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ABSTRACT

This study investigated the effects of the velocity of muscular contraction on the effective force (torque) exerted by forty 18- to 21-year-old males. The dynomemeter lever arm, the fulcrum of which was aligned with the axis of elbow rotation, allowed extension and flexion for the subjects. All subjects were tested at three velocities (.10, .20, and .33 radians/sec) for each mode of contraction: concentric and eccentirc. Subjects tested in the concentric mode accelerated the lever arm by contraction of the elbow extensors, while subjects in the eccentric mode resisted elbow flexion forced upon them by the dynomometer. The hypothesis that forces observed would have an inverse relationship to the speed of muscle shortening or lengthening was rejected. Analysis revealed similar force curves at all speeds, in terms of peak forces and slopes of the curves. Mean peak forces occurred approximately at the same point in the curves, regardless of mode or speed. Eccentric forces were consistently higher than concentric forces. It was concluded that subtle adaptations in the muscoloskeletal linkages resulted in relatively constant force output, regardless of variations in rate of muscle shortening. (Author/BRB)

EFFECTS OF RATE OF MOVEMENT ON EFFECTIVE MAXIMAL FORCE GENERATED BY ELBOW EXTENSORS. (PRESENTED AT AAHPER, RESEARCH SECTION: MINNEAPOLIS, MINN., APRIL 13, 1973)

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I. The Problem

The Dynamics of Muscle Contraction have undergone intensive study and are, in general, well defined. Although the various theories of muscular contraction have not yet adequately accounted for all observed phenomena, or for the specific mechnaisms by which strength is improved, there are many aspects of muscle function concerning which there is general agreement.

One widely accepted concept is that relating to force-velocity relationships in muscle. The equation published by A. V. Hill in 1938 dictates that the rate of shortening is inversely proportional to the force produced for external work. Thus, at a given velocity V, the force exerted would be twice that produced at a contraction velocity of 2V, and three times that produced at 3V.

Although there has been little apparent reason to question the validity of the force-velocity relationships observed in isolated muscle preparations (at least for concentric contraction), or to object to the theoretical application to human performance, there is little empirical evidence concerning the actual operation of this phenomenon in human beings.

II. Purpose

The purpose of this investigation was to study the effects of the velocity of muscular contraction on the effective force (torque) exerted by a human subject.

The muscle group selected for study was the triceps brachii. Its action, at least with respect to the elbow joint, is less complicated than some other commonly studied muscles and was relatively easily adapted to the test conditions.

Concentric contraction of the triceps acts to extend the elbow joint. Eccentric contraction of the triceps acts to prevent flexion of the elbow caused by an external force.

Subjects were placed in the supine position on a narrow table with shoulders securely clamped in place. The rotating lever arm of the electrically powered dynamometer was aligned with the lateral surface of the left forearm (which was held midway between pronation and supination) and connected to the arm just above the wrist by means of a special cuff. The fulcrum of the lever as aligned with the axis of elbow rotation permitting movement of the forearm in the saggital plane only. Clockwise and counter clockwise rotation of the lever arm corresponded to elbow extension and flexion respectively.

III. Procedure

Forty male volunteer subjects (aged 18-21 years) were tested at three different velocities for each of two modes of contraction: (1) concentric (2) eccentric.

Although all velocities were in the low range in terms of muscular capability, they were designed to be in the order of 1:2:3. (Actual velocities were .10, .20, and .33 radians per second.) (Approximately 6, 12, and 18 degrees per second.)

Force exerted on the cuff was continuously recorded throughout the range of movement by means of a temperature-compensated strain gage. A simultaneous recording was made of the angle of the forearm with respect to the horizontal.

(Perhaps it should be noted that the actual angle observed was that of the forearm with respect to the horizontal plane, i.e., not with reference to the upper arm. Therefore, full elbow extension corresponded to 0 degrees rather than to 180 degrees in the data.) The full range of movement exceeded 100 degrees but data were plotted for forces recorded between 10 degrees and 90 degrees only.

The rate of rotation of the lever arm was strictly controlled by a 3/4 horsepower electric motor equipped with a special gearing system, and electronics to correct for voltage fluntuations due to back Emf.

In the concentric mode subjects started with the elbow in a position of full flexion and attempted to accelerate the rotation of the lever arm by maximal, sustained dynamic contraction of the elbow extensors. (Isokinetic contraction)

In the eccentric mode subjects started in a position of full elbow extension and vigorously <u>resisted</u> the elbow flexion being forced upon them by the powered movement of the dynamometer. (The motor was powerful enough to prevent any change in rate of rotation due to efforts of the subjects.)

