = 2.89$, and anesthesia by pad placement effects, $F(1, 22) = 0.02$. There was a significant effect for pad postion, $F(1, 22) = 19.03$, however, the distal pad position produced higher torque values than the proximal position. This is the opposite of what would be expected if the joint receptors inhibited force production. Additionally, the ANOVA revealed a significant interaction for contraction type by velocity, $F(7,154) = 28.85$. The means and standard errors are presented in Fig. 1. The trend analysis for the velocity by contraction interaction revealed a significant linear component, $F(1, 154) = 161.14$ ($\eta^2 = 5.0\%$), quadratic component, $F(1, 154) = 24.82$ ($77^2 = 0.8\%$), and cubic component, $F(1,154) = 5.29$ (η^2

Table 1
Velocity rotation

Subject	Velocity (°s^{-1})							
S01	25	50	75	100	125	150	175	200
S02	200	25	50	75	100	125	150	175
S03	175	200	25	50	75	100	125	150
S04	150	175	200	25	50	75	100	125
S05	125	150	175	200	25	50	75	100
S06	100	125	150	175	200	25	50	75
S07	75	100	125	150	175	200	25	50
S08	50	75	100	125	150	175	200	25
S09	200	25	50	75	100	125	150	175
S10	150	175	200	25	50	75	100	125
S11	100	125	150	175	200	25	50	75
S12	50	75	100	125	150	175	200	25

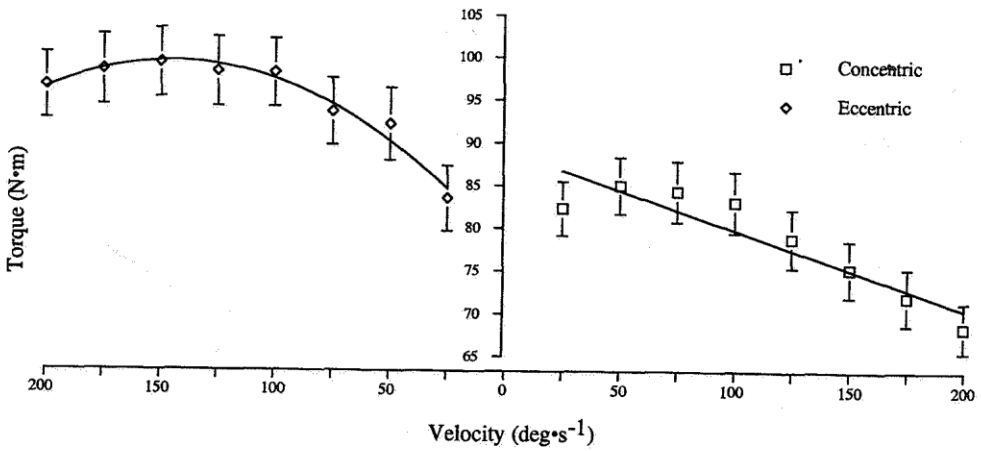

Fig. 1. The concentric and eccentric torque–velocity relationships pooled across anesthesia.

= 0.1%), for the concentric contractions. Additionally, there was a significant linear component, $F(1,154) = 41.28$ (172 = 2.0%), and quadratic component, $F(1, 154) = 25.85$ ($\eta^2 = 1.0\%$), for the eccentric contractions.

4.DISCUSSION

The major findings of this study were that anesthetizing the cutaneous receptors under the dynamometers force pad did not affect the quadriceps femoris concentric or eccentric torque—velocity relationship. Additionally, there was no evidence that the joint receptors altered the torque—velocity relationship.

4.1. *Cutaneous and joint receptors*

The results of this study differ from what was hypothesized based on the studies of Hagbarth [71 and Lundberg et al. [14,15]. One explanation might be that the above studies were conducted on low spinal animals. Lundberg et al. [14] suggested that these reflexes might not operate in the more complex Ib patterns found in high spinal animals- or during supraspinal stimulation. More specifically, two different studies [2,41 demonstrated that descending tracts from the brain stem may inhibit the intemeurons of Ib inhibitory pathways. Thus, these brain centers may have overridden the effects of cutaneous and joint afferents.

