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STRENGTH AND POWER IN ELITE SWIMMERS

By

Bonnie Lee Smoak

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ABSTRACT
STRENGTH AND POWER IN ELITE SWIMMERS

By
Bonnie Lee Smoak

One hundred and twenty-one national-caliber swimmers underwent Cybex testing and a modified vertical jump to provide descriptive data about strength and power in elite swimmers. Isokinetic absolute and relative torque and power measurements during elbow extension, shoulder joint extension, shoulder joint inward rotation, and knee extension at angular velocities of 30, 180, 240, and 300°/s were obtained. Absolute and relative average power, work, and vertical distance achieved during a modified vertical power jump were analyzed also. Five comparison groups were defined as follows: (a) male vs. female swimmers; (b) male sprinters vs. middle-distance swimmers; (c) female sprinters vs. middle-distance swimmers; (d) upper- vs. lower-twenty percent of male swimmers; and (e) upper- vs. lower-twenty percent of female swimmers.

Analyses of variance indicated that elite male swimmers were significantly stronger and more powerful than female swimmers. These differences were still apparent when body size and shape were considered.

Both male and female sprinters had mean torque and power values which were consistently higher than those recorded for male

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and female middle-distance swimmers respectively. Thirty-four of 160 comparisons were statistically significant.

Analyses of variance revealed that there were no significant differences in the majority of comparisons between upper- vs. lower-twenty percent of either male or female swimmers.

DEDICATION

To my brothers and sister and their families.

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Mary Ann V

ACKNOWLEDGMENTS

I would like to express my deep appreciation to Dr. William Heusner for his support during my graduate career and for his continual guidance during the writing of this dissertation. I am also grateful to Dr. Robert Echt for his personal assistance in my medical education and for his participation in my graduate school experience. I would like also to thank Dr. Kwok-kai Ho and Dr. Herbert Olson for their help in the preparation of this manuscript. Special thanks are given to Bruce and Mary Jo Alexander and Bob and Mary Ann Villaneuva for their hospitality and friendship.

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CHAPTER I

THE PROBLEM

Muscular strength and power are important, if not crucial, factors in many athletic events. While many studies have been performed in this area, few have contributed to a clear theoretical foundation of knowledge. One possible reason is that muscular strength is a complex phenomenon which is difficult to characterize. Multiple factors influence strength data. Age, sex, motivation, and test position as well as type, rate, and duration of muscular contraction are important (11, 13, 18, 51, 55, 73).

Early studies used isometric measurements to access human strength. A variety of instrumentation, such as spring dynamometers, strain gauges, cable tensiometers, and myometers, were used and detailed studies were performed to determine optimal body position during testing (17, 49). Measurements from these studies were reliable, but they did not correlate well with dynamic muscular performance (14, 30, 38, 63, 86).

Isotonic measurements have been used in strength studies, but several practical aspects of testing have limited its use. Subjects often had to lift several weights before the maximal resistance was determined. In addition, this method measures the weakest point in the range of movement.

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In 1967, Hislop and Perrine (44) introduced the concept of isokinetic exercise. Isokinetic movement is defined as joint motion in which the limb's angular velocity is held constant. This is accomplished by an external machine which provides a resistive force that matches the applied force. Muscular torque is measured continuously throughout the movement.

The Cybex,¹ an isokinetic dynamometer, allows various parameters of muscular function to be examined (i.e., torque, work, and power). In addition, these parameters can be examined near the angular velocities used during athletic events.

Several problems have been reported with the use of the Cybex in scientific measurements. Gravitational corrections should be made on raw data if comparisons between studies are planned (111). In addition, certain precautions must be observed to avoid confusing the peak values resulting from the deceleration of fast-moving limb with true peak torque values (88, 90, 102, 111). Finally, the torque-measuring transducer must be tested and calibrated to ensure valid measurements (31, 59).

The development of the Cybex has allowed several theoretical questions about human in vitro muscular performance to be examined. Studies comparing human torque-velocity curves and animal force-velocity curves have been performed (88, 102, 109). Other areas of research include studies examining the relationship

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of muscle fiber composition to torque-velocity curves (19, 25, 36, 52, 53, 91, 102, 103, 112) and the relationship of velocity-specific training to torque development (10, 26, 56, 67, 75, 95). Insufficient knowledge exists in these areas and further research is needed before definitive conclusions about such relationships can be made.

Strength differences between sexes also have been investigated. Untrained females have been reported to be only 59% to 84% as strong as untrained males (65). These differences are greater in upper body measurements than in lower body measurements (45, 65, 80, 110).

Relatively few studies have investigated strength and power in swimmers. This is surprising because strength training is a major component of the dry-land training performed by swimmers. One study reported that strength, determined by composite isometric measurements, in post-pubertal males was approximately equal to norms established for age and weight (105).

Significant negative correlations have been reported for isokinetic strength and power measurements and swim time (74, 93). Miyashita and Kanehisa (74) observed significant correlations between peak torque of armpull muscles at 210 °/s and the best performance time in 100M freestyle in both males (-.728) and females (-.515). Sharp, Troup, and Costill (93) observed a significant correlation (.90) between arm power, measured on a Biokinetic Swim Bench, and 25-yd swim velocity in a wide variety of competitive

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swimmers which included 22 females and 18 males. There was a gradual decline in the relationship between arm power and swim velocity as the distance increased ($r = 0.86$ at 100 yds, $r = 0.85$ at 200 yds, and $r = 0.76$ at 500 yds). However, these studies suggest that muscular strength and power is important in middle-distance as well as sprint events.

One study has investigated differences in strength between male sprinters and middle-distance swimmers. While the mean values of the sprinters were higher than those of the middle-distance swimmers, no significant differences were observed in the isometric measurements of shoulder joint flexion, shoulder joint extension, hip flexion, hip extension (6).

In summary, little information exists about strength and power in male and female swimmers. Some previous studies have used isometric measurements which have low correlations with dynamic performance. The development of an isokinetic dynamometer has allowed strength and power values to be determined at joint velocities used in swimming.

Purpose of the Study

The purpose of this study was to provide information about the muscular strength and power of elite swimmers. One hundred and twenty-one national-caliber swimmers served as subjects. Five comparisons of interest were defined. They were male vs. female swimmers, male sprinters vs. middle-distance swimmers, female sprinters vs. middle-distance swimmers, upper-twenty percent vs.

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lower-twenty percent of male swimmers as determined by best competitive times, and upper-twenty percent vs. lower twenty percent of female swimmers. Absolute and relative peak torque and power values in four joint movements at four angular velocities were analyzed. In addition, absolute and relative work, average power, and height attained in a modified vertical jump were analyzed.

Research Hypotheses

Elite male swimmers are stronger and more powerful than elite female swimmers. These differences exist even if body size and shape are considered.

The differences in strength and power between elite male and female swimmers is greater in upper body movements than in lower body movements.

Elite male and female sprinters exhibit greater strength and power at joint angular velocities near swimming rates than do male and female middle-distance swimmers.

The upper-twenty percent of elite male and female swimmers exhibit greater strength and power than do the lower-twenty percent of elite male and female swimmers.

Antecedent Problem

An easily administered test of leg power which would yield measurements in power units was needed for the assessment of elite swimmers. A modified vertical power jump was developed. This required a new derivation for the calculation of average power ($\bar{P}$) generated during the acceleration phase of a vertical jump. Its

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theoretical development is presented in Appendix A. An inexpensive but unique apparatus was developed to allow for easy measurements of displacement values.

Cinematographic techniques were used to validate the apparatus as a test of leg power. Twenty subjects were filmed using a Locam camera during an actual jump on the apparatus. The power values from film analyses were calculated with the following formula:

$$\frac{\text{Weight} \times \text{Gravity} \times \text{Total jump displacement}}{\text{Acceleration time}}$$

Highly visible markers were placed on the crest of the ilium to aide measurement of jump displacement. An electronic clock, accurate to one-thousandth of a second, was placed near the subject during filming. The acceleration time for film analyses was obtained by recording the time taken by the subject to rise from the lowest position of the squat to a position when the feet had just left the platform.

A Pearson product moment correlation coefficient of 0.95 was obtained between the $\bar{P}$ values obtained from the apparatus and the power values calculated from film analyses.

Reliability values were obtained through a test-retest study involving fifteen subjects. Each subject had six attempts at the power jump. The attempts were grouped into two rounds of three jumps each. A twenty- to thirty-minute interval was allowed between the test situations. The best performance in each test

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was used in the calculation. A reliability coefficient of .975 was obtained for the average power measurements.

Research Plan

The subjects were 121 swimmers who had been invited to a training camp on the basis of their outstanding swimming performance during the past year. The study was organized as five ex post facto one-way designs, each with two comparison groups. The groups were as follows: male ($n = 55$) vs. female ($n = 66$); male sprinters ($n = 38$) vs. middle-distance swimmers ($n = 17$); female sprinters ($n = 45$) vs. middle-distance swimmers ($n = 38$); upper-twenty percent of male swimmers ($n = 12$) vs. lower-twenty percent of male swimmers ($n = 9$); and upper-twenty percent of female swimmers ($n = 14$) vs. lower-twenty percent of female swimmers ($n = 12$).

The subjects underwent isokinetic testing of elbow extension, shoulder joint inward rotation, shoulder joint extension, and knee extension at angular velocities of 30, 180, 240, and 300 degrees per second. The protocols for testing the various joint movements will be described in Chapter III. Relative values by body weight, lean body weight, height, and ponderal index as well as absolute peak torque and power values were analyzed. Absolute and relative average power, work, and distance-jumped from the modified vertical power jump were analyzed also.

Rationale for the Research Plan

Several relative values of torque and power were obtained to facilitate comparisons between swimmers. Relative measurements

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by body weight and lean body weight were analyzed since strength is correlated with body size (16, 64, 107).

Unlike many sports, performance in swimming is affected only slightly by gravity. Relative strength values by factors other than weight may be more appropriate in comparisons of swimmers. Height was used to reflect lever length as well as body size. Ponderal index was selected to represent body shape (66, 107) which may be related to drag.

Limitations of the Research Plan

The results of this study can be generalized only to the age range and swimming caliber of the subjects used in this study.

Swimming involves complex joint actions. The isokinetic joint actions tested in this study do not duplicate the varying angles of pull, accelerations, and patterns of movement used in the crawl stroke.

Peak torque and power values may not measure the characteristics of strength and power that are needed to be successful in swimming.

The Cybex data were not corrected for gravitational errors. However, all measurement techniques were standardized and comparisons within this investigation are valid.

During isokinetic testing some subjects may not be able to achieve constant velocities of 240 or 300 $^{\circ}$ /s quickly enough in various joint actions to record valid peak torques.

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Each subject was encouraged and appeared to give maximal effort in each test procedure, but there was no attempt to quantify each subject's motivation.

Significance

Strength and power are important physical attributes in many athletic events. This study will help assess the relative importance of these attributes in elite swimmers. The results of this investigation may guide training methods in swimming and may help determine the significance of strength and power as a factor of success at high levels of competition.

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CHAPTER II

RELATED LITERATURE

The following sections will review the use and limitations of the Cybex in the measurement of muscular strength and power. In addition, several fundamental questions concerning in vivo muscle function, as determined by isokinetic testing, will be described. Discussions of the relationship between in vivo human torque-velocity (T-V) curves and in vitro animal force-velocity (F-V) curves, the relationship between T-V curves and muscle fiber composition, and the relationship between training and T-V curves will be presented.

The Cybex in Scientific Measurements

In 1967, Hislop and Perrine (44) introduced the concept of isokinetic exercise. During isokinetic exercise the rate of movement of body segments is held constant by an external machine. Torque is measured throughout the range of motion by means of a load cell oriented perpendicularly to the limb segment. Acceleration of the limb segment is prevented because the resisting force is proportional to the magnitude of the muscular force at every point in the range of motion. Thus, at the extreme ends of a joint movement, when the muscle has poor mechanical advantage, the resistance is the least. This enables a subject to exert maximum

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voluntary muscular contraction at each joint angle while maintaining a particular angular velocity. The muscle can perform maximum voluntary work at the preset speed.

The Cybex also allows several other variables to be measured. Work and power can be calculated from the observed torque curve. Maximal torque and power outputs can be determined by varying the angular velocity. When the number of contractions or a time duration is imposed, an average power output can be ascertained. Finally, the fatiguability of muscle groups can be measured by determining the percent decline in maximal torque that occurs after 50 contractions at a high angular velocity (104).

There has been confusion in the literature as to whether isokinetic refers to constant angular velocity of a limb segment or to constant linear velocity of muscular shortening. These two concepts are not synonymous. Using a mathematical model of elbow flexion, Hinson, Smith, and Funk (42) proved that a uniform angular velocity of a limb is not accompanied by a uniform linear rate of muscular contraction. While Perrine's work is somewhat ambiguous, his U.S. patent (No. 3465592) strongly suggests that isokinetic refers to exercise during which the angular velocity is held constant (44, 87). In this study, the term "isokinetic" will refer to movement involving constant angular velocity of a limb segment.

When the Cybex was first marketed, it was promoted not only as an exercise device but also as a scientific instrument that could measure muscle performance with great accuracy and reliability.

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Initial studies reported validity measurements of .92 to .99 (25, 67, 78, 102). These values were obtained by placing weights on the lever arm and comparing the observed torque, produced both statically at different angles and at different speeds, to calculated torques. Test-retest reliability with fixed loads were measured from .98 to .995 (25, 67, 71, 78, 101, 102). Following an initial acceleration period, angular velocities were found to be accurate to within the reading accuracy of the machine (25, 102).

In 1981, Winter, Wells, and Orr (111) reported on two potential sources of error in measurement with Cybex. First, they noted that vertical movements of body segments were affected by gravitational forces and that these forces were not reflected in uncorrected data generated by the Cybex. For example, if the weight of the limb segment was not considered, then the recorded torque involving joint motion against gravity was falsely low in value. Those acting with gravity had falsely elevated recorded torques. In addition, the magnitude of the error was potentially larger with submaximal contractions. This occurred because the gravitational correction factor remained the same regardless of the magnitude of the contraction. In contractions that produce large torque values, the gravitational correction factor represented a smaller percentage error. Due to differing limb masses and angles at which peak torque occurred, the gravitational correction factor was not constant between subjects.

Winter proposed a relatively simple solution for the above problem. By attaching an accelerometer, which acted as a cosine

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generator, to the lever system and by recording the torque produced when the limb-lever system was allowed passively to drop through the range of motion, a correction for gravitational errors over the full range of movement was made easily.

The second source of error noted by Winter is more troublesome and difficult to overcome. A large initial "peak" torque followed by a variable period of oscillation was observed to occur and to be more pronounced during higher velocity and larger torque-producing contractions. Several authors had noted these spikes (88, 102). Winter postulated that this prominent initial spike was caused by an impact artifact. During the initial phase of the movement, the limb is allowed to freely accelerate until it reaches a preset velocity. This initial acceleration is not recorded by the machine. A torque is recorded only when the velocity of the limb matches the preset angular velocity. However, since the limb may be moving very fast, the imposed fixed speed causes a deceleration of the limb. This produces a large initial torque which may be mistaken for a peak torque when in fact, it is an impact artifact. If the overshoot is mistaken for an actual torque, then not only will the magnitude of the peak torque be in error, but the angle at which it occurs will be in error.

Sapega et al. (90) further investigated this overshoot phenomenon to determine whether these spikes represented artifact or transient surges of muscular tension. Using cinematographic analyses with both inert weights and human subjects, they determined

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that the deceleration of the limb-lever system observed in the film quantitatively accounted for all the initial recorded overshoot torque. The secondary oscillations were also inertial in nature. They noted that the overshoot was greatest with limb-lever systems having large masses, with long lever systems, and with high angular accelerations. They concluded that these prominent initial spikes represent the sum of gravitational and muscular force as well as inertial forces and that they should not be mistaken for true muscular tension development.

Sapega et al. reported two methods to avoid the above error. One way is to eliminate all electronic damping of the torque signal. This allows the point at which the oscillations stop to be more easily identified. Torque values can be obtained accurately after that initial range. This technique was first reported by Perrine and Edgerton (88). The difficulty with this method is that at higher velocities the oscillations occur throughout most of the range of motion. Perrine and Edgerton reported that artifact-free data obtained at $288^{\circ}/s$ occurs only in the final thirty degrees of knee extension. Sapega et al. were unable to obtain artifact-free data during hip abduction at 180 degrees per second.

The second method of correcting the overshoot phenomenon involves using a damping circuit in the Cybex recorder. At low angular velocities, the overshoot is typically a sharp spike with a frequency of oscillation that is much higher than the overall torque curve. The use of selective electronic suppression in this

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instance corrected the artifact. However, as the test velocity increases, the primary overshoot is spread over a larger portion of the torque curve. This causes the frequency of the artifactual oscillations and the true torque curve to approach each other. Consequently, at higher velocities, the ability to selectively damp the overshoot is reduced.

Damping affects the torque curve in other ways. It lowers absolute torque values. In addition, in joint motion involving large masses and a relatively short range of motion, the damped curve exhibits a non-specific flattening and a rightward shift (94).

Gransberg and Knutsson (34) have reported an alternative method that corrects for the initial overshoot and secondary oscillations. It involves the use of computer-controlled resistance during the initial acceleration phase of the limb-lever system and the control of the start of joint motion at a predetermined torque level. Explicitly, joint movements are not allowed to start until some preset level of torque is reached. Then a preset angular acceleration is allowed through feedback of a computer until the selected angular velocity is achieved. The rate of increase of rotation speed is determined for each subject. If the angular acceleration is set too high, the torque of the lever arm will fall. If the angular acceleration is set too low, the time taken to reach the test angular velocity will be unnecessarily long. The use of controlled acceleration results in a longer period of time to reach the pre-selected angular velocity than is the case with the use of

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free acceleration. However, since the overshoot oscillations are minimized, the angular range with constant angular velocity is larger. This allows a larger portion of the torque curve to be used for data analysis.

Another potential source of error in the measurement of muscular force with the Cybex may occur in the detection of the recorded torque. Some authors have reported that the original oilcell used to detect torque produced a non-linear output (31, 59). Ericsson et al. (31) replaced the oilcell with a temperature compensated strain gauge transducer. Using this transducer, they found that the calibration constant differed between extension and flexion movement of the knee joint. During extension, the calibration constant was independent of joint angle. During knee extension, the calibration constant was dependent on the angle of flexion.

As described above, there have been some questions concerning the validity of uncorrected Cybex data. Other questions have arisen concerning which measurements to report. Most investigators have used maximum peak torque as the dependent variable. Other authors have questioned its validity and have suggested that angle-specific torque be used (10, 36, 37, 88, 108).

Angle-specific torque refers to the torque produced at some specific joint angle in a range of motion regardless of angular velocity. There are several advantages in using angle-specific torque (10, 36, 37, 88, 108). If a joint angle that occurs near the end of a joint movement is selected, then data can be collected

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in an area of the torque curve that is not affected by the overshoot phenomenon. More importantly, the use of angle-specific torque allows measurements to be made at a relatively constant muscle length and moment arm within each subject. In addition, the use of a joint angle near the end of the joint movement may allow the muscle sufficient time to generate maximum tension, especially at higher test angular velocities.

A possible problem in using human angle-specific T-V curves may develop when these curves are compared to in vitro F-V curves obtained in animals. Angle-specific torque curves, especially when joint angles occurring late in the joint movement are used, may be influenced by the mechanical relationships between the muscle and the joint. This would make comparisons to in vitro curves, where a straight line of force operates, difficult.

While the use of maximum peak torque appears empirically appropriate, there is question as to its validity in isokinetic movement. First, peak torque must not be confused with the overshoot spike. Second, theoretical and empiric observations suggest that peak torque may not be an appropriate measure in comparisons of torques produced at different angular velocities. For example, it has been reported that peak torques during knee extension occur at progressively smaller angles as angular velocity increases (76, 85, 88, 92). This observation has several possible explanations. First, as angular velocity increases, joint movement time decreases. However, the time for a muscle to reach maximum tension

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is relatively fixed (25). Thus, at higher velocities, the observation that peak torque occurs later may merely reflect the time needed for tension development. Second, since the peak torque occurs at later angles in rapid joint movements, the measured torque is influenced both by a change in the angle of muscular pull and by a change in the length of the muscle.

Some authors have used both peak torques and angle-specific torques in their investigations. When angle-specific torques are graphed from data provided by Thorstensson, Grimby, and Karlsson (102) and compared to peak T-V curves in the same study, the curves appear different. Angle-specific curves are lower in magnitude and appear to plateau at slow velocities.