The order of test administration was randomized among subjects with rest periods of two minutes duration interposed between trials. All six trials (in addition to two warmup trials) were conducted in a single testing session.

Torque curves were plotted based upon averages computed over all subjects for every five degrees of rotation from zero to 90 degrees. (Every ten degrees for speed 3)

Best fitting regression equations, based on pooled concentric and eccentric data, were computed for all contraction velocities.

IV. Results

Examination of the raw mean curves for concentric contraction shows that the postulates of the Hill Equation are not supported. There appears to be no relationship of any kind between velocity and force.

Regression curves plotted for the concentric data confirm the fact that no real differences exist in the force produced regardless of the velocity at which the muscle was contracting.

Torques produced by eccentric contraction revealed quite a different picture. The raw mean curves appear to indicate that velocity of lengthening against resistance did have an effect upon the torque produced.

Regression curves would seem to indicate that the expected relationship between velocity (of lengthening, in this case) and force are observed. At least the curves are not generally overlapping and they appear to be arranged in the expected order (slowest speed lowest, - and fastest speed highest). There does appear to be an inexplicable discrepancy in terms of proportional differences observed.

Considering the velocities studied, theory would lead one to expect that the difference between the moderate and rapid torque curves to be at least as great as that between the slow and moderate curves. This was obviously not the case.

It might be noted at this point that, contrary to reports in some related studies, torque produced by eccentric contraction was not uniformly greater than that produced by concentric contraction. This is most apparent in the curves of mean torque. For much of the range tested there appears to be no difference between torques produced by either type of contraction. An exception is the fact that the curve for the fastest eccentric contraction is consistently higher than the others (except for the sharp dropoff over the last ten degrees).

As expected, peak torques were generated at approximately the same angle regardless of speed or contraction mode.

This latter fact is obscured in the regression equations, however, by the steep terminal dropoff noted previously.

Closer examination of this factor led to the conclusion that the regression equations appeared to fit the concentric data much more closely than the eccentric data.

It was also apparent that the sharp dropoff observed over the last ten degrees of eccentric contraction had a profound effect on the regression plot. Curves obtained for the moderate velocity illustrate these discrepancies.

Following these observations, new regression equations were computed after eliminating the data points for the last ten degrees on either end of the curve. Separate equations were computed for each type of contraction.

The effect on the concentric regression curves was negligible. The Quadratic equation continued to be the best fit. Torque generated is clearly independent of contraction velocity under these conditions.

On the other hand, an astonishing change was observed for the eccentric mode. The equations generated proved to be remarkably linear.

Further analysis revealed no significant differences in slopes of the three plots.

In order to determine whether the torques produced at the separate speeds were significantly different from each other, a randomized block analysis of variance was computed for the mean differences at 80 degrees.

A significant difference ($P > .99$) was observed. Tukey's test indicated significant differences between velocity 1 and velocity 3 only.

These findings serve to reinforce the speculation that, contrary to commonly accepted theory, velocity of lengthening contraction is not proportional to force exerted. In fact, there appears to be a diminishing effect as velocity is increased. (Such a conclusion is consistent with the findings of Chaplain, 1972, for Frog Sartorious.)

V. Conclusions

1. The Torques exerted by the human triceps in concentric contraction was found to be independent of contraction velocity.
2. Triceps torque produced by eccentric contraction was affected significantly by velocity of contraction but not in a directly proportional manner.
3. Eccentric contractile force was not found to be consistently superior to concentric contractile force.
4. The optimal elbow angle for maximal torque was the same regardless of velocity or mode of contraction.

5. Torques produced by concentric contractions appear to have been fundamentally different from those generated by eccentric contraction when viewed as a function of angle. Best fitting regression equations for concentric data were quadratic, whereas eccentric data were found to yield linear equations.

VI. Speculation

Speculation about the practical significance of these findings is dangerous because of the vast number of variables in this type of study. (Physiological, Mechanical, Psychological)

1. Our data support the idea that there is an interindividual specificity in terms of which type of contraction produces the greatest force (supports Hinson and Rosentsweig, 1973)
2. Discrepancies in results reported concerning the effects of eccentric training may be related to the rate of contraction. Our data seem to support the idea that slow eccentric training is superior to training involving rapid contraction. (Re: strength).
3. The data seem to support the notion that the molecular dynasmic dynamics of lengthening contraction are fundamentally different from concentric contractions.

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