Eccentric and Concentric Force-Velocity Relationships of the Quadriceps Femoris Muscle

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Most functional activities utilize all three types of muscle contraction. The purpose of this study was to examine concentric and eccentric force-velocity relationships of the knee extensors of 30 young, healthy females at seven velocities between 30 and 210°/sec using the Kinetic Communicator. The average force produced by the quadriceps during three concentric and three eccentric contractions was calculated at each velocity. The force-velocity relationships were graphed and analyzed using linear regression techniques. Results showed that the mean slope of the combined linear regression lines of concentric data was −0.55, which is significantly different from a zero slope. This indicates that concentric force of the knee extensors decreases as velocity increases. The mean slope of the combined linear regression lines of the eccentric data was −0.04, indicating no significant change in eccentric force with an increase in velocity. It appears, therefore, that in the knee extensors of healthy, young females, concentric force decreases as velocity increases to 210°/sec, while eccentric force remains the same. Both concentric and eccentric work are often emphasized in strength training programs. It is, therefore, important for professionals involved in the rehabilitation or training of patients and athletes to be aware of differences between eccentric and concentric force-velocity relationships.

Key Words: *quadriceps femoris, force-velocity relationships, concentric/eccentric*

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Functional activity involves patterns of concentric, eccentric, and isometric contractions. All components of motion, such as initiation, force production, coordination of muscle groups, change of direction, and velocity, are necessary for function and are addressed in the training of an athlete and the rehabilitation of a patient. Research has shown that a torque produced against a load is related to the velocity at which the movement occurs. In concentric contractions, force decreases as velocity increases. The force-velocity relationship of eccentric action, however, has not been established. Some of the variation in findings may be due to differences among researchers in test protocols, instrumentation, muscle groups tested, measurements taken, and types of subjects examined.

LITERATURE REVIEW

In numerous studies that have used isokinetic dynamometers to examine force-velocity relationships, authors consistently report that the force of concentric upper extremity muscle contractions decreases as velocity increases to 210°/sec (6,12–14). Investigators have shown similar force-velocity relationships for concentric contractions of the lower extremity. This finding has been demonstrated across a wide velocity spectrum (0–330°/sec) and in a variety of populations (3,5,10,12,19,22). One report that contrasted other findings was that of Perrine and Edgerton (17). They found an increase in concentric peak torque of the knee extensors when velocity increased from 45 to 96°/sec, while at velocities above 96°/sec, the usual decline in peak torque was noted. The differences in this concentric force-velocity curve may be due, in part, to methodological differences in the measurement of force. That is, the authors recorded peak torque values achieved at a set angle of knee extension rather than recording peak torque values obtained throughout the range of motion. The angle at which minimum torque is achieved in the knee extensors has since been shown to change at different velocities (16).

The force-velocity relationship of eccentric action has also been examined. In studies performed on upper extremity muscles, most authors agree that the force of eccentric muscle action increases as velocity increases to 210°/sec (1,13,14,21). Griffen reported that eccentric elbow flexor peak torque increases as velocity increases between 0 and 120°/sec but then decreases between 120 and 210°/sec (6).

Results from lower extremity force-velocity studies of eccentric isokinetic action have been less consistent. Eloranta and Komi used eight linear velocities between 0.12 and 0.97 m/sec on a specially constructed dynamometer to examine the eccentric force-velocity relationship of the quadriceps (3). The authors found no significant change in eccentric peak force as velocity increased. Hageman et al (7) measured the absolute peak torque during eccentric contractions of quadriceps and hamstring muscles of normal volunteers on the Kinetic Communicator at 30 and 180°/sec. No significant difference in peak torque was found between the two velocities in males. In females, however, an increase in eccentric hamstring torque was observed as velocity increased. Knee extensors of normal male volunteers tested eccentrically at 60, 120, and 180°/sec on the Kinetic Communicator by Chandler and Duncan showed a slight but significant decrease in average force with increased velocity (2).

In summary, during concentric contractions of both the upper and lower extremities, force decreases as velocity increases. The eccentric force-velocity relationship, however, has not been consistently described. In the upper extremity, it generally appears that eccentric force increases as velocity increases. However, in the lower extremity, eccentric force may increase, decrease, or stay the same as velocity increases. Some of the inconsistency in results may be accounted for by differences in testing protocols, instrumentation, muscle groups tested, force or torque measurements recorded, and types of subjects examined.