In a later study, Yates and Kamon (112) compared the T-V curves produced during knee extension from peak torque values and from angle-specific measurements. They reported significant differences in the magnitude of absolute values at randomly assigned velocities from 30 to 300 $^{\circ}$ /s. However, the curves ran parallel to each other and were similar in shape. When the curves were normalized with respect to torque produced at 30 $^{\circ}$ /s, no significant differences were observed.

Coyle et al. (26) simultaneously measured damped peak torque and undamped angle-specific torque during knee extension. They found a difference in magnitude between the two curves. After training, both curves changed. Peak torque was observed to be a more reliable measure ($r = .96$) as determined from test-retest measures on alternate days.

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It is not clear from the literature whether peak torque values or angle-specific values should be used. With the use of a computer, both values are obtained easily. Past investigators have used mostly peak torque values. This fact, combined with the current knowledge concerning the limitations of uncorrected Cybex data, may explain partly the conflicting studies in this area.

Despite the technical and procedural difficulties noted above, the development of the Cybex has allowed the investigation of fundamental questions concerning in vivo muscle function. The following sections will discuss the relationship between human T-V curves and animal F-V curves, the relationship between torque-velocity curves and muscle fiber composition, and the relationship of training to alterations in T-V curves

Relationship of In Vivo T-V Curves to In Vitro F-V Curves

In the early 1900s several investigators developed empirical equations describing the relationship between the force generated and the velocity of muscular shortening in isolated animal tissues. One well-known equation was constructed by Hill (39). His equation implied that the speed of muscular shortening is inversely related to the load against which the muscle shortens. The relationship followed a rectangular hyperbolic curve with the force rising increasingly as the velocity decreased until a maximum was attained at zero degrees. Hill was able to fit most of the observed values in his experiments to the curve defined by his equation. However,

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values obtained in the low tension, high velocity portion of the curve showed some deviations. He attributed these discrepancies to the presence of a certain number of fibers with high intrinsic speed (41).

In 1950, Wilkie (109) conducted comprehensive experiments with isotonic loading to determine the specific relationship between maximum myometric force and velocity in human muscle. He concluded that, after a mathematical correction for the effects of inertia had been made, the in-vivo muscle appeared to exhibit the same F-V relationship that had been determined previously for isolated animal muscles.

In Wilkie's studies, the actual force outputs of the subjects' muscles were not measured directly. The development of the Cybex allowed for the direct measurement of torque produced at specific velocities in various human muscle groups.

Thorstensson, Grimby, and Karlsson (102) studied the T-V curves of human knee extensors using a Cybex. They concluded that their observations on intact human muscle were consistent with earlier findings in animal preparations.

Perrine and Edgerton (88) disagreed with the conclusions of earlier investigators. In a study of ten males and five females of widely varying physical fitness levels, they concluded that there were major discrepancies between the T-V curves found for maximal angle-specific torques during knee extension and the F-V curves reported for animal muscle. At high test velocities (192, 240,

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288 $^{\circ}/s$), the data appeared to follow a curve similar to animal preparations. However, as velocity decreased, their curve appeared to plateau and follow a distinctly different pattern. The torques at the lower velocities and under isometric conditions were lower than predicted values. In addition, torques at low velocities were sometimes higher than those generated isometrically.

Perrine and Edgerton critically reviewed the data presented by Thorstensson, Grimby, and Karlsson (102). When peak torque values were plotted, the Thorstensson data appear to follow curves similar to those found in animal in vitro studies. When angle-specific torque values were graphed, curves similar to those of Perrine and Edgerton were generated. The major exception was that torque at zero degrees per second appeared to have higher values in Thorstensson's data. Other authors have reported a plateau region at slow velocities during knee extension using peak torque values (19, 58, 92) and angle-specific torque values (76). Torques at zero $^{\circ}/s$ were more consistent in Thorstensson's data.

Several characteristics of the plateau effect should be noted. The plateau is more readily identified when several test velocities below 90 $^{\circ}/s$ are used. The plateau is more pronounced during knee extension as the angle at which torque is measured becomes smaller. This is seen in Thorstensson's data and was noted by Perrine and Edgerton in their data.

The plateau may be more pronounced in untrained individuals. Caiozzo, Perrine, and Edgerton (10) reported that untrained subjects

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who trained for four weeks with an isokinetic dynamometer showed a marked improvement in angle-specific torque at low velocities which decreased the plateau effect.

Similar plateau regions in angle-specific torque curves have been reported for muscle groups used in knee flexion, plantar flexion, and dorsal flexion in untrained subjects (108).

While it remains to be determined to what extent human T-V curves resemble animal F-V curves, clearly their interpretation must be different. In classical F-V studies, the force of an isolated muscle is measured in a direct line of pull. The force is representative of muscular tension. In human studies, torque values do not measure actual muscular force. Joint position-tension relationships and the time needed to development maximum tension may confound interpretations. The use of angle-specific measurements may overcome these shortcomings.

Relationship Between T-V Curves and Muscle Fiber Composition

An athlete's performance in a particular event may be dependent on the individual's muscle fiber composition. Several investigators have suggested that athletes who have a higher proportion of fast contracting muscle fibers are more likely to succeed in events that require maximal force production at high velocities (62, 102, 103). The development of the Cybex has allowed investigators to explore the functional significance of different muscle fiber compositions in the generation of torque and power at different velocities.

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Significant relationships between relative peak torque and muscle fiber composition have been reported (25, 36, 53, 102). Coyle, Costill, and Lesmes (25) studied twenty-one physically active males. The subjects were divided on the basis of a needle muscle biopsy of the vastus lateralis into a fast-twitch (FT) group, having greater than 50% FT fibers, and a slow-twitch group (ST), having less than 50% FT fibers. The FT subjects were able to generate 11, 16, 23, and 47% greater relative (normalized to peak torque produced at $57^{\circ}/s$) torque at velocities of 115, 200, 287, $400^{\circ}/s$ respectively than the ST group during leg extension. Correlations between relative torque production and the percentage of FT fibers were significant and rose in value as velocity increased. The results suggest that muscle fiber composition becomes increasingly related to power performance as velocity increases.

These observations were consistent with results reported by Thorstensson, Grimby, and Karlsson (102). They found a significant correlation in males between the percentage of maximal isometric torque that a subject could generate at a velocity of $180^{\circ}/s$ during knee extension and the percentage as well as the relative fiber area of FT fibers. In addition, there was a significant positive correlative between the maximal contraction velocity and the percentage and relative area of FT fibers.

Thorstensson, Larsson, Tesch, and Karlsson (103) reported that the proportion of FT fibers in the vastus lateralis was related to the peak torque produced during knee extension in elite athletes.

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The subjects included track and field athletes, skiers, race walkers, and orienteers.

Ivy et al. (53) studied muscle fiber composition and relative torque production in fifteen active males during knee extension. The subjects were divided into a FT group (greater than 60% FT fibers), and intermediate group, and a ST group (greater than 60% ST fibers). The FT group exerted more relative torque (per unit fat-free thigh volume) at each test velocity than either the intermediate or ST groups. However, there was a significant difference between the FT and ST groups only at 180 $^{\circ}$ /s. Peak power was significantly correlated to the percentage of FT fibers at 60, 120, 180, and 240 $^{\circ}$ /s.

During the initial contractions of an isokinetic fatigue test, Tesch et al. (98) found significant correlations between the percentage and relative area of FT fibers and knee extensor peak torques at 180 $^{\circ}$ /s in nine physical education students.

Clarkson, Kroll, and Melchionda (19), in a study involving five male and four female elite canoe and kayak paddlers, found significant correlations between the diameters of fast oxidative-glycolytic (FOG) and fast glycolytic (FG) fibers in the biceps brachii and peak torques at 0, 60, and 180 $^{\circ}$ /s during knee extension. FT fiber size and percentage area of FT fibers significantly correlated with peak torque at the test velocities.

Other investigators have reported no significant relationships between muscle fiber composition and torque production during

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isokinetic movement. Schantz et al. (91) observed no significant correlations between relative torque (per muscle cross-sectional area times body height) and the percentage area of ST fibers from the vastus lateralis and triceps brachii in seven female and eleven male physical education students. Ingemann-Hansen and Halkjaer-Kristensen (52) reported no significant correlations between percent or relative area of ST fibers and the slope of the peak T-V curves plotted on a semilogarithmic scale.

In the preceding investigations, peak torque values were analyzed. As mentioned earlier, the use of peak torque values may not differentiate whether FT subjects actually generate greater muscular tension at high velocities or if the higher peak torques merely reflect the ability of FT subjects to accelerate faster (25). Nilsson, Tesch, and Thorstensson (79) reported a significant correlation between the percentage of FT fibers and the time required to accelerate to a constant velocity. This characteristic would enable FT subjects to achieve the test velocity in a faster time and at an angle closer to the optimal angle for torque production. The use of angle-specific torque may overcome this problem.

Gregor et al. (36), in a study involving 22 elite track and field female athletes, reported significant differences in angle-specific knee extensor torques at 96, 196, and 288 $^{\circ}/s$ between subjects who had greater than 50% ST fibers in the vastus lateralis and subjects who had less than 50% ST fibers. Relative torque values (per kg body weight) were significant only at 192 $^{\circ}/s$.

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Significant correlations, which increased in value as the angular velocity increased, were observed between relative FT fiber area and angle-specific torque.

Yates and Kamon (112) compared peak T-V curves and angle-specific T-V curves during knee extension. The subjects were separated into a FT and ST group based on a muscle biopsy from the vastus lateralis. When angle-specific torque values were used, the FT group was able to generate a significantly greater percentage of normalized torque at 180, 210, 240, 270, and 300 $^{\circ}$ /s than the ST group. No significant differences existed between the groups when normalized peak T-V values were used. The results suggested that angle-specific measurements may be more sensitive to differences in fiber type.

No definitive conclusions can be drawn about the relationship of muscle fiber composition and the T-V curve. It appears that there may be a significant relationship between the percentage of FT fibers and relative knee extensor torques. The weak association of muscle fiber composition to the torque-velocity curve may be due to the current instrumentation. The maximum speed of the Cybex is approximately 30-40% of the maximum contractile velocity of the knee extensors. The peak efficiency of a predominantly fast twitch muscle may not have been tested.

The above studies had other limitations. None of them used gravitational corrections with their data. The biopsy investigations attempt to categorize subjects into slow-twitch and fast-twitch

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groups based upon limited data obtained from a single leg muscle that may not be critical in the sport studied. In addition, heterogeneous groups of subjects and small sample sizes limit the conclusions of some studies.

Relationship of T-V Curves to Training

Numerous studies have tried to determine the optimum method for increasing strength and power. With the aid of the Cybex, researchers have investigated the effects of velocity-specific training in human strength development.

One of the earliest studies was performed by Moffoid and Whipple (75) in 1970. Twenty-three females and five males were divided into three groups: one group trained at a velocity of $36^{\circ}/s$ (group I), one trained at $108^{\circ}/s$ (group II), and one served as a control group. The subjects performed two minutes of maximal exercise every other day for six weeks. Group I showed significant improvement in peak torque at 18 and $36^{\circ}/s$ and non-significant increases at all other test velocities. Group II showed even gains in peak torque at all test velocities except zero degrees per second. These gains were greater than those observed in the control group, but were not significant. While the authors concluded that low speed exercise produces strength gains only at slow speeds and that high speed exercise produces strength gains at the below the training speed, it should be noted that knee extension at $180^{\circ}/s$ is not a high-speed exercise. Maximal knee extension velocities averaging $687^{\circ}/s$ have been reported (102). Furthermore, the limb velocities in sport activities have been reported to be $180^{\circ}/s$ or higher.

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The terminology of "fast" and "slow" speeds should be avoided. In this paper, actual test velocities will be stated.

Lesmes et al. (67), as part of a larger investigation reported significant improvement in peak torques during knee extension after training four times per week for seven weeks. Five male subjects trained at 180 $^{\circ}$ /s. Significant gains in peak torques were observed at 0, 60, 120, and 180 $^{\circ}$ /s. Nonsignificant gains were reported at velocities of 240 and 300 $^{\circ}$ /s. These results support the work of Moffoid and Whipple (75) and suggest that gains in strength from isokinetic training at 180 $^{\circ}$ /s occur at the training velocity and at slower velocities.

Later studies included higher limb velocities. Smith and Mellon (95) investigated the effect of training on knee extension at low angular velocities (30, 60, 90 $^{\circ}$ /s), at higher angular velocities (180, 240, 300 $^{\circ}$ /s) and with a variable-resistance machine (Nautilus). The subjects trained three times a week for six weeks. Sample size was small ($n = 3$) and the entire T-V curve was not reported. The slower isokinetic group demonstrated significant gains at both low and high velocities (.5, 21, 25% at 0, 60, and 240 $^{\circ}$ /s, respectively). The faster isokinetic group had significant gains only at higher speeds (7, 3, 61% at 0, 60, and 240 $^{\circ}$ /s, respectively).

Coyle et al. (26), in an interesting experiment, divided 22 physically active males into five groups: a control group, an isokinetic group training at 60 $^{\circ}$ /s, an isokinetic group training at 300 $^{\circ}$ /s, a mixed group training at both 60 and 300 $^{\circ}$ /s, and a

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placebo group. The placebo group received low-level faradic muscle stimulation. Each group trained three times per week for six weeks. The placebo group showed a significant gain in two-legged knee extension peak torque values at 0 °/s only. The 60 °/s group exhibited significant gains of 20.3, 31.8, and 9.2% at 0, 60, and 180 °/s respectively. The 300 °/s group demonstrated gains of 23.6, 15.1, 16.8, and 18.5 at 0, 60, 180, and 300 °/s respectively. The mixed group had significant gains of 18.9, 23.6, 7.9, and 16.1 at 0, 60, 180, and 300 °/s respectively. In comparison to the placebo group, the 60 °/s group and the mixed group had significantly greater gains at a velocity of 60 °/s. At a test velocity of 180 °/s, only the 300 °/s group had a significant gain over the placebo group. Finally, at a test velocity of 300 °/s, the fast and the mixed group were significantly different from the placebo group. The results of this study indicate that training at a slow velocity of 60 °/s does not improve performance at higher velocities of 300 °/s. However, training at high velocity (300 °/s) may improve performance, not only at that velocity, but at slower velocities as well.

Caizzo, Perrine, and Edgerton (10) used angle-specific torque as the dependent variable in their study of training-induced alterations in the T-V curve. Twelve males and five female sedentary subjects were divided into a control group, a group trained at 96 °/s, and a group trained at 240 °/s. The subjects trained three times a week for four weeks. The 96 °/s group had significant gains of 14.7, 14.2, 8.0, 7.8, 7.9, and 5.5% for test

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velocities of 0, 48, 96, 144, 192, and 240 $^{\circ}$ /s respectively. The 240 $^{\circ}$ /s group had significant gains of 5.9, 6.6, and 8.8% at 144, 192, and 240 $^{\circ}$ /s respectively. In contrast to the results found in some studies the fast group did not show improvement at slower velocities.

Kanehisa and Miyashita (56) randomly divided 21 males into three experimental groups: one group training at 60 $^{\circ}$ /s, one at 180 $^{\circ}$ /s, and one at 300 $^{\circ}$ /s. Each group trained six times a week for eight weeks. Significant gains in average power were reported in the 300 $^{\circ}$ /s group at velocities of 240 and 300 $^{\circ}$ /s. The 180 $^{\circ}$ /s group had significant gains at all test velocities (30 through 300 $^{\circ}$ /s) with the greatest gains occurring at 180, 240, and 300 $^{\circ}$ /s. The 60 $^{\circ}$ /s group showed significant increases in power at all test speeds, but greater gains were seen in the lower velocities.

The small number of studies in this area makes definitive conclusions difficult. The studies used several types of velocity curves which make comparisons inappropriate. In addition, the length and intensity of training varies greatly between the studies. Additional studies are needed in this area.

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CHAPTER III

RESEARCH METHODS

The purpose of this study was to provide descriptive strength and power data on elite male and female swimmers. Comparisons were drawn between sexes, between sprint and middle-distance swimmers, and between swimmers of different performance levels. Absolute and relative torque and power measurements during elbow extension, shoulder joint inward rotation, shoulder joint extension, and knee extension at angular velocities of 30, 180, 240, and 300 degrees per second were obtained. In addition, absolute and relative average power, work, and distance jumped during a modified vertical power jump were analyzed.

Several hypotheses were tested. First, elite male swimmers would be stronger and more powerful than elite female swimmers. Second, sprinters would be stronger and more powerful than middle-distance swimmers. Finally, the upper-twenty percent of swimmers would exert greater torque and power than the lower-twenty percent of swimmers.

Subjects

Based upon performances at the Junior National or Senior National Swimming Meets from the previous year, the subjects were selected and invited to participate in one of three two-week

training sessions at the Olympic Training Center in Colorado Springs, Colorado during the summer of 1979. Sixty-six females and 55 males accepted the invitation to participate.

The training camp was conducted by various nationally known coaches. The camp included training sessions and a series of physiological performance tests that were designed to assess the abilities of the athletes to perform the physical tasks involved in competitive swimming. These tests included a tethered swim with progressive restraining loads, anthropometric measurements, body composition determinations, Cybex testing, and a modified vertical power jump. The physiological testing was administered by a team of investigators from various universities and by the staff of the exercise physiology laboratory at the Olympic Training Center. In addition, each subject completed a training and performance questionnaire.

Prior to the testing, each subject was informed fully of the risks, discomfort, and possible benefits associated with these tests and each signed an informed consent form. If the subject was below the age of 18, a parent also signed the consent form.

The mean age for the females was 16 yrs 10 mos and the mean age for the males was 18 yrs 1 mo.

Testing Procedures

The procedures used in the collection of data during anthropometric measurements, body composition, Cybex testing, and the modified vertical power jump will be discussed.

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Anthropometric Measurements

The physique of the human body can be accurately described through a series of external measurements. In this study, height, weight, and ponderal index were obtained.

The stature of each subject was determined by having the individual, without shoes, stand with his/her back against a sliding scale on a wall. Heels were placed together and the toes were angled slightly out. A steel blade projected from the scale. The head was adjusted so that the blade formed a horizontal line and rested on the top of the subject's head. Height in tenths of a centimeter was read from the underside of the steel blade.

The weight of each subject was obtained by having the individual, wearing only a swimming suit, stand on a calibrated Toledo balance scale. Weight was measured to a tenth of a pound and converted to the nearest tenth of a kilogram.

The ponderal index was used as a measure of body shape (43). The ponderal index was calculated as:

$$\text{Ponderal Index} = \frac{\sqrt[3]{\text{Weight (kg)}}}{\text{Height (cm)}} \times 1000$$

Body Composition

The assessment of subcutaneous body fat was accomplished by the use of Lange calipers to measure the thickness of a double layer of skin and the interposed layer of fat in tenths of a millimeter.

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The following skinfold sites, as described by Behnke and Wilmore (3), were measured:

Subscapular. Inferior angle of the scapula with the fold running parallel to the axillary border.

Triceps. Midway between the acromion and olecranon processes on the posterior aspect of the arm, the arm held vertically, with the fold running parallel to the length of the arm.

Supra-iliac. Vertical fold on the crest of the ilium at the midaxillary line.

Thigh. Vertical fold on the anterior aspect of the thigh midway between the hip and knee joints.

The Sloan-Weir formulas were used to predict body density (D_b) from skinfold measurements. The formulas are as follows:

Male: $D_b = 1.1043 - 0.00133 (\text{thigh skinfold}) - 0.00131 (\text{subscapula skinfold})$

Female: $D_b = 1.0764 - 0.00081 (\text{suprailiac skinfold}) - 0.00088 (\text{triceps skinfold})$

The percentage of body fat was calculated from the following formula of Brozek et al. (9).

$\text{Fat \%} = 100((4.570/D_b) - 4.142)$

Lean body weight was determined simply as total body weight minus estimated fat weight.

Cybex Testing

Cybex testing was used to evaluate muscular strength and power. The Cybex is an isokinetic dynamometer that controls movement by giving resistance at a preset speed of angular rotation. Joint angular velocity is prevented from surpassing the preset level by the rotation of a motordriven axis kept at the preset speed by

a feedback control. The device allows maximum muscular contractions to be performed throughout a defined range of movement at the fixed velocity. At velocities lower than that preset, the movement is unresisted.

Torque is measured by a load cell oriented perpendicularly to the limb segment. The torque recorded reflects the dynamometer's resistance to the movement and may differ from the muscle force producing the movement. This concept was discussed in Chapter II.

Peak torque, regardless of joint angle, was measured by a Cybex II and recorded using a dual channel Cybex recorder. The Cybex unit was calibrated at the beginning of each test period or whenever a baseline drift occurred.

Measurement in foot-pounds was made in a section of the torque curve that avoided the overshoot phenomenon. When this study was performed, the necessity for a gravitational correction of limb segments was not appreciated. The data in this study represent uncorrected measurements.