4.2. *Trend analyses*

One of the difficulties in conducting a trend analysis is determining which trend best fits the data. For example, in this analysis there are seven velocity means for both the concentric and eccentric contractions. Thus, it is possible to have statistically signif-

Table 2
Peak torque (Nm) means and standard deviations with distalresistance pad placement

Velocity (°s^{-1})	Concentric				Eccentric			
	Anes.[a]	S.D.	No Anes.	S.D.	Anes.	S.D.	No Anes.	S.D.
25	93.2	19.0	97.2	19.7	97.6	21.9	97.9	27.5
50	94.8	17.6	102.6	22.9	109.3	27.9	109.8	22.4
75	102.2	19.0	100.5	23.5	104.0	17.8	113.5	23.9
100	102.3	18.1	100.8	19.2	116.0	17.0	112.8	25.0
125	98.2	19.7	91.3	20.6	119.8	21.4	110.2	22.1
150	92.6	18.8	89.8	22.3	115.8	26.5	113.5	23.7
175	88.3	19.2	85.2	22.5	114.4	29.9	113.0	18.8
200	81.1	16.8	82.3	20.1	107.3	27.1	112.2	20.4

[a]Anesthesia

Table 3
Peak torque (Nm) means and standard deviations with proximalresistance pad placement

Velocity (°s^{-1})	Concentric				Eccentric			
	Anes.[a]	S.D.	No Anes.	S.D.	Anes.	S.D.	No Anes.	S.D.
25	66.6	16.4	72.5	18.2	66.3	18.4	72.1	22.8
50	67.4	16.4	75.4	17.0	69.1	18.1	80.4	26.1
75	64.8	13.9	70.0	15.0	74.8	18.4	82.0	26.8
100	62.8	15.4	66.6	16.2	78.6	21.9	85.0	26.0
125	62.9	16.1	63.1	14.5	75.8	20.2	87.2	26.6
150	59.3	13.8	60.8	11.6	77.9	19.7	89.8	24.8
175	56.3	14.0	58.6	13.9	79.3	23.8	86.9	25.1
200	52.6	10.3	58.2	13.4	80.8	21.2	85.8	25.6

[a]Anesthesia

cant trends ranging from a linear trend to a sixth order polynomial trend for both the concentric and eccentric means. When multiple significant trends are possible, it becomes necessary to select trends that best represent the data. In this study we chose to use the η^2 values of each significant trend to aid in trend selection. Specifically, the eta2 represents the proportion of the total variance explained by a given trend. Thus, we selected the highest order trend which, when combined with lesser order trends, explained, in our judgment, an acceptable proportion of the total variance.

4.2.1. *Concentric contractions*

Visually, the concentric torque-velocity relationship of our study (Fig. 1) is consistent with the results of Perrine and Edgerton [17], and Wickiewicz et al. [26]. Perrine and Edgerton [17], using the Cybex, reported that as velocity decreased, quadriceps force production increased until approximately 96°$^{s-1}$, at which point the force peaked and then declined as the velocity approached 0° s$^{-1.}$ Similarly, Wickiewicz et al. [26] used the Cybex and reported that the concentric force increased as velocity decreased until approximately 60°s^{-1}, and then the force declined with decreasing velocity. It should be pointed out that neither of the above studies applied a statistical analysis to the data. Thus, it is not possible to determine the precise nature of the torque-velocity relationship.

As indicated in our results, the concentric torque-velocity relationship demonstrated significant linear, quadratic and cubic trends. However, the quadratic and cubic components only accounted for 0.8 and 0.1% of the total variance, respectively, indicating that the concentric torque-velocity relationship is best represented by a linear relationship. Thus, trend analysis indicates our results are inconsistent with the results of Perrine and Edgerton [17] and Wickiewicz et al. [26], and more consistent with the results of Thorstensson et al. [20], Thorstensson et al. [21] and Yates and Kamon [27]. These studies produced a torque-velocity relationship which had a much more

linear appearance than did Perrine and Edgerton [17] or Wickiewicz et al. [26], and none of them demonstrated a plateau or decline in force at slower velocities. However, exact comparison is impossible since these studies [20,21,27] did not perform a trend analysis of the torque-velocity relationship as part of their statistical analysis.