Because there are many variables that may affect force measurements, it is necessary to develop experimental protocols that control as many of these variables as possible. Isokinetic dynamometers that can measure both concentric and eccentric force allow investigators to examine both concentric and eccentric force-velocity relationships of specific muscle groups in a homogeneous population using the same measurement device. Data derived from experimental protocols using such devices may ultimately clarify the similarities and differences between concentric and eccentric force-velocity relationships of several muscle groups. Therapists and trainers often incorporate both concentric and eccentric work into rehabilitation and weight training programs in order to improve functional performance of patients and athletes. It is, therefore, important to understand differences between eccentric and concentric force-velocity relationships when designing strengthening programs.

The purpose of this study was to examine the eccentric and concentric force-velocity relationship of the right quadriceps femoris muscle from 30 to 210°/sec on the Kinetic Communicator in healthy young women. It was hypothesized that:

1) the force of concentric contractions produced by the knee extensors would significantly decrease as velocity of contraction increased, and

2) the force of eccentric contractions produced by the knee extensors would not change as velocity of contraction increased.

METHODS

Subjects

Thirty female volunteers from the Duke University Graduate School and from the Durham, NC community participated in this study. Ages ranged from 22 to 32 years (mean age = 25 years, S.D. = 2.6). Master athletes and weight trainers were excluded from the study, as were individuals with knee pathology, cardiovascular, neuromuscular, or musculoskeletal disease. All participants gave informed consent prior to testing.

Instrumentation

The Kinetic Communicator (Kin-Com II, Chattex Corp., Chattanooga, TN 37405) is a hydraulically driven dynamometer capable of measuring both concentric and eccentric force produced at speeds up to 210°/sec. Through feedback loops, the instrument controls the range of motion and velocity of the lever arm and registers the amount of force exerted by the user.

Farrell and Richards (4) have demonstrated that the Kin-Com is mechanically reliable and suitable for research needs (ICC = .948 to 999). Good clinical reliability of the Kin-Com has also been established, with ICCs ranging from .47 to .95 for eccentric and concentric torque and force measures (8,9,18,20).

Procedure

The Kin-Com II was used to measure the average force produced during maximum voluntary concentric and eccentric contractions of the right quadriceps femoris muscle group at test velocities of 30, 60, 90, 120, 150, 180, and 210°/sec. The order of the velocities was randomly assigned. In addition, the mode of contraction, concentric or eccentric, to be performed first was randomly selected. All testing took place in the Physical Therapy Department at Duke University Medical Center.

Subjects were seated on the Kin-Com with hips and knees flexed to 90°. The posterior aspect of the subject's right knee cleared the seat by 1/2 to 1 in. The axis of knee joint rotation was aligned with the axis of rotation of the lever arm on the Kin-Com. The pelvis was stabilized by a Velcro® strap placed over the anterior superior iliac spines. A second strap was used to stabilize the distal right thigh. The pad on the lever arm of the Kin-Com was attached with a Velcro strap to the anterior aspect of the distal tibia two finger widths proximal to the malleolli. A total range of motion of 85° was set by asking the subject to extend the knee to 5° and then to flex the knee to 90° as monitored by the Kin-Com's computer. Subjects were asked not to hold on to the Kin-Com with their hands. One researcher consistently aligned, instructed, and motivated the subjects, while the other attended to the computer and the collection of data.

To become familiar with the Kin-Com and alternating concentric and eccentric contractions, each subject was allowed 10 submaximal contractions in each mode at 105°/sec, followed by a 90-second rest. A middle range speed of 105°/sec was chosen for the initial practice session because it was believed to be in a more comfortable exercise velocity range than either the lower speeds (30–90°/sec) or the higher speeds (180–210°/sec). In addition, the investigators believed that 105°/sec, which was not one of the "testing" velocities, would allow the subjects to become used to the eccentric mode of exercise without letting them get additional practice at one of the test velocities. Then, prior to actual data collection at each velocity, the subject warmed up with two submaximal contractions followed by one maximal contraction in each mode at the specified velocity. This was followed by a 60-second rest period. The actual test from which average force data were collected involved three maximal contractions in each mode at the specified velocity. Three maximal contractions at each test velocity were believed to be representative of the subject's maximal effort without causing undue muscle fatigue during the testing procedure. Each maximal effort was separated by a 5-second pause. Strong verbal encouragement was given during maximal contractions. After a 2-minute rest, the sequence of warm-up contractions followed by test contractions was performed at the next randomly selected velocity.

Data Collection and Analysis

The Kin-Com computer determined the average force in N generated during the three maximal concentric contractions and calculated the arithmetical mean of the three average force values. The same force data were collected for the eccentric trials. In addition, the computer produced plottings of the average force produced throughout the range (Figure 1).