Values of peak torque in foot-pounds were converted to units of newton-meters using the following formula:

$$\text{Torque (N} \cdot \text{mtr)} = 1.35582 \times \text{Torque (ft} \cdot \text{lbs)}$$

Peak power in watts was calculated from the original data using the following equation:

$$\text{Power (watts)} = .01745 \times \text{angular velocity (}^{\circ}\text{/s)} \times$$

$$\text{Torque (N} \cdot \text{mtr)}$$

Relative values of peak torque and peak power were calculated to facilitate the comparisons between swimmers of varying body sizes. Measurements of peak torque and power were divided by weight in kilograms, height in centimeters, lean body weight in kilograms, and ponderal index.

The joint movements tested were elbow extension, shoulder joint extension, shoulder joint inward rotation, and knee extension. Joint movements on both the right and left sides of the body were examined; however, for the purpose of the study, the maximum value obtained from either the right or left side was analyzed.

Each joint action was tested at velocities of 30, 180, 240, and 300 degrees per second. The rate of 30 $^{\circ}$ /s was selected to obtain strength data. The velocities of 180, 240, and 300 $^{\circ}$ /s were selected to obtain power data. The two highest rates are similar to angular velocities achieved at the shoulder joint during swimming.

Each joint movement was tested on separate days. Each subject was given a standard set of instruction and was encouraged to perform as well as possible. The subjects were allowed to warmup by performing several joint movements at each velocity prior to testing. After the warmup period at each velocity, the subject attempted two maximum contractions. The larger of the peak torques measured was recorded. Approximately one to two minutes were allowed between test motions. Slow velocities were measured first, with sequential testing of the faster velocities. Range of joint motion was not measured simultaneously with torque production.

Elbow extension was performed with the subject kneeling in front of the test table with the upper arm placed horizontally on the table. The forearm was pronated and the hand gripped a handle on the Cybex. The length of the dynamometer input lever arm was adjusted to each subject to allow smooth, comfortable movement throughout the range of motion. The axis of the Cybex was aligned as closely as possible to the axis of rotation of the elbow. Movement of the forearm was in a sagittal plane with a range of motion of approximately 150° to 0° (0° equals full elbow extension). The subject was not permitted to raise the shoulder or lift the upper-arm from the table during testing.

Shoulder joint extension was performed with the subject lying supine on the test table. The elbow was held in full extension throughout the movement. The hand, with the forearm in a slightly pronated position, grasped a handle on the input arm of dynamometer. The length of the input arm of the Cybex was adjusted to allow for comfortable movement throughout the range of motion. Limb movement occurred in a sagittal plane from 180° to 10° (0° equals arm adducted to the side of the body). The subject was not permitted to raise the shoulder from the table during testing.

Shoulder joint inward rotation was tested with the subject kneeling beside and facing the test table. The upperarm was placed horizontally on the table with the elbow held at a 90° angle. The forearm was held in a neutral position with the palm of the hand facing a sagittal plane through the midline of the body. The hand

grasped a handle attached to the input lever of the Cybex. The length of the input lever was adjusted to allow for comfortable movement throughout the range of motion. The forearm moved in a coronal plane from 90° (vertical) to 0° (horizontal).

Knee extension was tested with the subject sitting on a test chair. The thigh was stabilized with a velcro strap. A shinpad, attached to the input lever arm, was placed on the tibia just proximal to the malleoli. Limb movement occurred in a sagittal plane with a range of motion from 90° to 0° (0° equals leg at full extension).

Modified Vertical Power Jump

The use of a modified vertical power jump was included in this study to provide a measurement of total leg power. This action is important in starts and turns in swimming.

A new derivation for the calculation of average power generated during the acceleration phase of a vertical jump was developed. The new equation differs slightly from a formula reported by Gray, Start, and Glencross (35). Its theoretical development is presented in Appendix A. In its final form, the formula for average power production ($\bar{P}$) during a vertical jump is:

$$\bar{P} = \frac{w (.8644s_1 + .0046 + s_1)}{.8644s_1 + .0046} \frac{\sqrt{gs_2}}{2}$$

where:

g = force of gravity

s_1 = squat displacement

s_2 = jump displacement

w = body weight

Thus, average power can be calculated from the three measured variables of body weight, squat displacement, and jump displacement.

An inexpensive but unique apparatus was developed to allow easy measurement of squat displacement and jump displacement. The apparatus consisted of an L-shaped pole secured into a wooden platform (see Figure A1 in Appendix A). Measuring tapes were located at the top of the pole and beneath the wooden platform. A line connected the ends of the two tapes. Each tape traveled through a felt pad. The pad provided sufficient friction to stop the movement of the tape as soon as the force causing the movement was removed.

The line between the two measuring tapes was attached to the subject's lower back midway between the posterior superior iliac spines. During the attachment, the subject simulated the actual take-off position by standing in a planter-flexed posture. In the take-off position, both tapes recorded values of zero. As the subject assumed a natural squatting position, the upper tape on the pole was drawn out. This provided a measurement of squat displacement. From the time the subject passed the take-off position until the peak of the jump, the bottom tape was drawn out. This provided a measurement of jump displacement.

To ensure that the movement of the center of gravity was in a vertical direction with little lateral or anteroposterior

displacement, a 1 ft by 1 ft box was drawn on the wooden platform. If the subject landed outside the dimensions of the box, the jump was not recorded.

Arm movements were eliminated by having the subjects place both hands on the hips during the jump. The jump was initiated from a standing position and the subject was allowed to accelerate the body naturally. Each subject was allowed three warm-up jumps and three trial jumps. Between each trial jump, squat displacement and jump displacement were obtained and recorded to the nearest .5 cm.

Body weight was measured before the test situation.

Research Design

The present study was designed to provide data describing the muscular strength and power in elite swimmers. It was organized as five one-way ex post facto designs with each design having two treatment groups.

The first comparison involved the preassigned characteristic of sex. Data from 55 males and 66 females were analyzed.

The second and third comparisons were based on the distance swum during competition. Separate analyses were obtained for male and female swimmers. A subject was classified as a sprinter if his/her best performance time was in an event with a distance of 200 meters or less. A subject was classified as a middle-distance swimmer if his/her best performance time was in an event with a distance between 200 and 1,500 meters. If a swimmer had excellent

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times in both categories, the decision as to which group to place the subject was based on his/her training. Subjects who trained primarily at short distances and high intensities were classified as sprinters. Swimmers who trained at long distances were placed in the middle-distance group. Forty-five females and 38 males were classified as sprinters. Thirty-eight females and 17 males were classified as middle-distance swimmers.

The fourth and fifth comparisons were based on the quality of the best performance of each swimmer. Separate analyses were obtained for male and female swimmers. A quality rating was assigned to each subject that reflected the relationship between his/her best performance time and the American record in that event. If the swimmer held the American record, then a quality rating of 100.0 was given. If the swimmer's time was 4% slower than the American record, then a quality rating of 104.0 was assigned.

Two treatment groups in each comparison were obtained using the quality ratings. One group consisted of the upper-twenty percent of the swimmers based on performance. The second group was the lower-twenty percent. Fourteen females and twelve males represented the upper-twenty percent group, respectively. Twelve females and nine males were in the lower-twenty percent group, respectively.

Statistical Procedures

Independent variables in this study were sex, distance competitively swum (male and female), and quality of best performance (male and female).

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Dependent variables were analyzed using one-way fixed effect analyses of variance. The following dependent variables were analyzed: height, weight, lean body weight, ponderal index, absolute and relative torque and power values by weight, lean body weight, height, and ponderal index for elbow extension, shoulder joint inward rotation, shoulder joint extension, and knee extension at angular velocities of 30, 180, 240, and 300 degrees per second, absolute and relative average power, work, and distance jumped by weight, lean body weight, height, and ponderal index from the modified vertical power jump.

A statistical probability of less than 0.05 was considered to indicate significant differences between means.

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CHAPTER IV

RESULTS AND DISCUSSION

The material in this chapter is organized into eight main sections. The first part deals with the isokinetic and modified vertical power jump results from the male vs. female comparison. The second and third sections cover the isokinetic and modified vertical power results from the male and female sprinters vs. middle-distance swimmers, respectively. Strength and power results from the upper- vs. lower-twenty percent of male and female swimmers are discussed in the fourth and fifth sections. Discussions of the more important findings from the male vs. female, sprinter vs. middle distance swimmers, and upper- vs. lower-twenty percent of swimmers comparisons are given separately at the end of the chapter.

Standard errors were not included in the figures presented with the results because of the unequal number of subjects in each group. Standard deviations are given in Appendix B.

Males vs. Females

This section is subdivided into three parts. The first part describes the subjects. Next, the isokinetic data are presented. Modified vertical power results are given last.

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Subject Characteristics

Selected parameters of the subjects are presented in Table 1. Sixty-six females and 55 males participated in the study. The average age of the females was 16 years 10 months. The average age of the males was 18 years 1 month. The males were significantly older, taller, heavier, and leaner than the females. No significant differences were observed in ponderal index or quality of swimmer.

Isokinetic Data

Actual values and ANOVA results for each joint action and angular velocity are presented in Appendix B, Tables B1 through B5.

Cybox data obtained during elbow extension are presented in Figures 1 through 3. All comparisons between male and female swimmers, at each angular velocity using all absolute and relative values, were highly significant ($p < .001$). Both males and females showed an increase in power as velocity increased with maximal values of power occurring at 300 $^{\circ}/s$. The most significant difference in absolute power, as determined by the F ratio, occurred at 240 $^{\circ}/s$. This also was observed in power values relative to height and ponderal index.¹ When values relative to body weight and lean body weight were examined, the largest difference in power occurred at 300 $^{\circ}/s$. Furthermore, the sex-related differences in strength

¹Figures are not provided for data relative to height and ponderal index because the patterns observed with increasing joint velocities were identical to those shown for absolute torque and power values in these and all subsequent comparisons.

TABLE 1. Selected Parameters of Male vs. Female Swimmers

	Females			Males			ANOVA	
	<u>n</u>	<u>$\bar{x}$</u>	<u>s</u>	<u>n</u>	<u>$\bar{x}$</u>	<u>s</u>	<u>F</u>	<u>P</u>
Age (months)	66	202	18	55	217	17	20.04	<.001
Height (cm)	65	169.7	5.0	54	180.7	6.3	113.29	<.001
Weight (kg)	66	60.4	5.9	55	72.9	6.5	123.21	<.001
Lean Body Weight (kg)	66	48.9	3.9	55	66.3	5.6	395.85	<.001
Percent Body Fat	66	18.8	2.4	55	9.1	2.0	586.31	<.001
Quality of Swimmer	66	106.2	2.4	55	105.9	2.1	.37	.54
Ponderal Index	65	23.09	.67	54	23.10	.70	.006	.94

Torque (N·m)

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o—o Females (n = 64)

x—x Males (n = 54)

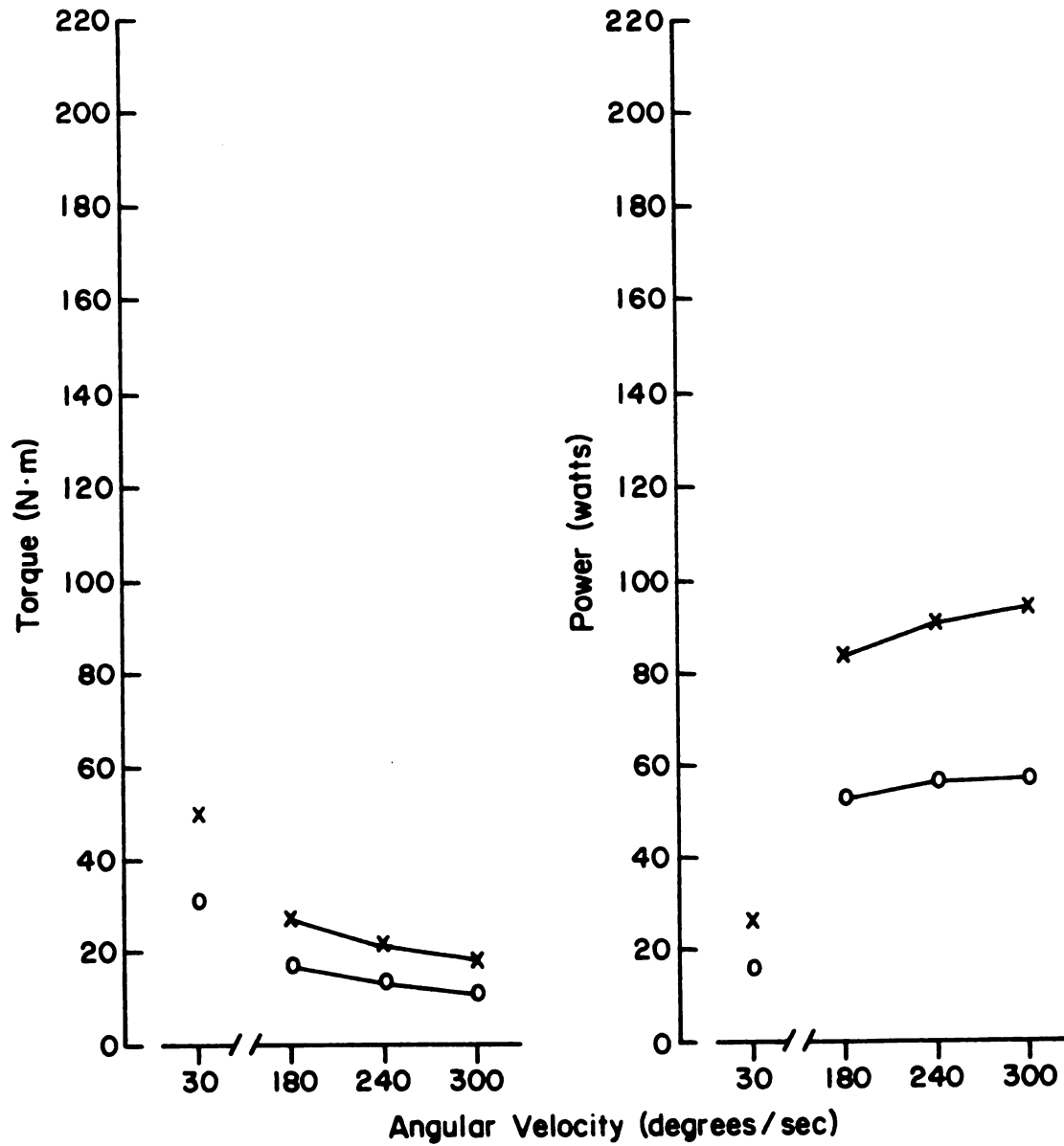
All contrasts are significant at $p < .05$ 

Figure 1.--Elbow Extension: Absolute Peak Torque-Velocity and Power-Velocity Relationships for Male vs. Female Swimmers.

Relative Torque (N·m/kg)

Fig

o—o Females (n = 64)

x—x Males (n = 54)

All contrasts are significant at $p < .05$

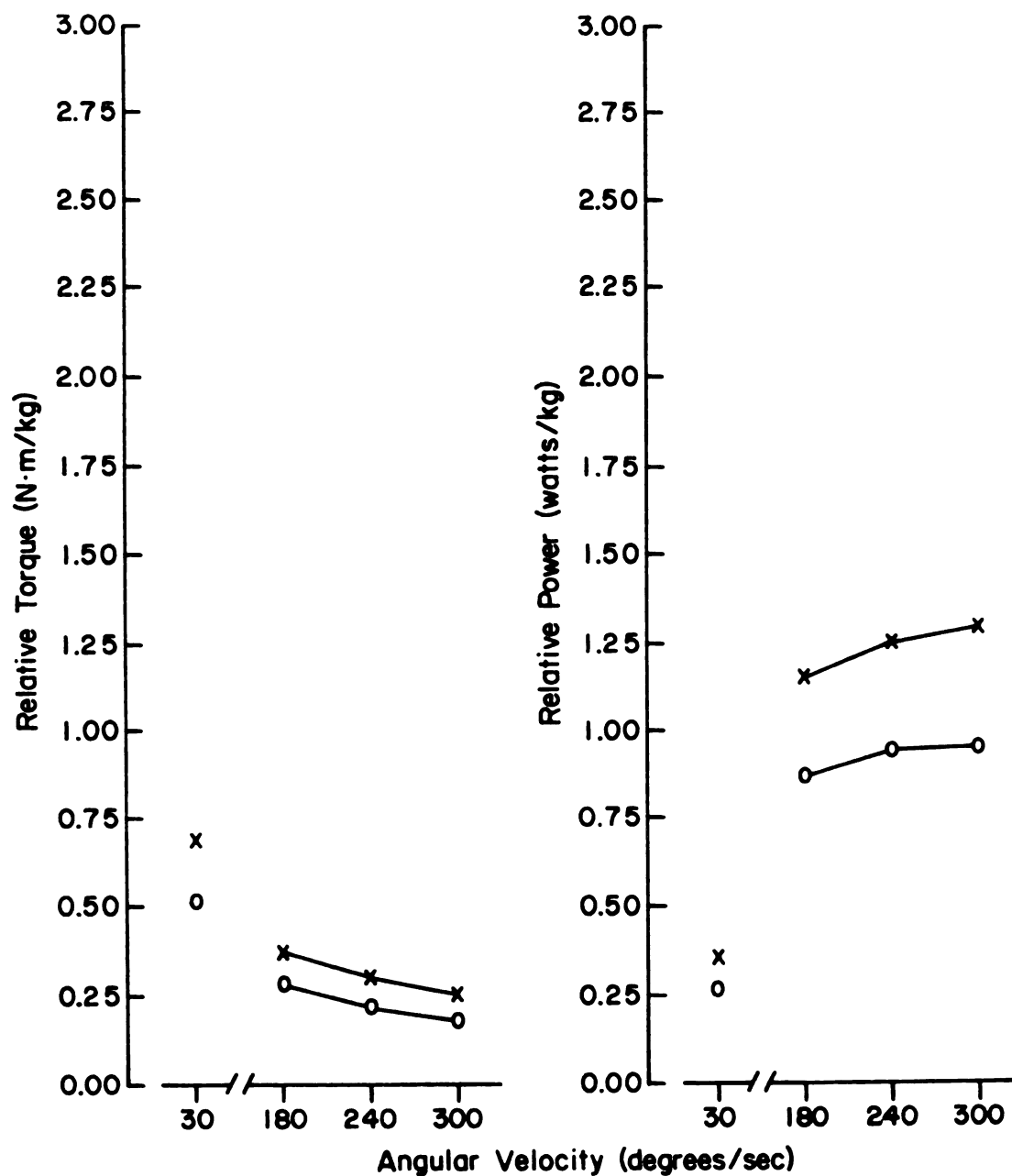


Figure 2.--Elbow Extension: Relative (by Body Weight) Peak Torque-Velocity and Power-Velocity Relationships for Male vs. Female Swimmers.