Our results are also inconsistent with the classic results of Hill [8]. However, re-examination of Fenn and Marsh's [5] data suggest that our results are consistent with the in vivo force-velocity relationship of the cat quadriceps femoris. Thus, the difference between our results and the classical work of Hill [8] suggests that the in vivo relationship may be different from the in vitro relationship. The exact mechanism of this difference is still unclear. However, the absence of significant higher order interactions involving anesthesia or pad position suggests that neither the skin receptors nor the joint receptors influence the torque-velocity relationship.

It is possible that the differences between our results and those of Hill [8] and of others [1,9,18] are due to species differences or to muscle group differences. This may be supported by the work of Fenn and Marsh [5] which examined the force-velocity relationship in frogs and mammals (i.e. cats). Visually, their results demonstrated a relatively linear relationship for the cat quadriceps while the frog sartorius demonstrated a curvilinear relationship similar to Hill [8]. Thus, it is possible the differences are due to either species differences or muscle group differences. However, two studies [11,12] using the human elbow flexors and extensors produced torque-velocity relationships similar to those found with the human quadriceps. This suggests that the difference between our study and the classic work of Hill [8] may be due to differences between mammals and other animals rather than muscle group differences.

4.2.2. *Eccentric contractions*

The eccentric torque—velocity relationship demonstrated significant linear ($\eta^2 = 2\%$) and quadratic ($\eta^2 = 1\%$) components. Since the η^2 values for the two components are both statistically significant and relatively similar in magnitude, the quadratic component combined with the linear component (i.e. a quadratic polynomial) best explains the relationship. This suggests that the shape of the eccentric torque—velocity relationship (Fig. 1) is not flat as has been suggested by Westing et al. [24], Westing and Seger [23], Westing et al. [25] and Westing et al. [22], but is curvilinear as suggested by Levin and Wyman [13]. Additionally, our results do not support the suggestions of Westing et al. [25] and Westing et al. [22] that neural feedback from cutaneous and joint receptors may prevent an increase in eccentric torque as velocity increases.

One of the potential reasons for the differences between our study and those of Westing may be the type of dynamometer used. In all of the studies conducted by Westing, the Spark dynamometer was used. Francis and Hoobler [6], using the Cybex II and Lido 2.0, and Thompson et al. [19], using the Cybex II Plus and Biodex B-2000, reported that different dynamometers produce different results when measuring peak torque. Additionally, Francis and Hoobler [6] reported reliability coefficients of 0.90 and 0.85 for the CybexII and Lido 2.0, respectively, and concluded that the differences were due to measurement differences not error difference's. Thus, it is possible that different dynamometers do not measure the same variable.

It is also possible that differences in methodology may have produced the differences. In all of the studies by Westing et al. [22-25] the peak torque value was extracted from the single

muscular contraction producing the greatest amount of work or average torque. This is in contrast to our method which extracted the peak torque from the mean curve of three contractions. Thus, it is possible that the method of identifying peak torque may have produced the differences between our results and those of Westing. In summary, our results suggest that neither the cutaneous nor the knee joint receptors have an effect on the quadriceps femoris torque—velocity relationship. Furthermore, in contrast to the classic work of Hill [8] and the contemporary work of Perrine and Edgerton [17] and Wickiewicz et al. [261 the concentric torque—velocity relationship is best described by a linear relationship. Finally, the eccentric torque—velocity relationship is best represented by a quadratic relationship consistent with the classic work of Levin and Wyman [13] but inconsistent with the more contemporary studies of Westing et al. [22-25]. Thus, it is clear that when assessing concentric and eccentric strength, it is necessary to use multiple test velocities. Otherwise, an inadequate assessment of muscle function may result.

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