Linear regression techniques were used to determine the slopes of the regression lines for each subject's concentric and eccentric data. A mean slope for all the concentric data and a mean slope for all the eccentric data were calculated. A nonparametric equivalent to the t-test was used to determine if the mean slope in each case was different from the slope of a horizontal line, or zero.

RESULTS

The mean slope of the combined regression lines of the concentric data was −0.55 (SD = .25) and was found to be significantly different from zero ($p < .01$) (Figure 2). A mean slope of −0.04 (SD = .34) was determined for the combined eccentric regression lines (Figure 3). This slope was not found to be significantly different from zero.

DISCUSSION

The negative slope of the combined regression lines for the concentric data indicates that concentric force decreases as velocity increases to 210°/sec (Figure 2). This is consistent with the study hypothesis as well as with previous research of concentric force-velocity relationships in both the upper and lower extremities (2,3,4,6,10,12–15,17,19,22,23). Klopfer and Greij present a possible explanation, suggesting that faster speeds allow less time in which to recruit motor units for a strong contraction (11). Therefore, as velocity increases, fewer muscle fibers contract and force decreases.

The finding that the concentric force-velocity relationship appears linear has not been reported previ-

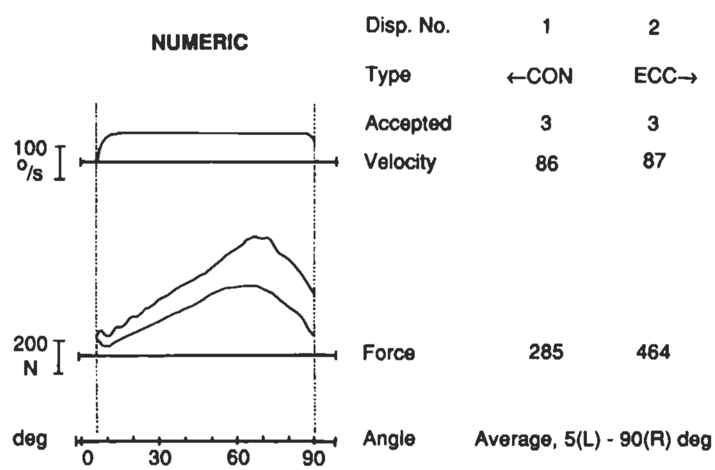

FIGURE 1. *Example of data produced by the Kin-Com computer showing the average force produced concentrically and eccentrically by one subject at 90°/sec.*

ously in the literature. This inconsistency may be explained by the fact that a relatively narrow velocity spectrum, 30 to 210°/sec, was used in this study. Ingemann-Hanson and Halkjaer-Kristenson (10) tested subjects on a modified Orthotron using a wider velocity range from 30 to 360°/sec. At the higher velocities, they noted a "leveling off" of concentric force. This finding is supported by the work of Wyatt et al (23) and Montgomery et al (15), who tested force produced at velocities up to 300 and 330°/sec, respectively, on the Cybex II. It is possible that concentric force generated over a wider velocity range might result in a logarithmic rather than linear force-velocity curve (22).

The slope of the combined regression lines for the eccentric data is essentially zero (Figure 3). No trends toward either an increasing slope or a decreasing slope seem to emerge from the data. In fact, of the 30 individual regression lines, half had a slightly positive slope and half had a slightly negative slope. This finding is consistent with the hypothesis that there is no significant change in eccentric force as velocity increases to 210°/sec.

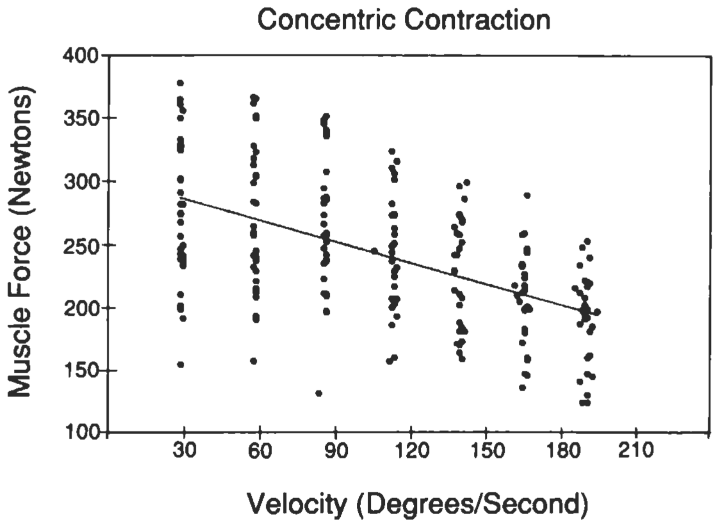

FIGURE 2. *Average concentric force of the quadriceps plotted against velocity of contraction. The line drawn here represents the mean slope of the regression lines for all 30 subjects.*