Relative Torque (N·m/kg)

Fig

○—○ Females (n = 64)

x—x Males (n = 54)

All contrasts are significant at $p < .05$

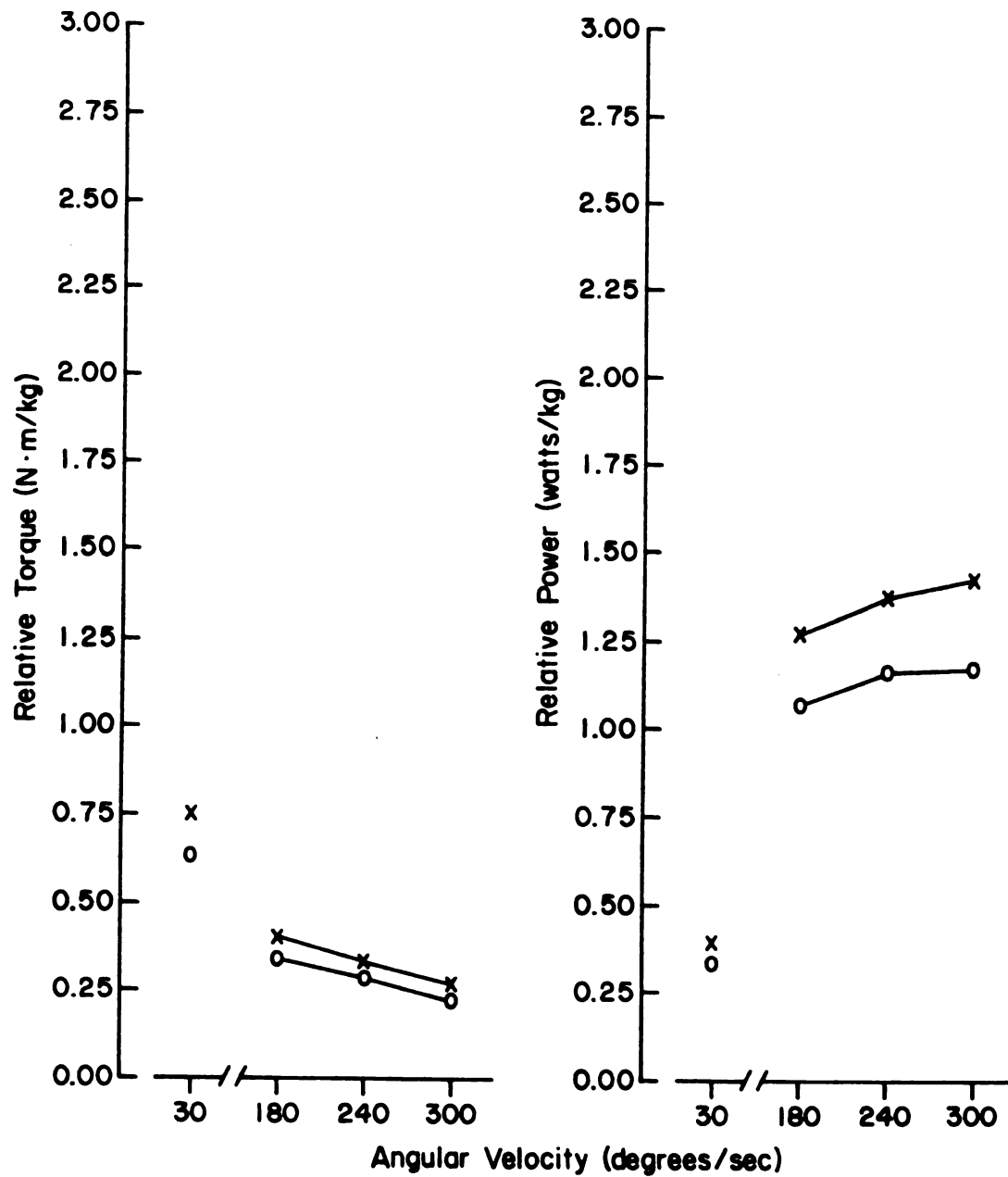


Figure 3.--Elbow Extension: Relative (by Lean Body Weight) Peak Torque-Velocity and Power-Velocity Relationships for Male vs. Female Swimmers.

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and power were observed to decrease when values relative to body weight and lean body weight were considered.

Cybex data obtained during shoulder joint extension are presented in Figures 4 through 6. All comparisons between sexes were highly significant ($p < .001$). The female power curve demonstrated increasing power as velocity increased. Maximal values occurred at 300 $^{\circ}/s$. The male power curve had maximal power values at 240 $^{\circ}/s$ with a slight decline at 300 $^{\circ}/s$. The most significant differences in strength and power occurred at 30 $^{\circ}/s$. When values relative to body weight and lean body weight were examined, the differences between sexes were less.

Strength and power values during shoulder joint inward rotation are graphed in Figures 7 through 9. All comparisons were highly significant ($p < .001$). The female power curves appeared to rise until 240 $^{\circ}/s$ and then leveled off. The male power curves continued to rise to maximal values at 300 $^{\circ}/s$. The greatest difference in power between male and female swimmers occurred at 300 $^{\circ}/s$. Values relative to height and ponderal index appeared to follow a pattern similar to the absolute power curves. Values relative to body weight and lean body weight followed a similar pattern, but the differences between male and female swimmers were less.

Cybex data during knee extension are shown in Figures 10 through 12. All absolute values and values relative to body weight, height, and ponderal index were significant ($p < .001$). Maximal

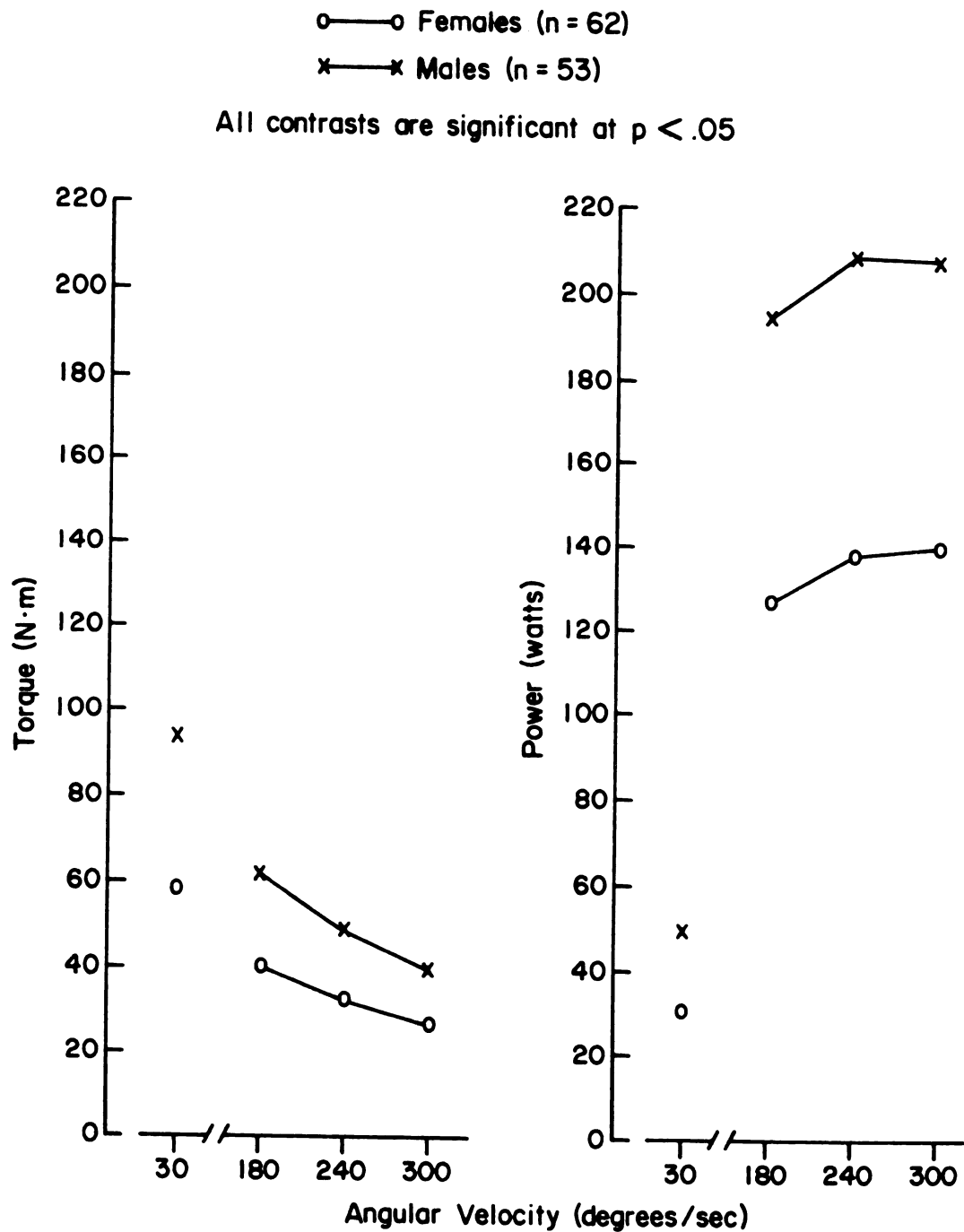


Figure 4.--Shoulder Joint Extension: Absolute Peak Torque-Velocity and Power-Velocity Relationships for Male vs. Female Swimmers.

○—○ Females (n = 62)

x—x Males (n = 53)

All contrasts are significant at $p < .05$

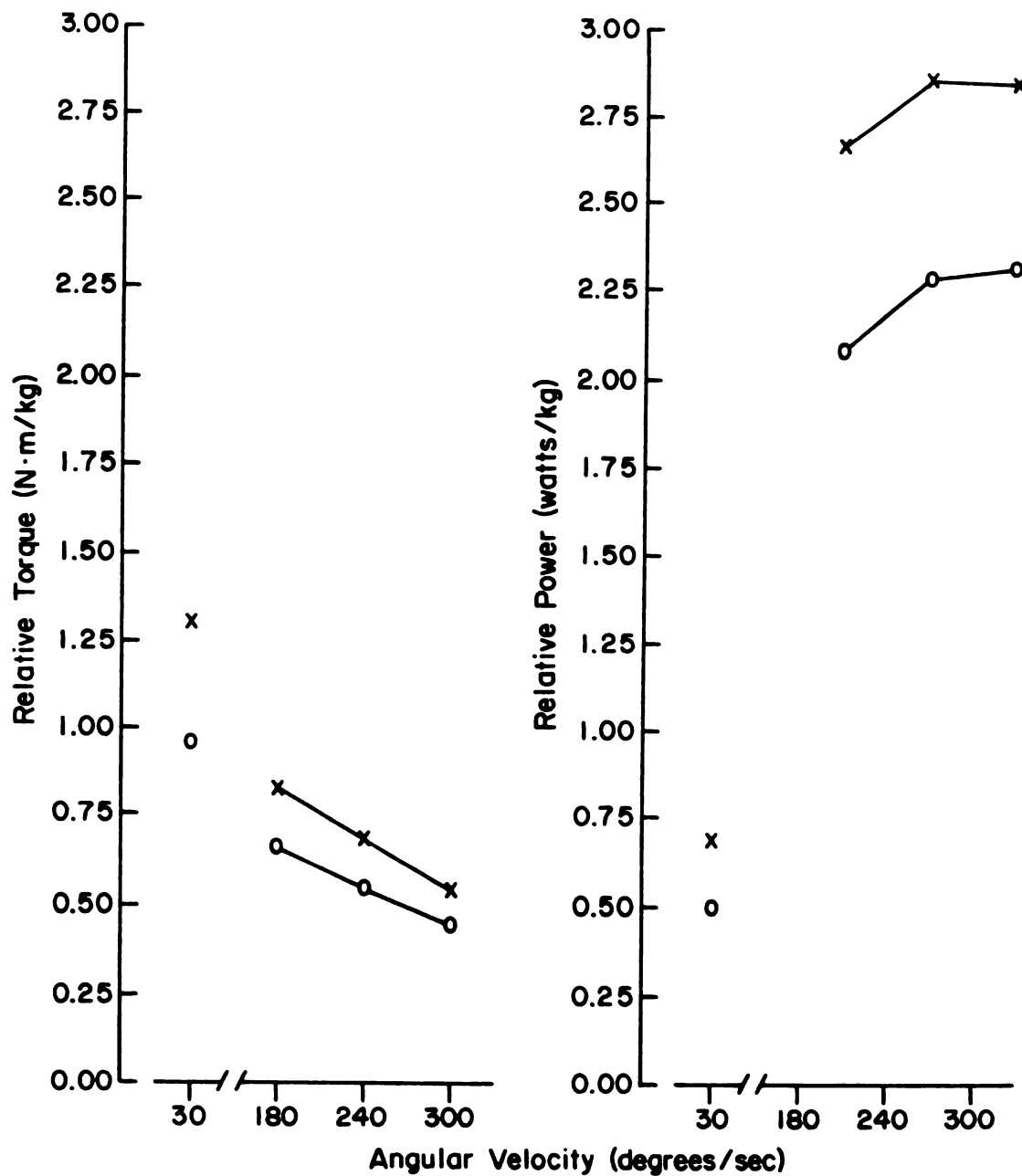


Figure 5.--Shoulder Joint Extension: Relative (by Body Weight) Peak Torque-Velocity and Power-Velocity Relationships for Male vs. Female Swimmers.

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Relative Torque (N·m/kg)

Figure 6.-

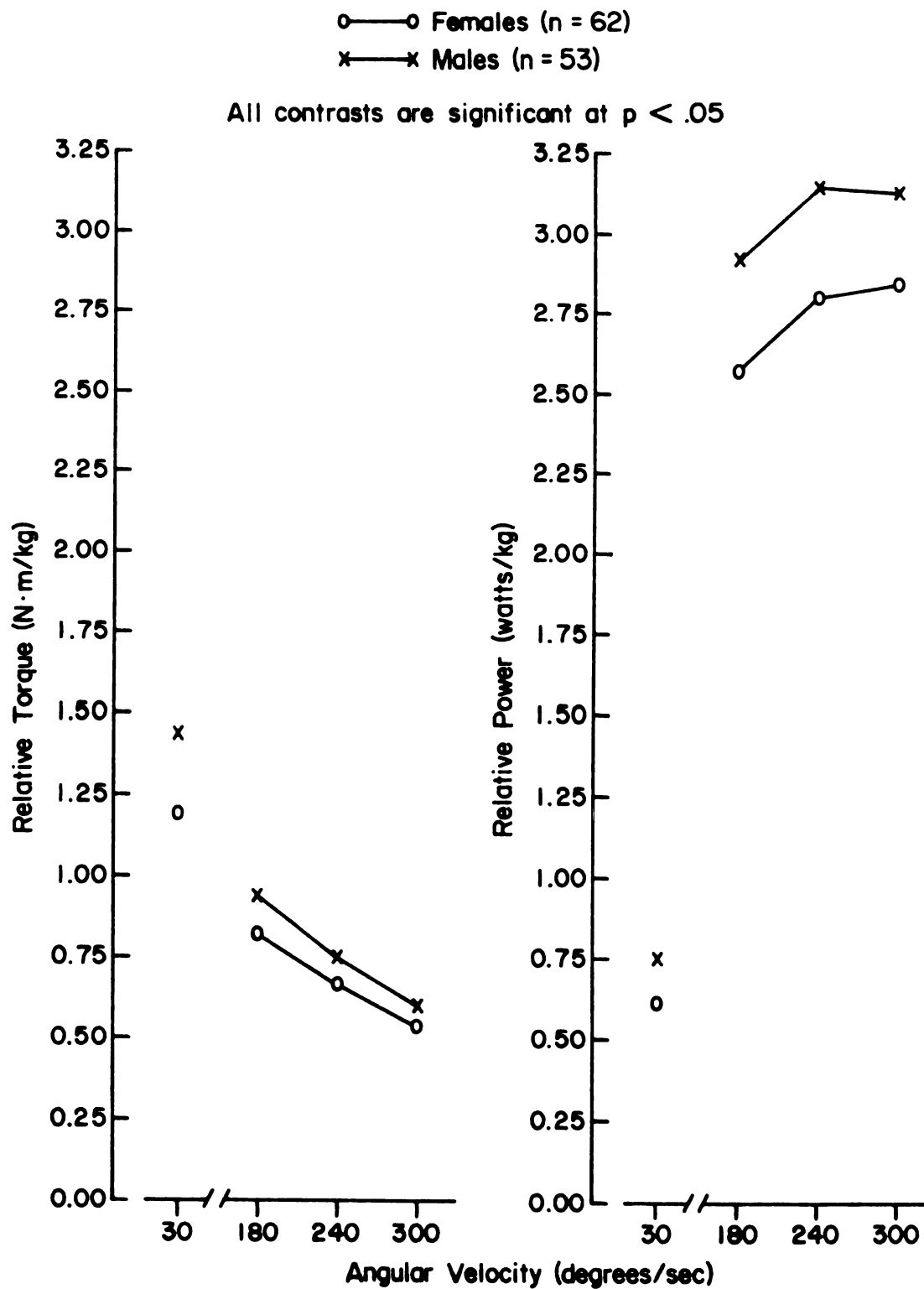


Figure 6.--Shoulder Joint Extension: Relative (by Lean Body Weight) Peak Torque-Velocity and Power-Velocity Relationships for Male vs. Female Swimmers.

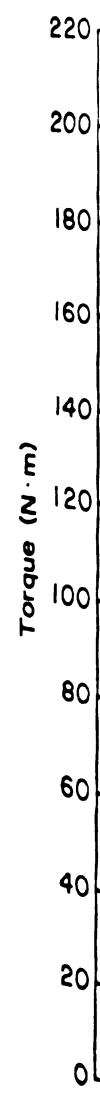


Figure 7

o—o Females (n = 63 - 66)

x—x Males (n = 53 - 54)

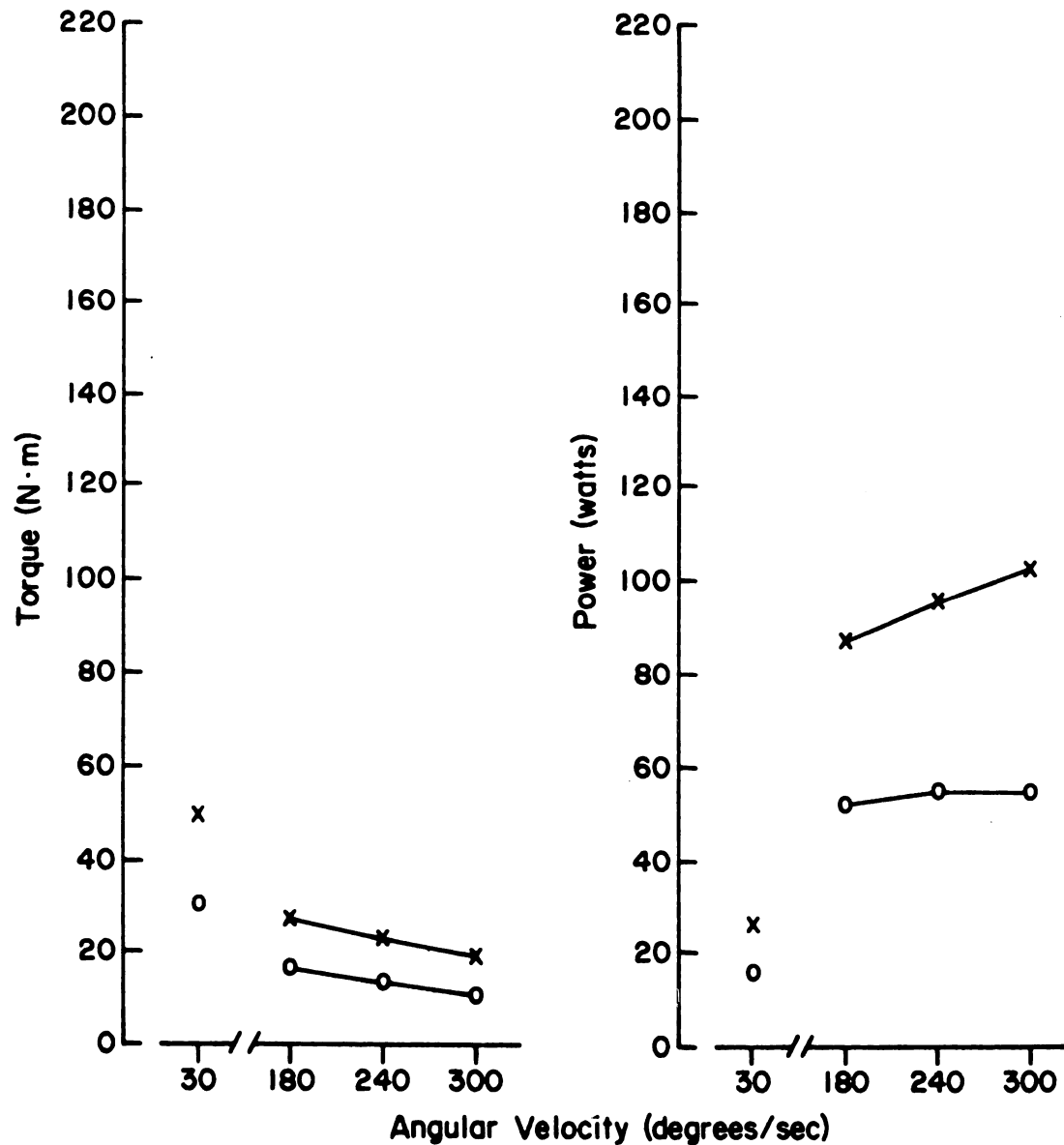
All contrasts are significant at $p < .05$ 

Figure 7.--Shoulder Joint Inward Rotation: Absolute Peak Torque-Velocity and Power-Velocity Relationships for Male vs. Female Swimmers.

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Relative Torque (N·m/kg)

Figure 8.

○—○ Females (n = 63-66)

x—x Males (n = 53-54)

All contrasts are significant at $p < .05$

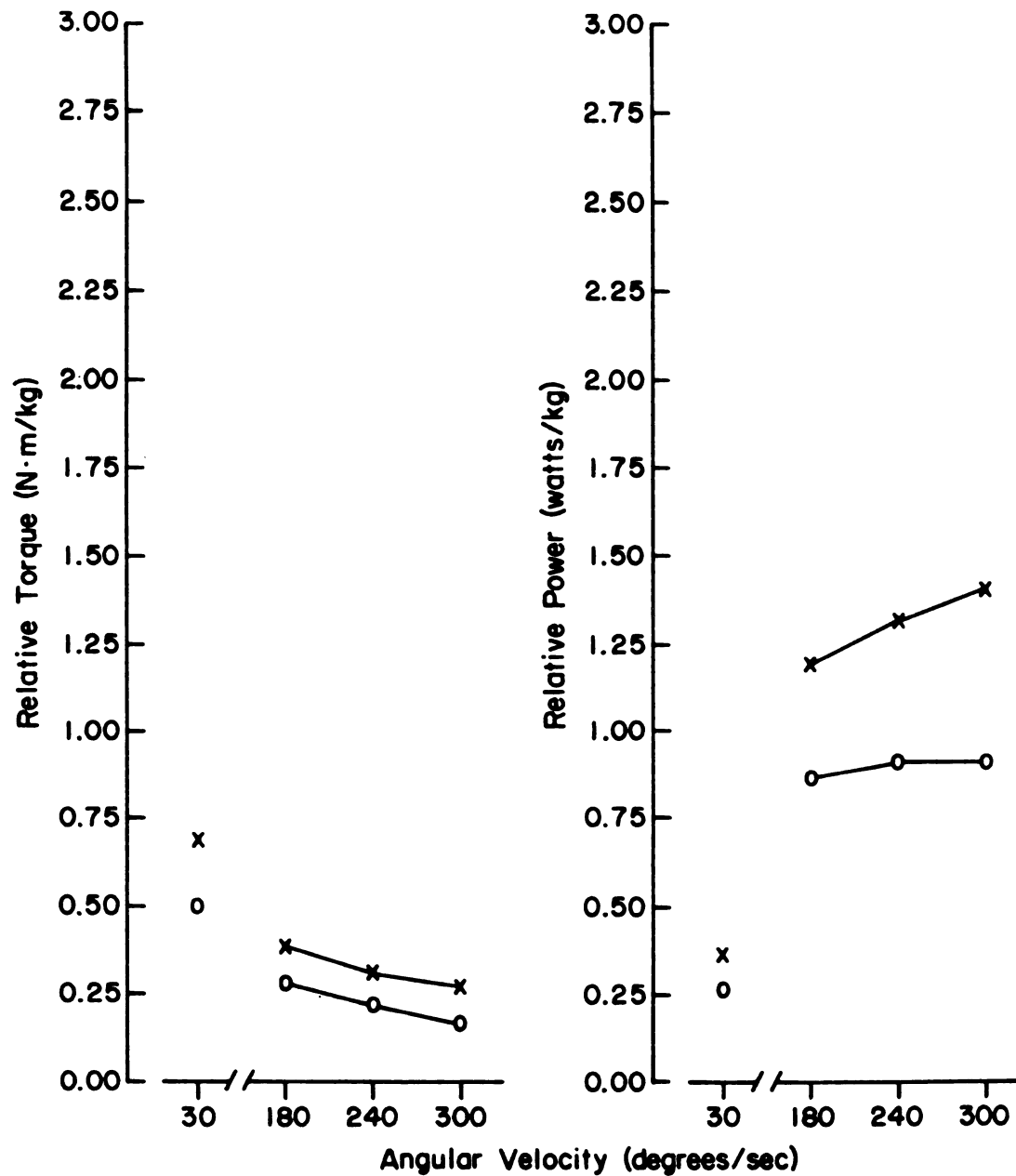


Figure 8.--Shoulder Joint Inward Rotation: Relative (by Body Weight) Peak Torque-Velocity and Power-Velocity Relationships for Male vs. Female Swimmers.

o—o Females (n = 63 - 66)

x—x Males (n = 53 - 54)

All contrasts are significant at $p < .05$

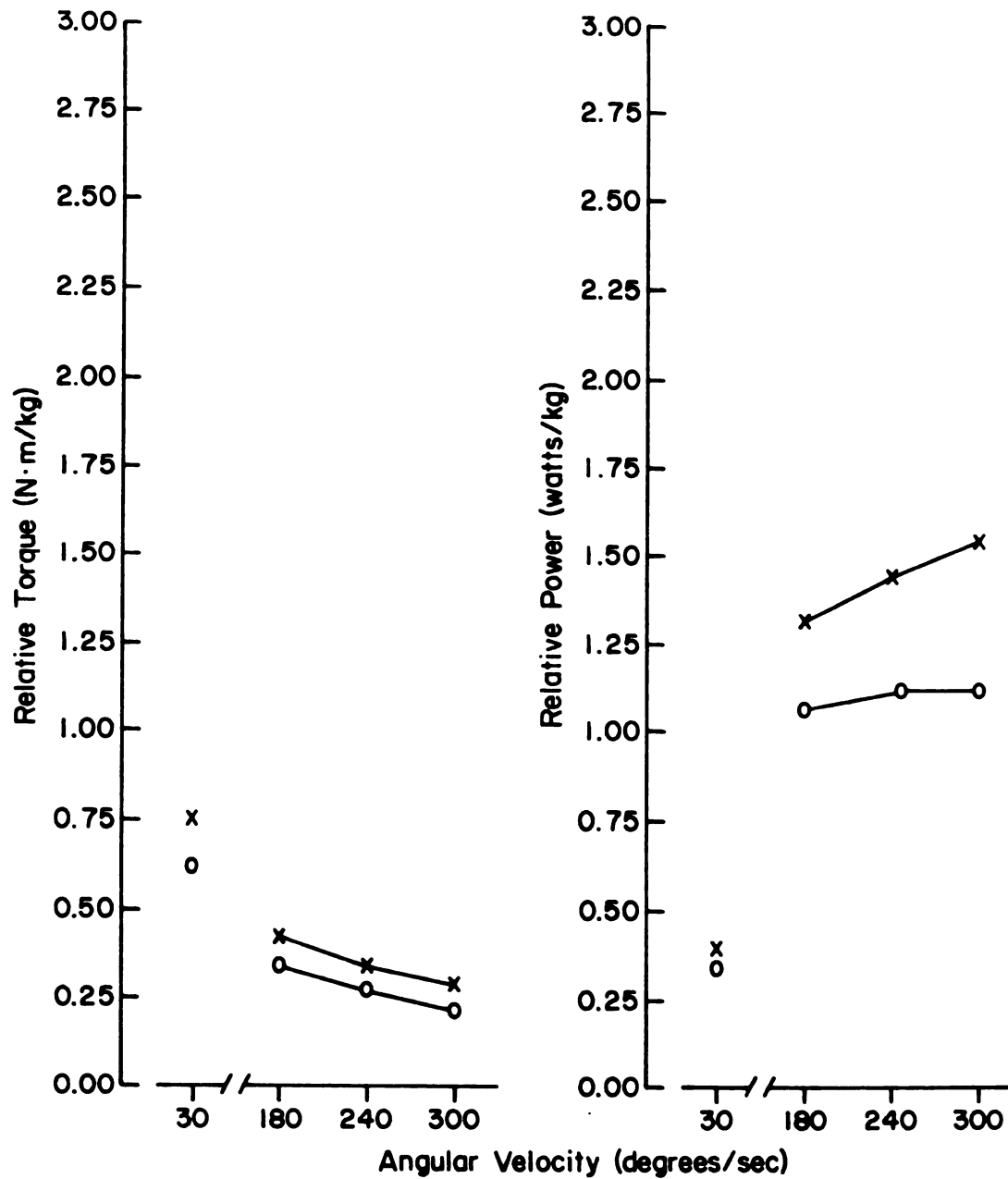


Figure 9.--Shoulder Joint Inward Rotation: Relative (by Lean Body Weight) Peak Torque-Velocity and Power-Velocity Relationships for Male vs. Female Swimmers.

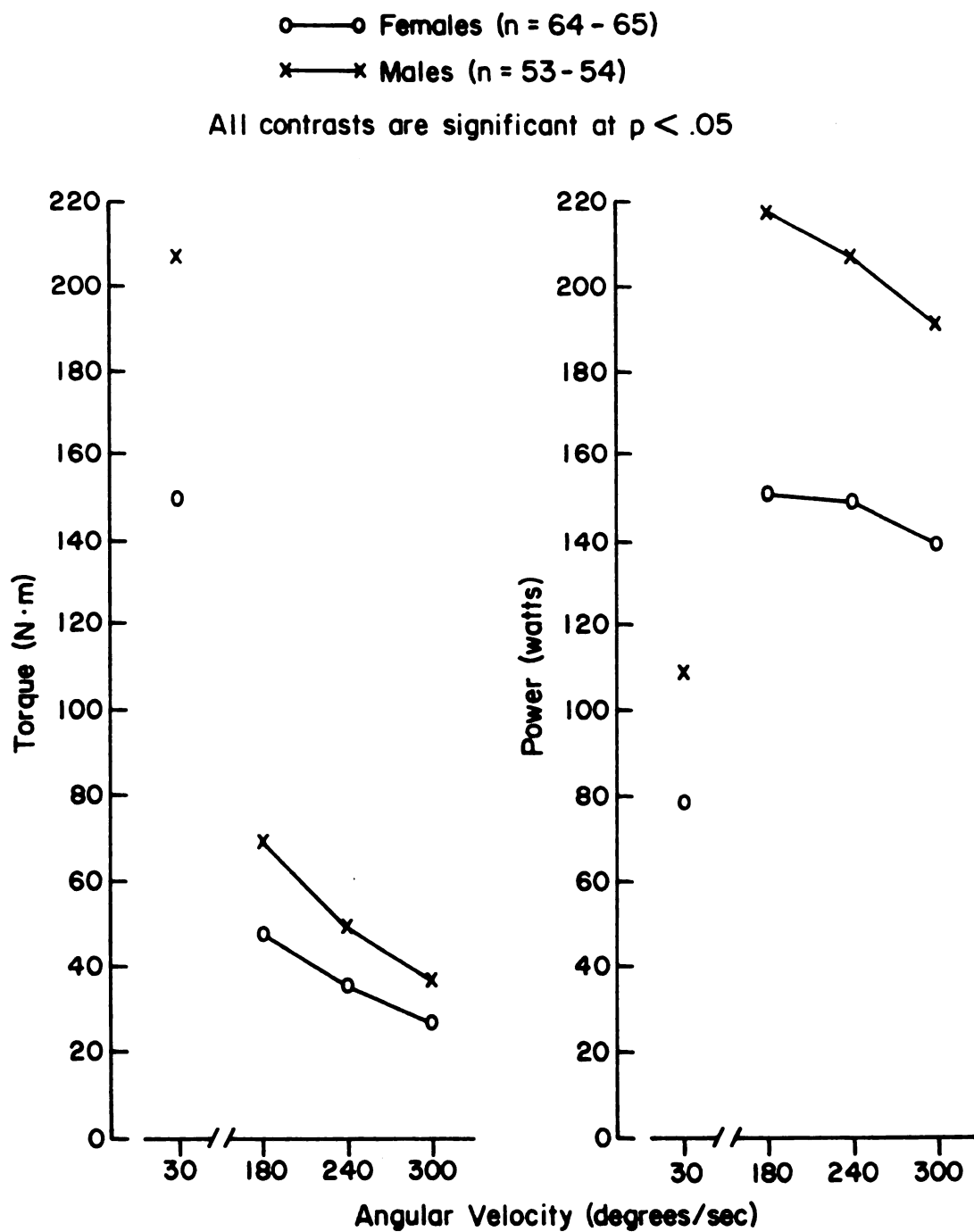


Figure 10.--Knee Extension: Absolute Peak Torque-Velocity and Power-Velocity Relationships for Male vs. Female Swimmers.

o—o Females (n = 64 - 65)

x—x Males (n = 53 - 54)

All contrasts are significant at $p < .05$

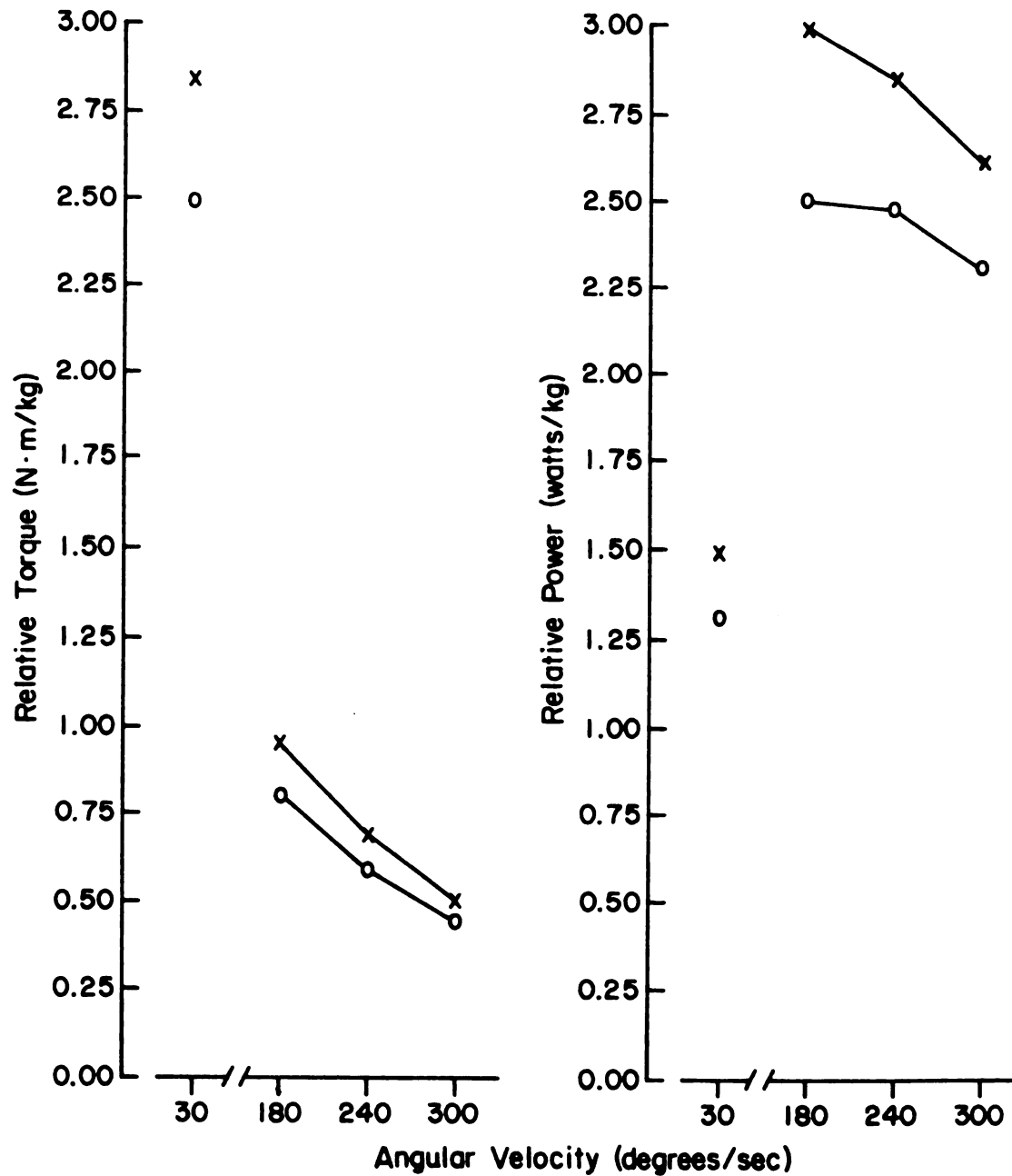


Figure 11.--Knee Extension: Relative (by Body Weight) Peak Torque-Velocity and Power-Velocity Relationships for Male vs. Female Swimmers

o—o Females (n = 64 - 65)

x—x Males (n = 53 - 54)

$p < .05$ at $180^\circ/\text{s}$

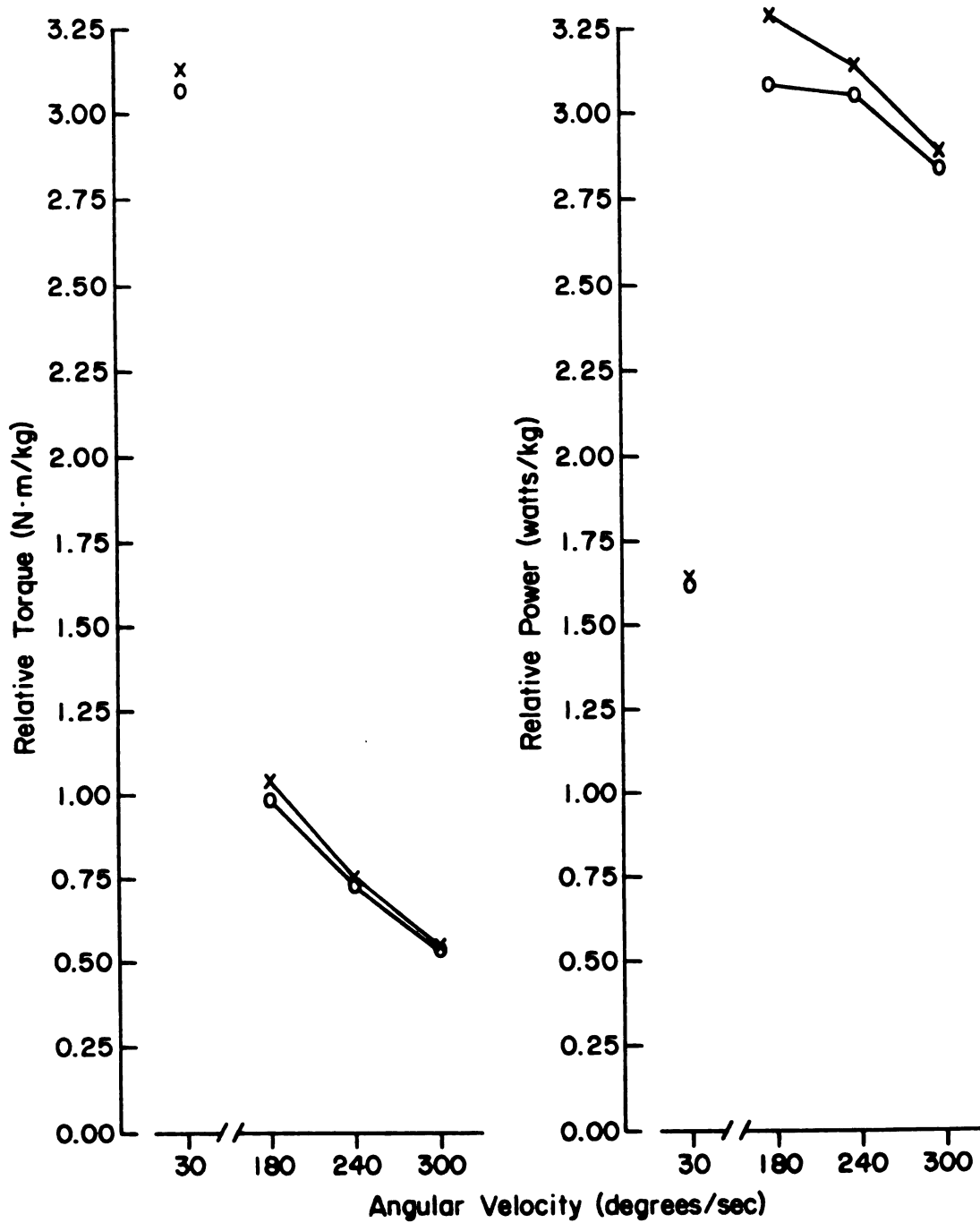


Figure 12.--Knee Extension: Relative (by Lean Body Weight) Peak Torque-Velocity and Power-Velocity Relationships for Male vs. Female Swimmers.

power values occurred at 180 °/s with a decline in power as velocity increased further. The curves of values relative to height and ponderal index were similar to the absolute strength and power curves. The greatest differences between sexes occurred at 180 °/s. This difference was less when values relative to body weight were considered, but it was still significant. When values relative to lean body weight were examined, the only significant difference between male and female swimmers occurred at 180 °/s ($p = .01$).

Modified Vertical Power Jump

The actual values and ANOVA results are presented in Appendix B, Table B6.

The males jumped significantly greater vertical distances than did the females (45.8 cm vs. 34.6 cm, $p < .001$). Values of distance relative to height and ponderal index were significant also ($p < .001$). While still significant, the difference between male and female swimmers was less when values relative to body weight were considered ($p = .01$). No significant difference was observed in values relative to lean body weight.

Male swimmers performed significantly more work during the jump ($\bar{X} = 551$ joules) than did the female swimmers ($\bar{X} = 383$ joules, $p < .001$). Values relative to height and ponderal index were highly significant also ($p < .001$). Differences between the sexes were less when body weight ($F = 52$, $p < .001$) and lean body weight ($F = 6.86$, $p = .01$) were considered.