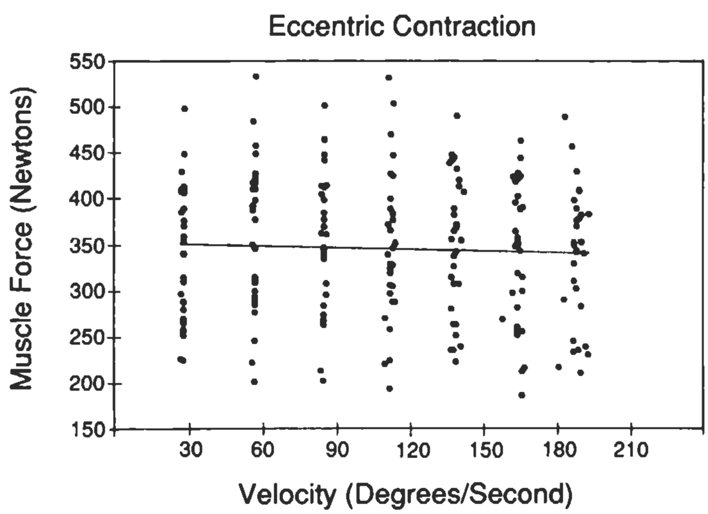

FIGURE 3. *Average eccentric force of the quadriceps plotted against velocity of contraction. The line drawn here represents the mean slope of the regression lines for all 30 subjects.*

An explanation for the maintenance of eccentric muscle force with increasing velocity in the lower extremity can be found in the physiology of muscle. A muscle has both contractile and elastic components. Active lengthening of muscle is, in part, controlled by the passive resistance to stretch of the elastic components, whereas shortening is controlled solely by the contractile elements. Thus, the elastic components contribute to force produced during an eccentric contraction but not during a concentric contraction. The physiologic behavior of the elastic elements may account for differences in eccentric and concentric force production as velocity increases.

The results of the eccentric data from this study are comparable to those of Eloranta and Komi (3) and Hageman et al (7), who found no change in eccentric peak force and peak torque, respectively, as velocity increased. Chandler and Duncan demonstrated a slight decrease in eccentric quadriceps muscle force with increasing velocities on the Kin-Com, but only examined a narrow velocity spectrum of 60 to 180°/sec (2).

Eccentric force-velocity relationships for the upper extremity appear to be different from those reported for the lower extremity. In the upper extremity, a slight positive slope with eccentric force increasing as velocity increases has been shown (1,13,14,21). Differences in the eccentric force-velocity relationships between upper and lower extremities could be explained by functional differences between the two muscle groups. The lower extremity muscles contract eccentrically for many functional activities. This is especially true of the knee extensors during walking and running. Compared to the lower extremity muscles, the upper extremity muscles may not perform as many functional tasks involving eccentric contractions or tasks that require heavy or high velocity loading. Therefore, it is possible that differences in the eccentric force-velocity relationships of upper and lower extremity muscle groups may be a result of differences in their functional behavior.

Factors that may have affected the results of this study should be considered. First, fatigue must always be a concern in studies involving multiple contractions. To minimize potential confounding effects of fatigue, speeds were randomly assigned for each individual and a 2-minute rest period was consistently provided between tests at each velocity. In addition, a few subjects complained of discomfort caused by the shin pad. Such discomfort may have inhibited their ability to produce a maximal contraction consistently. Because the data were remarkably consistent within individuals, however, it appears that neither pain nor fatigue were major confounding factors in this study.

Further investigation of this phenomenon might include similar testing over a wider velocity spectrum, especially at higher velocities, of both upper and lower extremity muscle groups. Comparisons among normal subjects, elite athletes, and patients may further elucidate physiological mechanisms underlying concentric and eccentric force-velocity relationships.

CONCLUSION

Results of this study demonstrate that concentric force of the quadriceps decreases when velocity of movement increases from 30 to 210°/sec on the Kin-Comdynamometer. Eccentric force production, on the other hand, appears to remain constant over the same velocity spectrum. These findings are consistent with previous reports in the literature for all concentric force-velocity relationships and for eccentric force-velocity relationships of the knee extensors.

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