Male swimmers ($\bar{X}$ = 2,664 watts) were more powerful than female swimmers ($\bar{X}$ = 1,663 watts). All comparisons were highly significant ($p < .001$); however, the differences were less when values relative to body weight and lean body weight were examined.

Male Sprinters vs. Middle-Distance Swimmers

This section is divided into three divisions. A description of the subjects, isokinetic results, and the modified vertical power jump results are discussed separately.

Subject Characteristics

Selected parameters of the subjects are shown in Table 2. Data from approximately 38 male sprinters and 17 male middle-distance swimmers were analyzed. The sprinters were not significantly different from the middle-distance swimmers in age, height, weight, lean body weight, ponderal index, or quality of performance. The sprinters had significantly less body fat than did the middle-distance swimmers (8.6% vs. 10.2%, $p = .005$).

Isokinetic Data

Actual values and ANOVA results for each joint action and angular velocity are presented in Appendix B, Tables B7 through B11.

Cybex data obtained during elbow extension are presented in Figures 13 through 15. In all comparisons, the sprinters had higher torque and power values than did the middle-distance swimmers. However, the difference was significant only when the value relative

TABLE 2. Selected Parameters of Male Sprinters vs. Middle-Distance Swimmers

	Sprinter			Middle-Distance			ANOVA	
	<u>n</u>	<u>$\bar{x}$</u>	<u>s</u>	<u>n</u>	<u>$\bar{x}$</u>	<u>s</u>	<u>F</u>	<u>P</u>
Age (months)	38	217	18	17	216	16	.06	.82
Height (cm)	37	180.9	6.5	17	180.3	6.0	.11	.74
Weight (kg)	38	72.8	6.4	17	73.2	6.9	.04	.85
Lean Body Weight (kg)	38	66.5	5.7	17	65.7	5.7	.28	.60
Percent Body Fat	38	8.6	1.8	17	10.2	2.1	8.50	.005
Quality of Swimmer	38	106.1	2.1	17	105.4	1.9	1.37	.25
Ponderal Index	37	23.07	.74	17	23.19	.60	.35	.56

Figure 13.--Elbow Extension: Peak Absolute Torque-Velocity and Power-Velocity Relationships for Male Sprinters vs. Middle-Distance Swimmers and for Female Sprinters vs. Middle-Distance Swimmers.

- Female Sprinter (n=43)
- Female Middle Distance (n=21)
- △—△ Male Sprinter (n=37)
- ×—× Male Middle Distance (n=17)

For Females: All contrasts nonsignificant

For Males: All contrasts nonsignificant

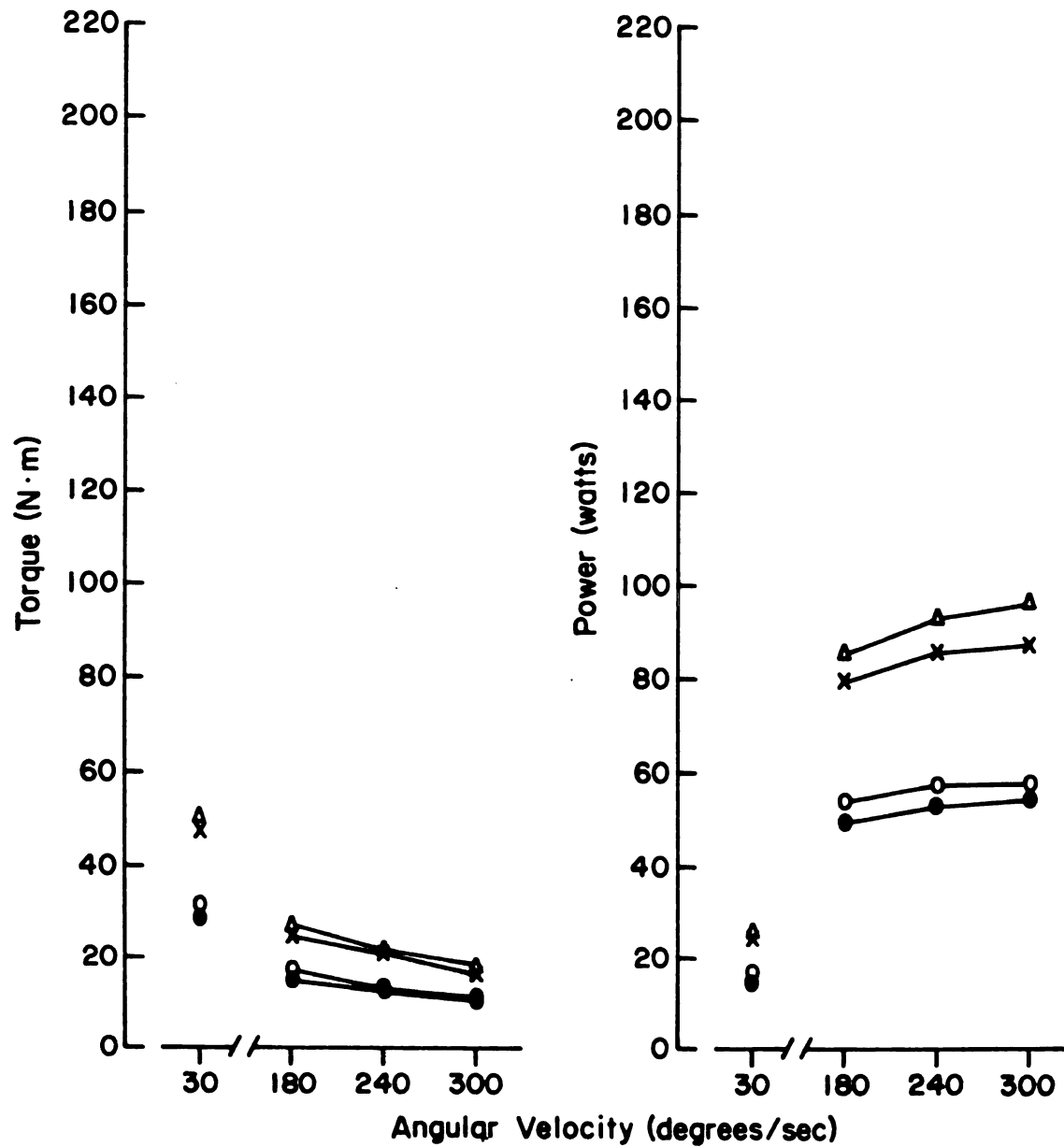


Figure 13

Figure 14.--Elbow Extension: Relative (by Body Weight) Peak Torque-Velocity and Power-Velocity Relationships for Male Sprinters vs. Middle-Distance Swimmers and for Female Sprinters vs. Middle-Distance Swimmers.

- Female Sprinter (n = 43)
- Female Middle Distance (n = 21)
- △—△ Male Sprinter (n = 37)
- ×—× Male Middle Distance (n = 17)

For Females: All contrasts nonsignificant

For Males: $p < .05$ at $300^\circ/s$

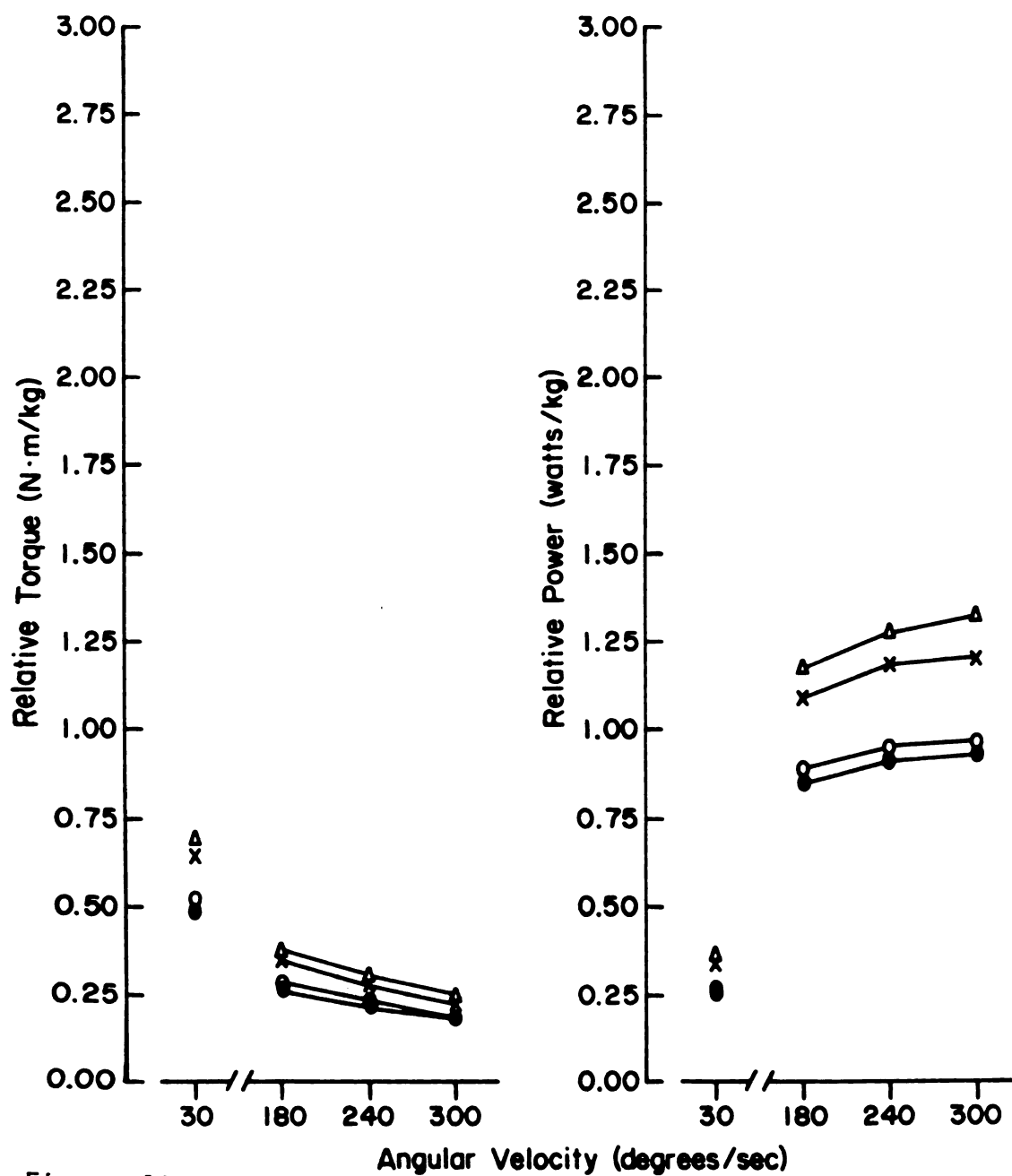


Figure 14

Figure 15.--Elbow Extension: Relative (by Lean Body Weight)
Peak Torque-Velocity and Power-Velocity Relationships for Male Sprinters vs. Middle-Distance Swimmers
and for Female Sprinters vs. Middle-Distance Swimmers.

- Female Sprinter (n = 43)
- Female Middle Distance (n = 21)
- △—△ Male Sprinter (n = 37)
- ×—× Male Middle Distance (n = 17)

For Females: All contrasts nonsignificant

For Males: All contrasts nonsignificant

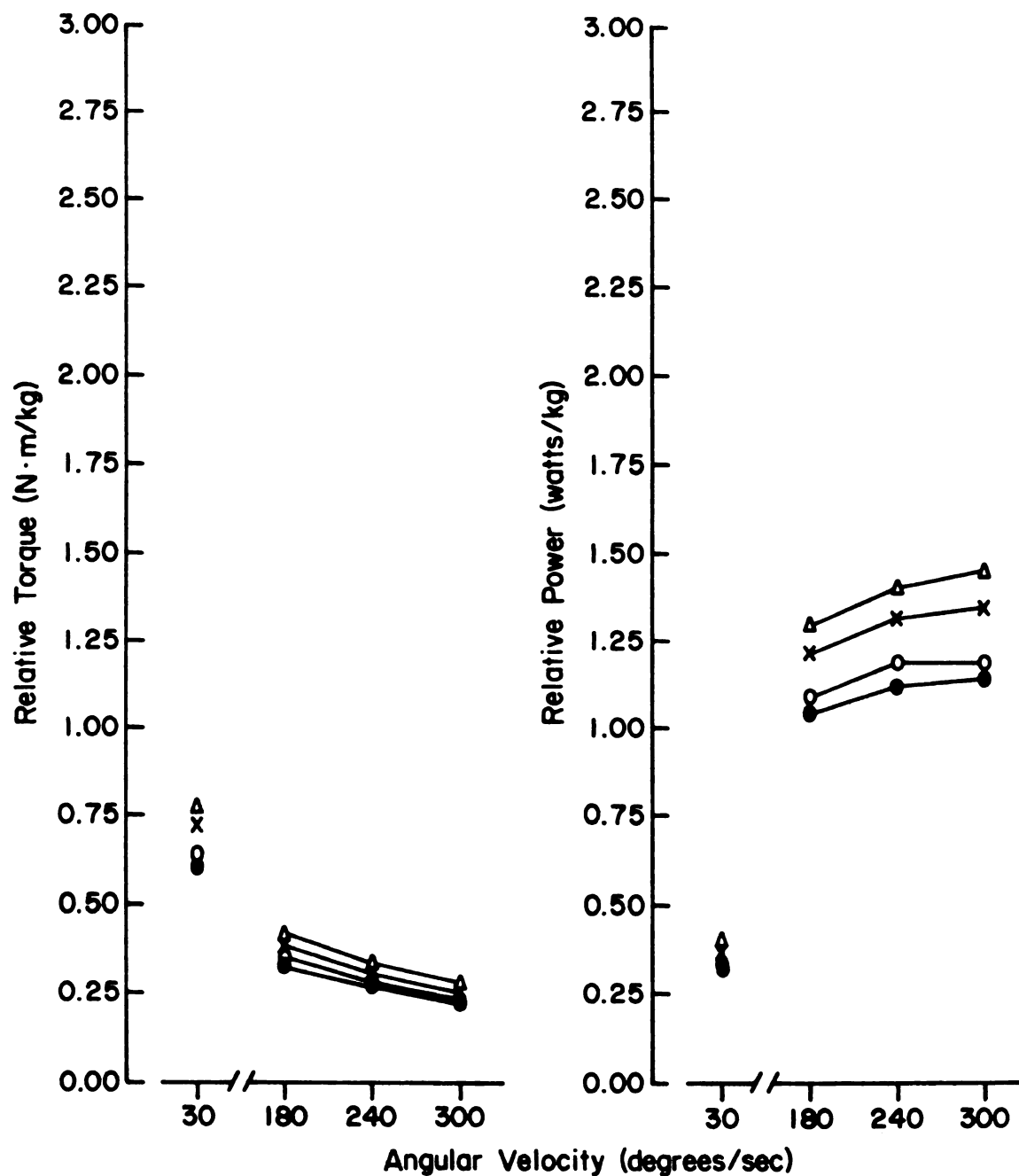


Figure 15

to body weight at 300 $^{\circ}$ /s was considered ($p = .049$). All power curves increased as velocity increased with maximal values occurring at 300 $^{\circ}$ /s. Values relative to height and ponderal index followed patterns similar to those observed with absolute torque and power comparisons.

Cybex data obtained during shoulder joint extension are presented in Figures 16 through 18. The torque and power curves had similar shapes in both absolute and relative contrasts. The sprinters had higher mean values at each velocity than did the middle-distance swimmers. The sprinters appeared to peak at 240 $^{\circ}$ /s, while the middle-distance swimmers had maximum values at 300 $^{\circ}$ /s. Both sprinters and middle-distance swimmers showed greater increases in power from 180 $^{\circ}$ /s to 240 $^{\circ}$ /s than from 240 $^{\circ}$ /s to 300 $^{\circ}$ /s, possibly indicating a leveling off in power production at the higher velocities. All contrasts were significant except for absolute values and values relative to lean body weight, height, and ponderal index at 30 $^{\circ}$ /s and for absolute values at 300 $^{\circ}$ /s.

Strength and power values during shoulder joint inward rotation are graphed in Figures 19 through 21. Both sprinters and middle-distance swimmers demonstrated increasing power as velocity increased, with maximal values occurring at 300 $^{\circ}$ /s in all comparisons. In addition, sprinters had higher mean values in all contrasts than did middle-distance swimmers. Significant differences were observed in absolute values at 300 $^{\circ}$ /s, in values relative to body weight at 240 $^{\circ}$ /s and 300 $^{\circ}$ /s, in values relative to lean body

Figure 16.--Shoulder Joint Extension: Peak Absolute Torque-Velocity and Power-Velocity Relationships for Male Sprinters vs. Middle-Distance Swimmers and for Female Sprinters vs. Middle-Distance Swimmers.

- Female Sprinter (n = 43)
- Female Middle Distance (n = 19)
- △—△ Male Sprinter (n = 37)
- ×—× Male Middle Distance (n = 16)

For Females: $p < .05$ at 240 and 300°/s

For Males: $p < .05$ at 180 and 240°/s

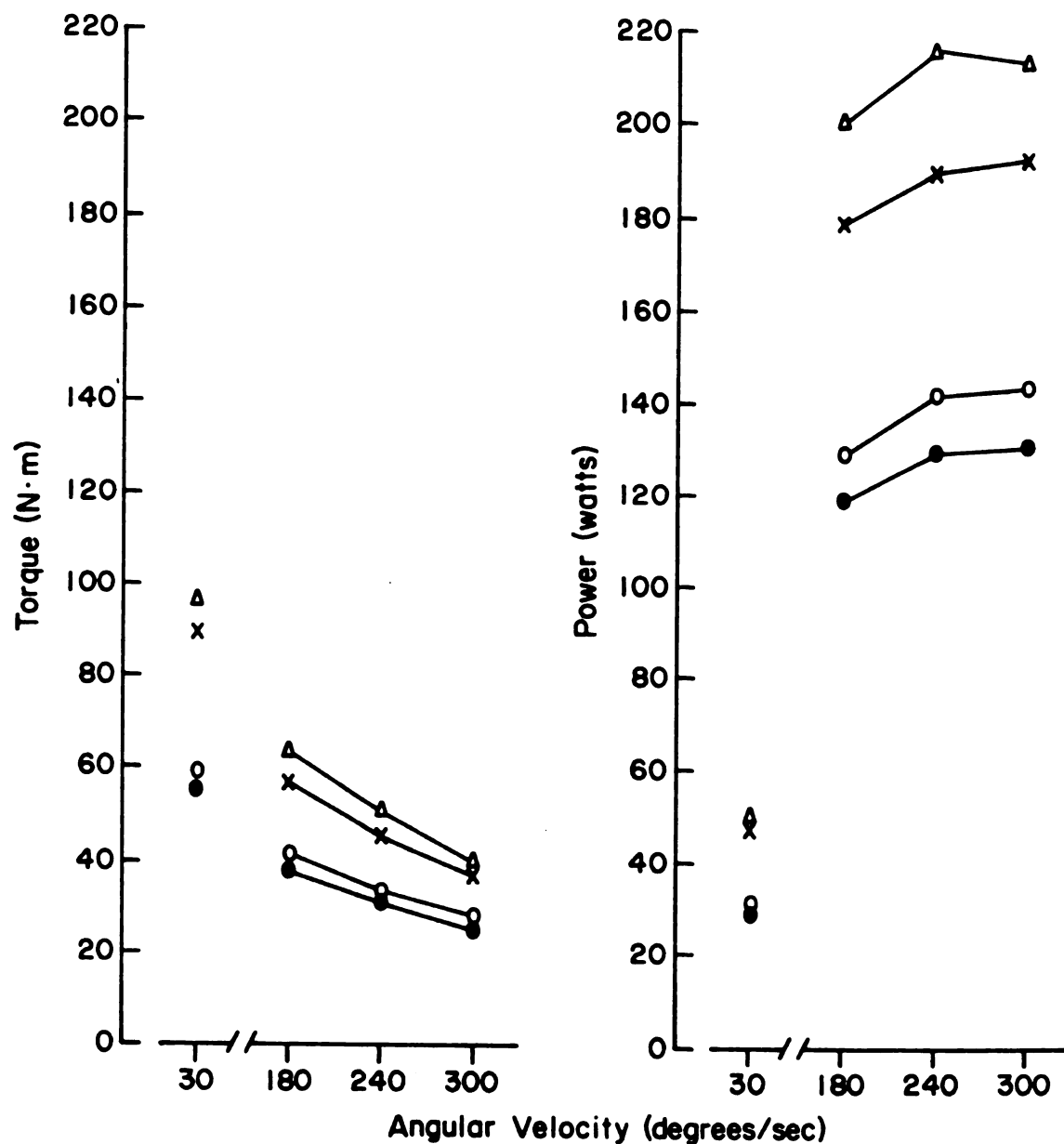


Figure 16.

Figure 17.--Shoulder Joint Extension: Relative (by Body Weight)
Peak Torque-Velocity and Power-Velocity Relationships
for Male Sprinters vs. Middle-Distance Swimmers and
for Female Sprinters vs. Middle-Distance Swimmers.

- Female Sprinter (n = 43)
- Female Middle Distance (n = 19)
- △—△ Male Sprinter (n = 37)
- ×—× Male Middle Distance (n = 16)

For Females: All contrasts nonsignificant

For Males: All contrasts are significant at $p < .05$

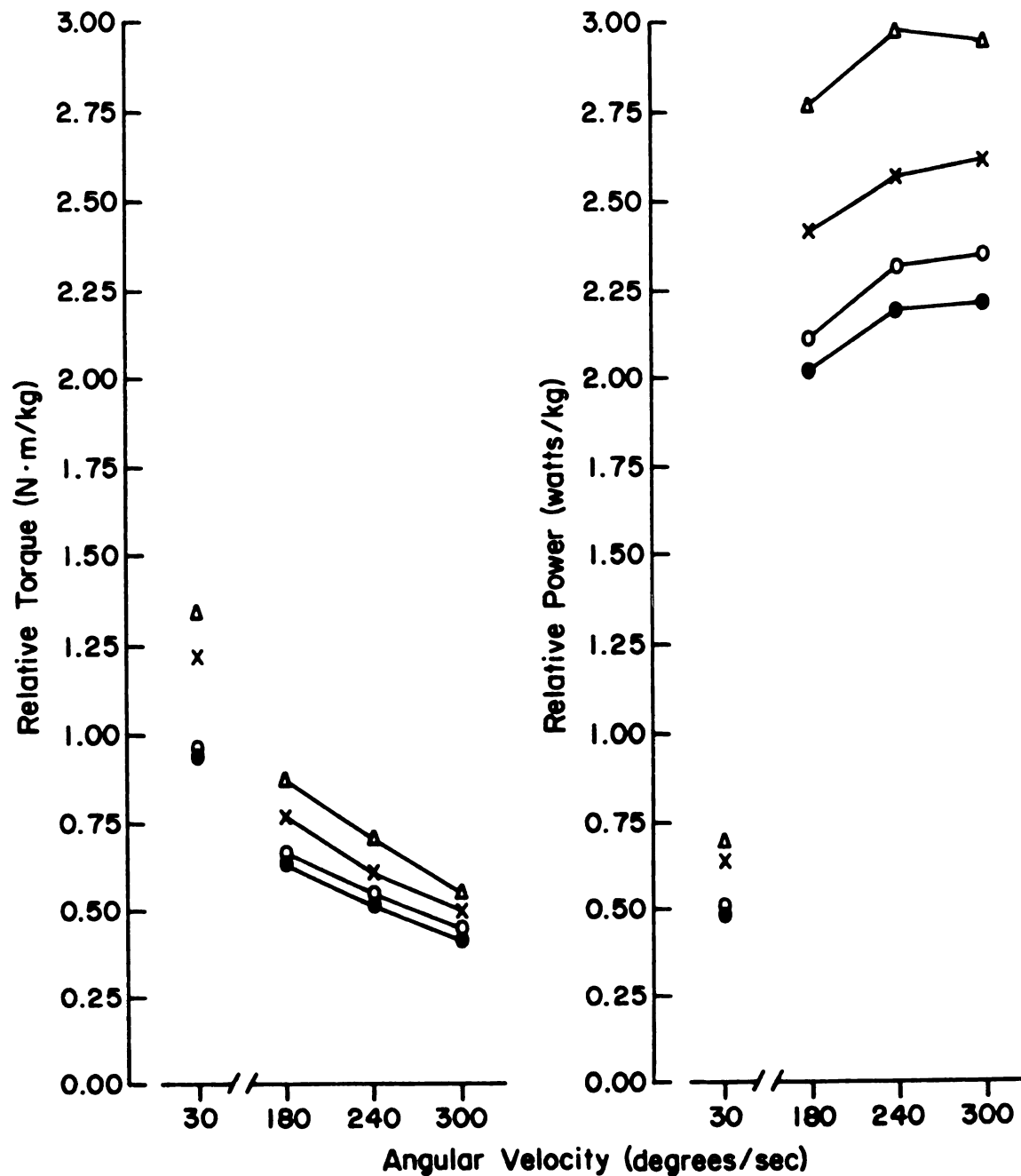


Figure 17

Figure 18.--Shoulder Joint Extension: Relative (by Lean Body Weight) Peak Torque-Velocity and Power-Velocity Relationships for Male Sprinters vs. Middle-Distance Swimmers and for Female Sprinters vs. Middle-Distance Swimmers.

- Female Sprinter (n = 43)
- Female Middle Distance (n = 19)
- △—△ Male Sprinter (n = 37)
- x—x Male Middle Distance (n = 16)

For Females: All contrasts nonsignificant

For Males: $p < .05$ at 180, 240 and 300°/s

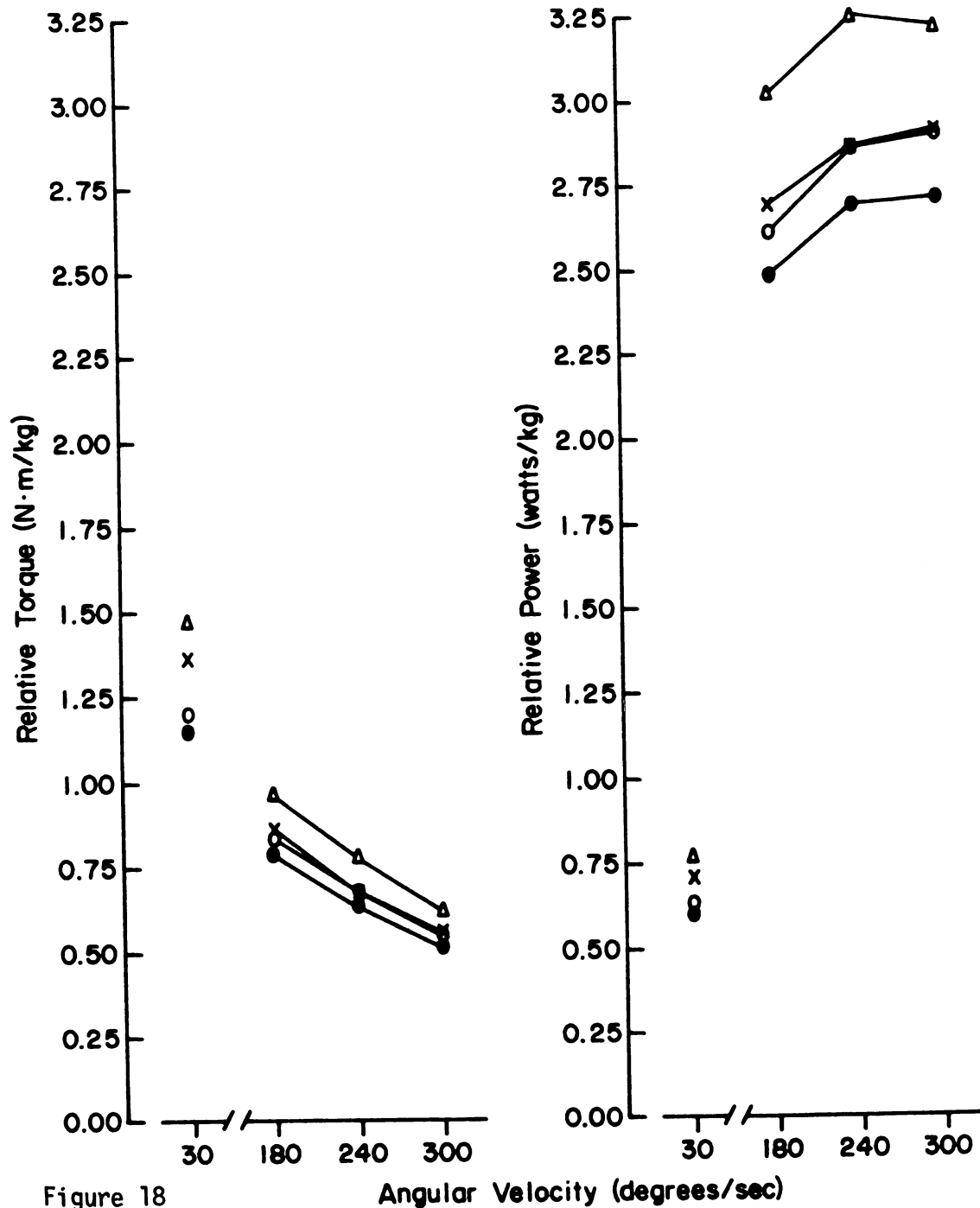


Figure 18

Angular Velocity (degrees/sec)

Figure 19.--Shoulder Joint Inward Rotation: Peak Absolute Torque-Velocity and Power-Velocity Relationships for Male Sprinters vs. Middle-Distance Swimmers and for Female Sprinters vs. Middle-Distance Swimmers.

- Female Sprinter (n = 43-45)
- Female Middle Distance (n = 20-21)
- △—△ Male Sprinter (n = 37)
- x—x Male Middle Distance (n = 16-17)

For Females: All contrasts nonsignificant

For Males: $p < .05$ at 300°/s

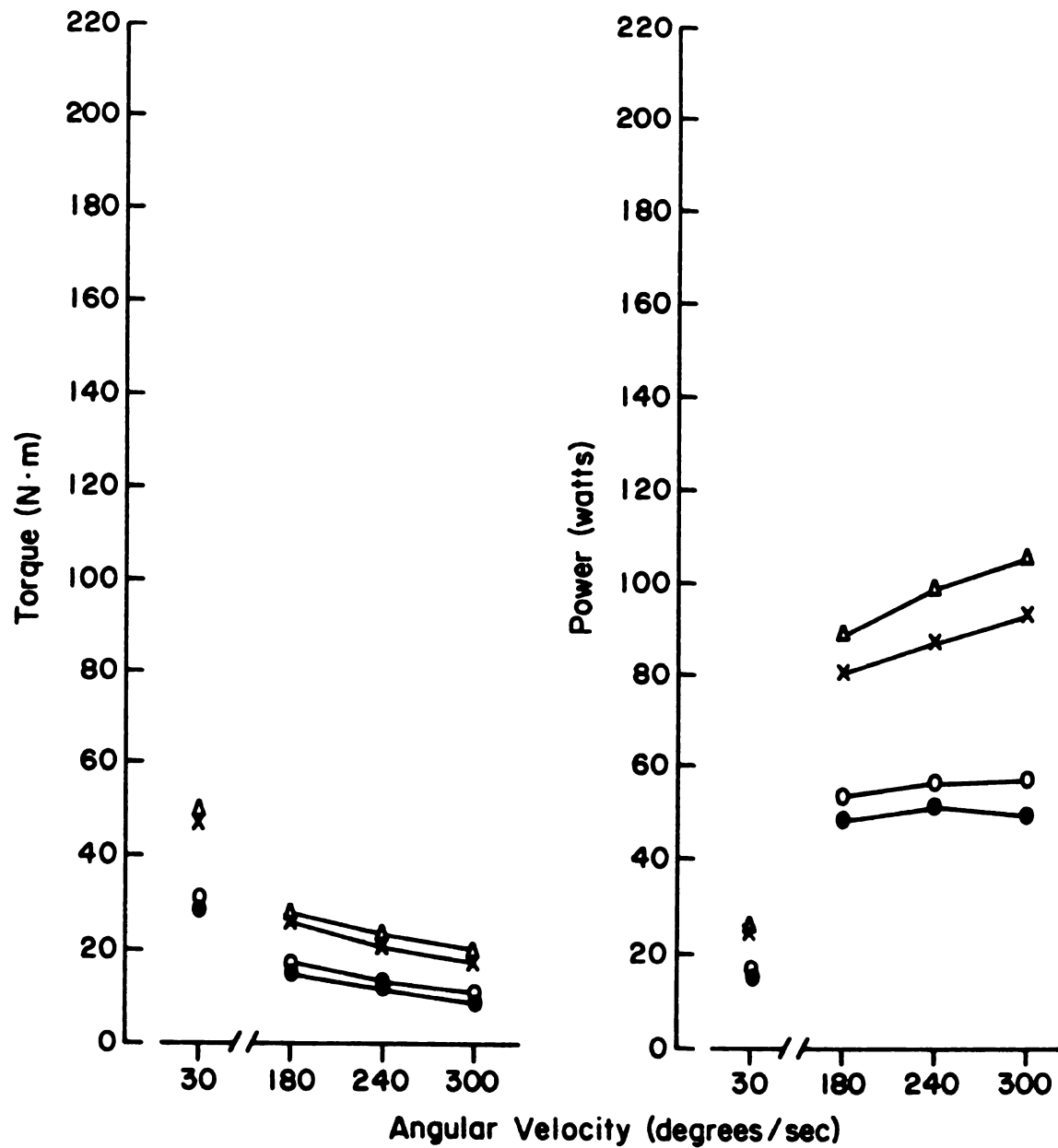


Figure 19

Figure 20.--Shoulder Joint Inward Rotation: Relative (by Body Weight) Peak Torque-Velocity and Power-Velocity Relationships for Male Sprinters vs. Middle-Distance Swimmers and for Female Sprinters vs. Middle-Distance Swimmers.

- Female Sprinter (n = 43-45)
- Female Middle Distance (n = 20-21)
- △—△ Male Sprinter (n = 37)
- ×—× Male Middle Distance (n = 16-17)

For Females: All contrasts nonsignificant

For Males: $p < .05$ at 240 and 300°/s

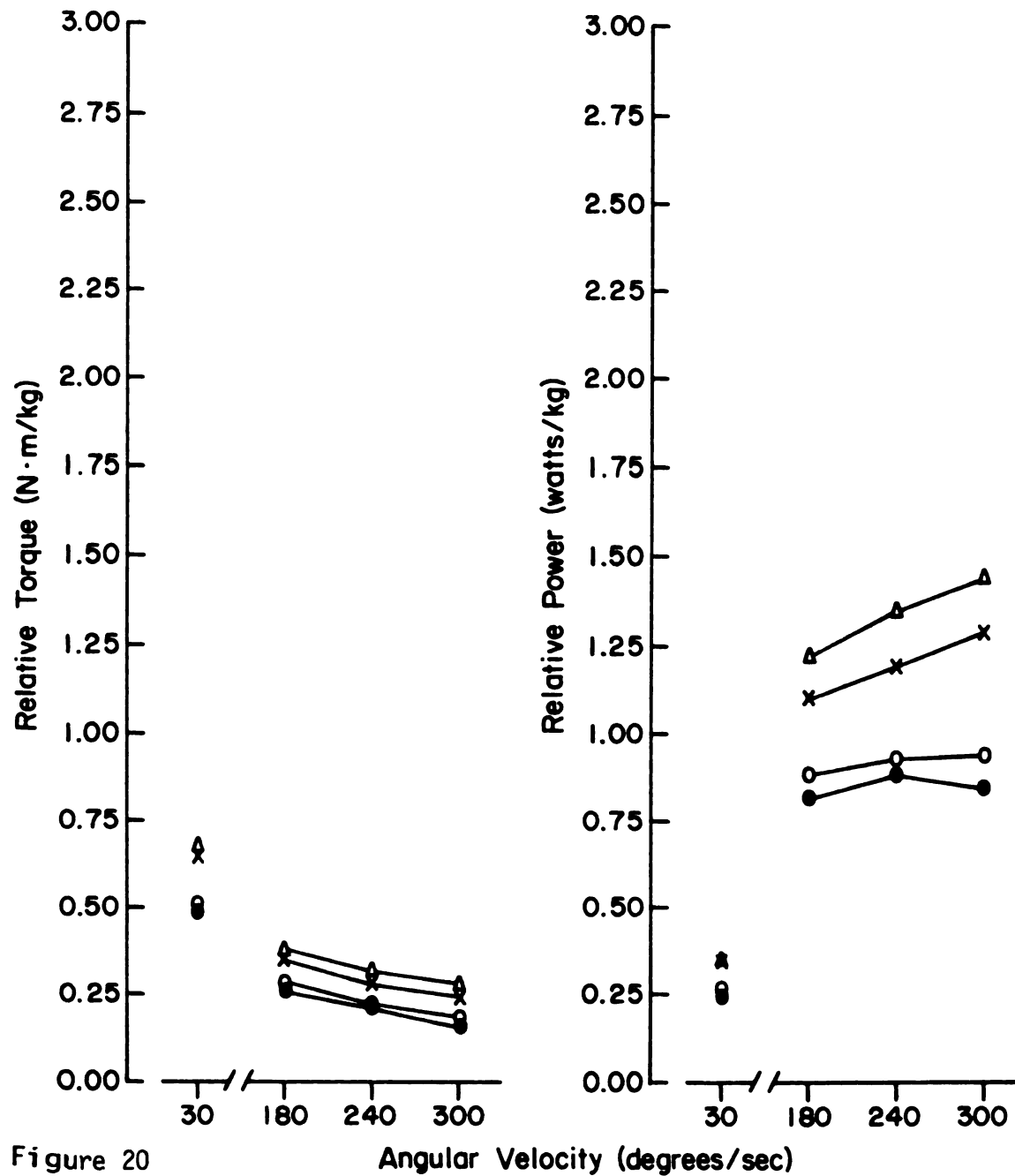


Figure 20

Figure 21.--Shoulder Joint Inward Rotation: Relative (by Lean Body Weight) Peak Torque-Velocity and Power-Velocity Relationships for Male Sprinters vs. Middle-Distance Swimmers and for Female Sprinters vs. Middle-Distance Swimmers.

- Female Sprinter (n = 43-45)
- Female Middle Distance (n = 20-21)
- △—△ Male Sprinter (n = 37)
- x—x Male Middle Distance (n = 16-17)

For Females: All contrasts nonsignificant

For Males: $p < .05$ at $300^\circ/\text{s}$

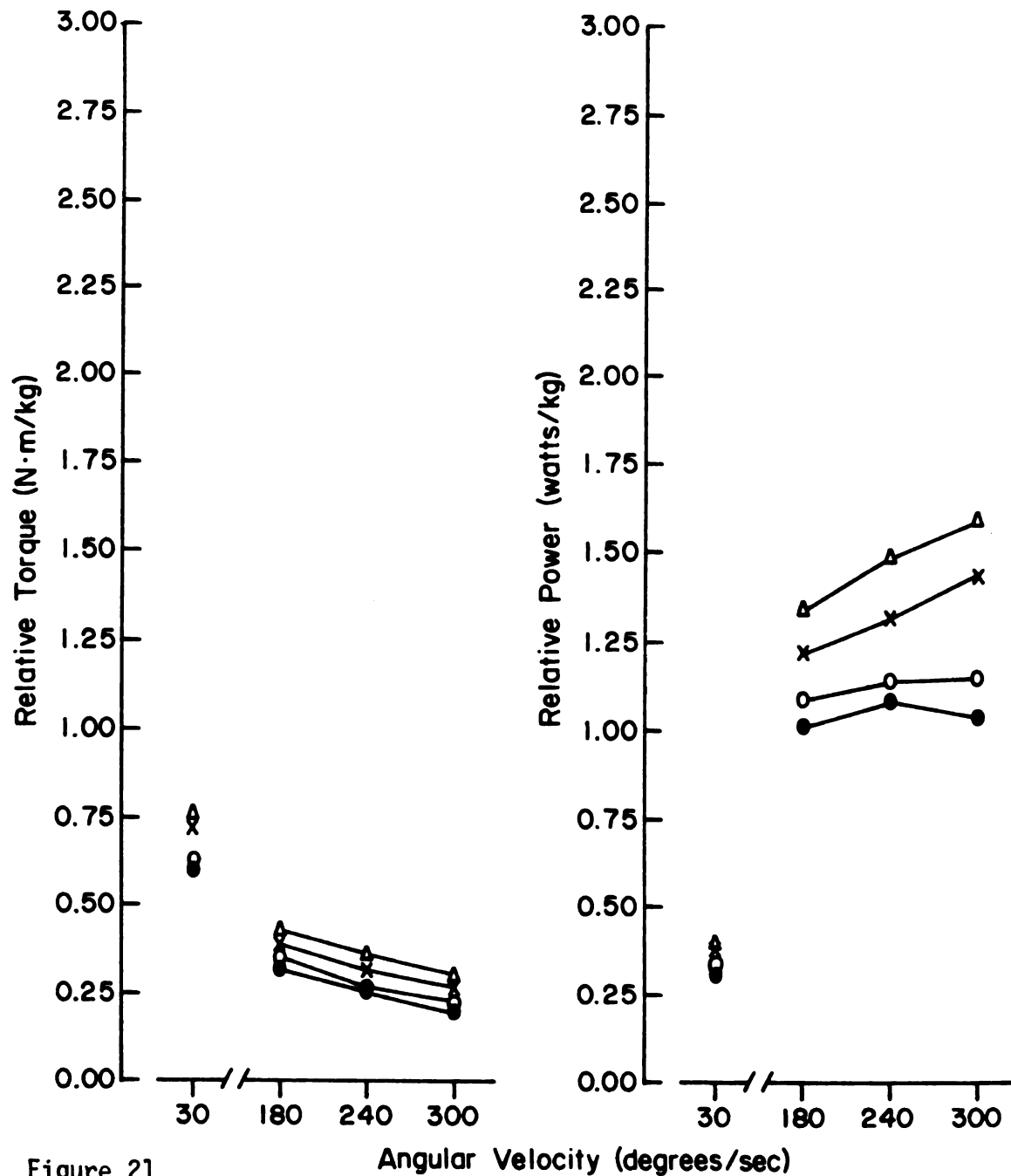


Figure 21

weight at 300 °/s, and in values relative to the ponderal index at 300 °/s.

Cybex data during knee extension are shown in Figures 22 through 24. While sprinters had greater mean values in all comparisons than did the middle-distance swimmers, the only significant contrast occurred in the values relative to body weight at 300 °/s ($p = .04$). In both groups, maximal power values occurred at 180 °/s. Thereafter, power decreased as velocity increased.

Modified Vertical Power Jump

Actual values and ANOVA results are presented in Appendix B, Table B12.

The sprinters jumped significantly greater vertical distances than did the middle-distance swimmers (47.4 cm vs. 42.2 cm, $p = .005$). Significant differences were observed also in values relative to weight ($p = .01$), lean body weight ($p = .02$), height ($p = .002$), and ponderal index ($p = .003$).

While sprinters had higher mean values of work performed during the vertical jump (than did the middle-distance swimmers) (566 joules vs. 519 joules, $p = .08$), statistically significant differences were noted only in values relative to weight ($p = .02$) and lean body weight ($p = .04$).

No significant differences were observed in the absolute and relative power values in the vertical jump. However, the sprinters had higher mean values than did the middle-distance swimmers.

Figure 22.--Knee Extension: Peak Absolute Torque-Velocity and Power-Velocity Relationships for Male Sprinters vs. Middle-Distance Swimmers and for Female Sprinters vs. Middle-Distance Swimmers.

Torque (N · m)

Figure

- Female Sprinter (n = 44-45)
- Female Middle Distance (n = 20)
- △—△ Male Sprinter (n = 36-37)
- ×—× Male Middle Distance (n = 17)

For Females: $p < .05$ at 30 and 180°/s

For Males: All contrasts nonsignificant

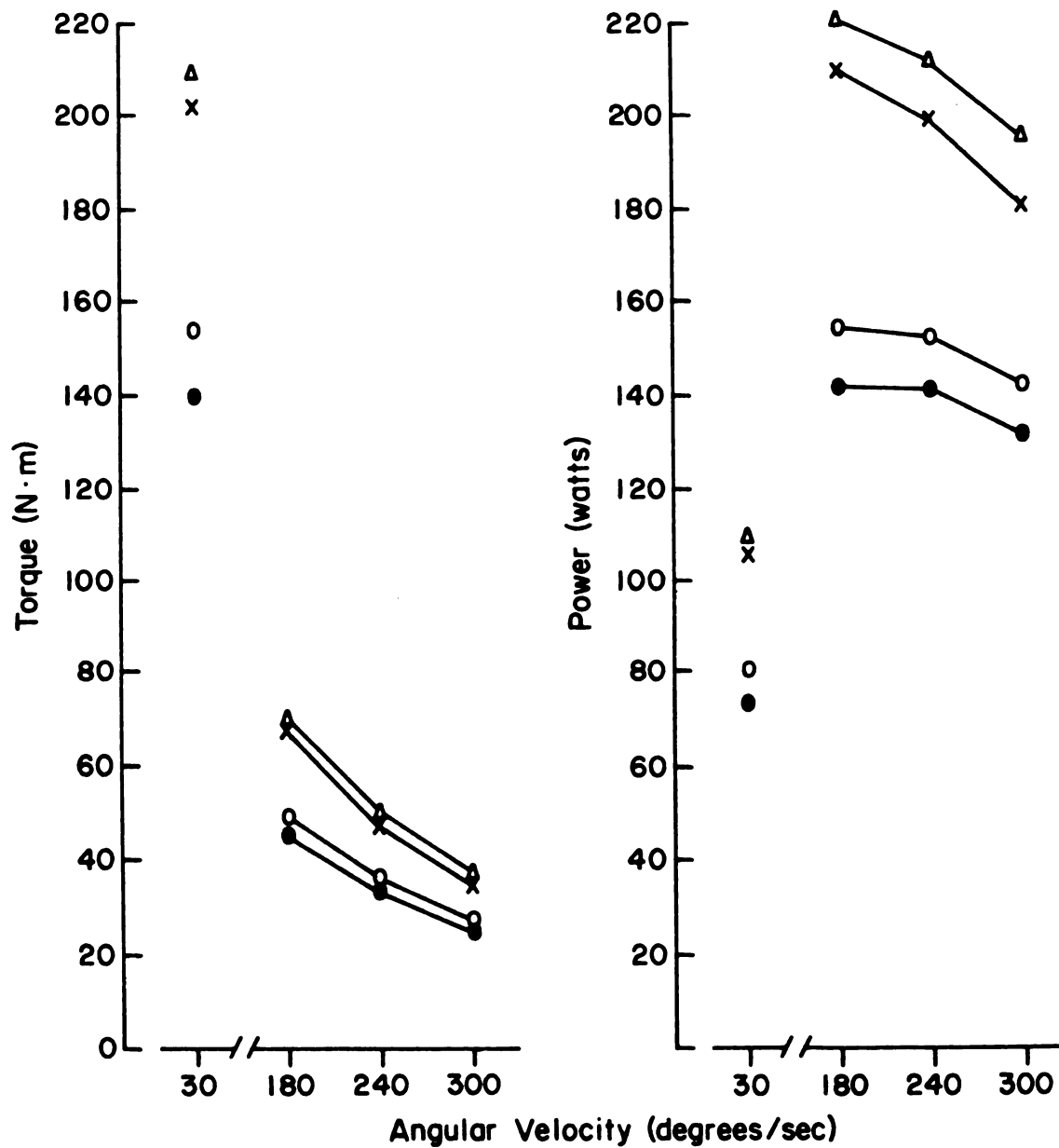


Figure 22

Figure 23.--Knee Extension: Relative (by Body Weight) Peak Torque-Velocity and Power-Velocity Relationships for Male Sprinters vs. Middle-Distance Swimmers and for Female Sprinters vs. Middle-Distance Swimmers.

- Female Sprinter (n = 45)
- Female Middle Distance (n = 20)
- △—△ Male Sprinter (n = 36-37)
- x—x Male Middle Distance (n = 17)

For Females: All contrasts nonsignificant

For Males: $p < .05$ at 300°/s

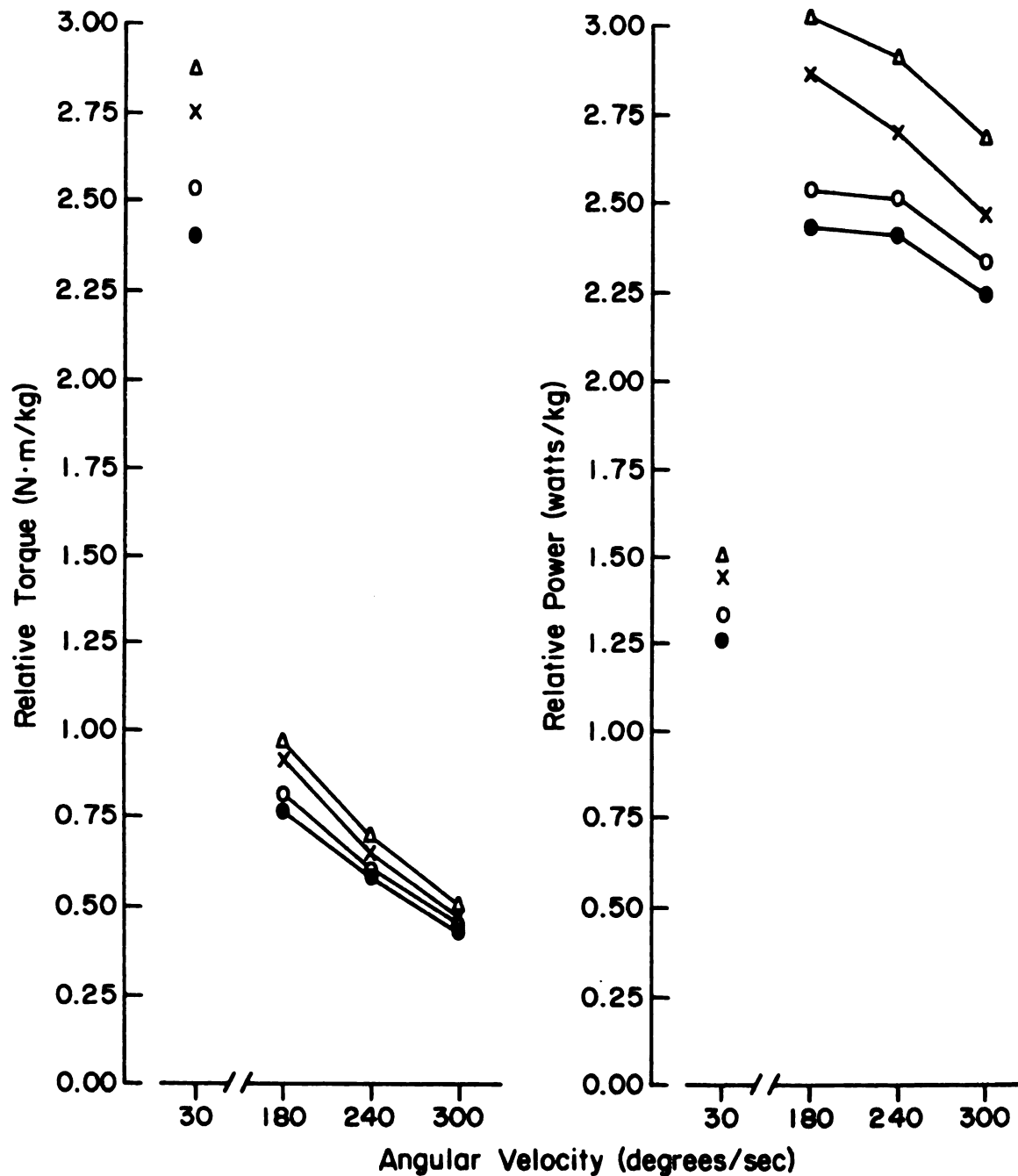


Figure 23

Figure 24.--Knee Extension: Relative (by Lean Body Weight) Peak Torque-Velocity and Power-Velocity Relationships for Male Sprinters and Middle-Distance Swimmers and for Female Sprinters vs. Middle-Distance Swimmers.

(N.m/kg)

- Female Sprinter (n = 45)
- Female Middle Distance (n = 20)
- △—△ Male Sprinter (n = 36-37)
- x—x Male Middle Distance (n = 17)

For Females: All contrasts nonsignificant

For Males: All contrasts nonsignificant

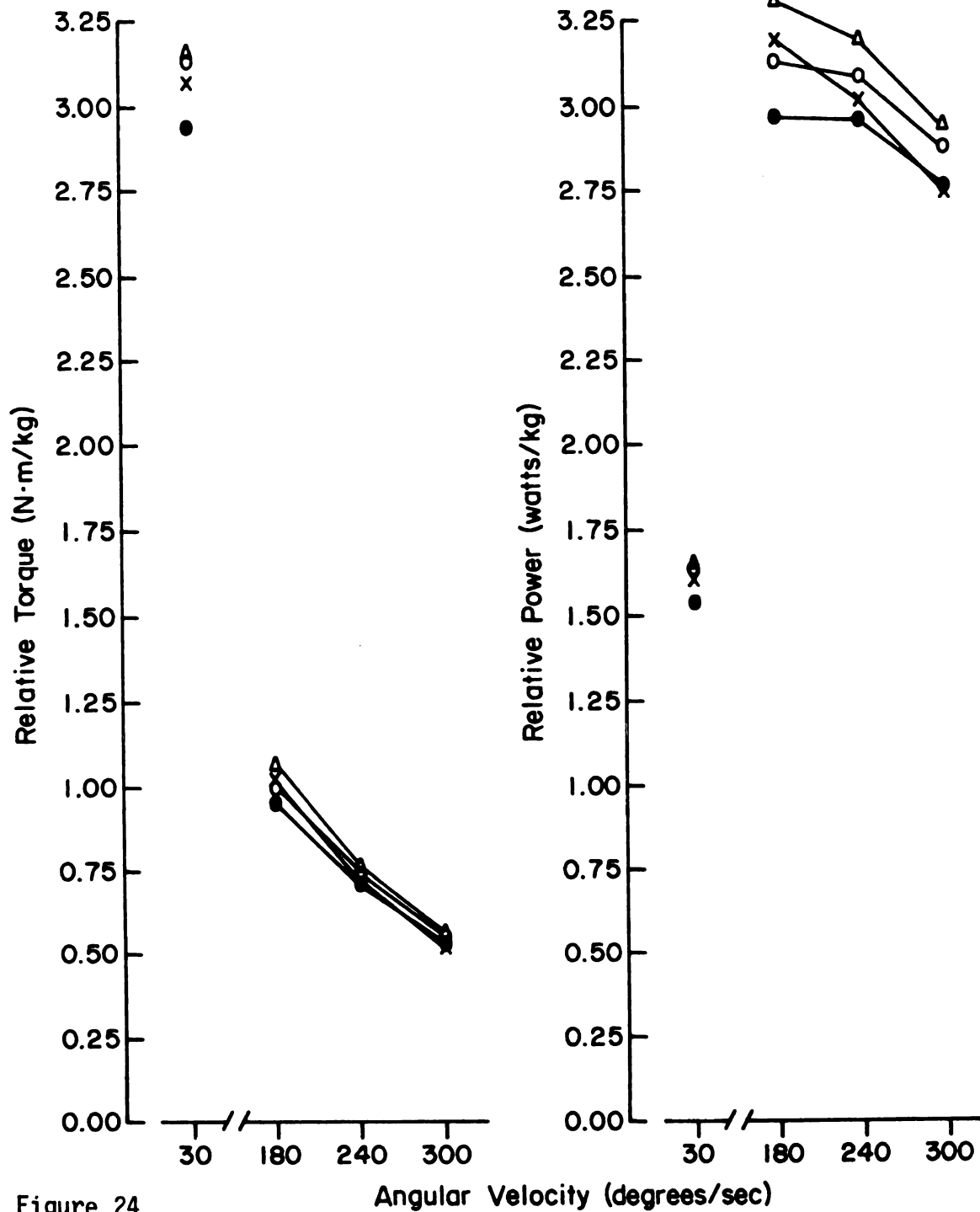


Figure 24

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Female Sprinters vs. Middle-Distance Swimmers

This section has three parts. The first part describes the subjects. Isokinetic results and the results from the modified vertical power jump are discussed in the final two parts.

Subject Characteristics

Selected parameters of the subjects are presented in Table 3. Data from approximately 45 sprinters and 21 middle-distance swimmers were analyzed. No significant differences between sprinters and middle-distance swimmers were observed in age, height, weight, lean body weight, percentage of body fat, and ponderal index, or quality of swimmer.

Isokinetic Data

Actual values and the ANOVA results for each joint action and angular velocity are presented in Appendix B, Tables B13 through B17.

Cybex data obtained during elbow extension are presented in Figures 13 through 15. No significant differences were observed between female sprinters and female middle-distance swimmers in any absolute or relative comparisons. However, the sprinters' mean values were greater than the middle-distance swimmers in each case. Differences between the two groups were less when values relative to body weight and lean body weight were considered.

Strength and power data during shoulder joint extension are graphed in Figures 16 through 18. Significant differences were

TABLE 3. Selected Parameters of Female Sprinters vs. Middle-Distance Swimmers.

	Sprinters			Middle-Distance			ANOVA	
	n	$\bar{x}$	s	n	$\bar{x}$	s	F	P
Age (months)	45	204	20	21	199	13	1.01	.32
Height (cm)	44	170.0	4.8	21	169.2	5.3	.33	.57
Weight (kg)	45	61.0	6.2	21	59.0	5.3	1.65	.20
Lean Body Fat (kg)	45	49.4	4.1	21	48.0	3.5	1.81	.18
Percent Body Fat	45	18.9	2.4	21	18.6	2.4	.34	.56
Quality of Swimmer	45	106.2	2.3	21	106.1	2.7	.003	.95
Ponderal Index	44	23.14	.65	21	23.00	.69	.63	.43

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observed in absolute strength and power values at 240 $^{\circ}/s$ ($p = .02$) and 300 $^{\circ}/s$ ($p = .045$), in values relative to height at 180 $^{\circ}/s$ ($p = .04$), 240 $^{\circ}/s$ ($p = .02$), and 300 $^{\circ}/s$ ($p = .04$), and in value relative to ponderal index at 240 $^{\circ}/s$ ($p = .03$). No significant differences were observed in values relative to body weight or lean body weight. The mean values of sprinters were greater than those of the middle-distance swimmers in all comparisons. Both groups demonstrated an increase in power as velocity increased with maximal values occurring at 300 $^{\circ}/s$. The values for both groups also appear to plateau between 240 $^{\circ}/s$ and 300 $^{\circ}/s$.

Because overall male vs. female comparisons were conducted separately, no statistical analyses were made between male sprinters or middle-distance swimmers vs. female sprinters or middle-distance swimmers. However, the graphing of the data on the same page provided some interesting comparisons. In Figure 18, the power values relative to lean body weight of female sprinters at 240 $^{\circ}/s$ and 300 $^{\circ}/s$ appeared to equal those of male middle-distance swimmers.

Cybex data obtained during shoulder joint inward rotation are presented in Figures 19 through 21. No significant differences were observed in any absolute or relative comparisons; however, the sprinters' mean values were consistently higher than the middle-distance swimmers. The middle-distance swimmers appeared to have maximal power values at 240 $^{\circ}/s$, while the sprinters' values continued to rise to 300 $^{\circ}/s$. In comparison to those of the male swimmers, the females power curves had relatively moderate slopes.

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Cybex data during knee extension are graphed in Figures 22 through 24. Significant differences were observed in absolute values and values relative to height and ponderal index at 30 $^{\circ}$ /s and 180 $^{\circ}$ /s. No significant differences were observed in values relative to body weight and lean body weight. Sprinters had consistently higher mean values than did the middle-distance swimmers. Maximum power values were observed at 180 $^{\circ}$ /s in both groups. In comparison to the shape of males' power curves, the females' power curves appeared to be suppressed at 180 $^{\circ}$ /s, creating a plateau effect. Interesting comparisons between male and female sprinters and middle-distance swimmers may be seen in Figure 24. When values relative to lean body weight were considered, female sprinters had higher mean values at 240 $^{\circ}$ /s than did male middle-distance swimmers. At 300 $^{\circ}$ /s, both female groups had higher values than did the male middle-distance swimmers.

Modified Vertical Power Jump

Actual values and ANOVA results are presented in Appendix B, Table B18.

The sprinters jumped significantly greater vertical distances than did the middle-distance swimmers (35.7 cm vs. 32.2 cm, $p = .01$). Significant differences were observed also in values relative to height ($p = .02$) and ponderal index ($p = .02$). Comparisons with values relative to body weight and lean body weight were not significant ($p = .19$ and $p = .12$ respectively).

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Sprinters performed significantly greater work during the jump than did the middle-distance swimmers (396 joules vs. 356 joules, $p = .01$). Significant differences were observed in all relative values.

The sprinters had significantly greater power production than did the middle-distance swimmers (1,734 vs. 1,513 watts, $p = .002$). Significant differences were observed in values relative to weight ($p = .01$), lean body weight ($p = .01$), height ($p = .004$), and ponderal index ($p = .003$).

Upper- vs. Lower-Twenty Percent of Male Swimmers

This section is subdivided into three parts. A description of the subjects is followed by a discussion of the isokinetic results and the results from the modified vertical power jump.

Subject Characteristics

Selected parameters of the subjects are presented in Table 4. Twelve subjects were classified in the upper-twenty percent (UTP) group and nine subjects were in the lower-twenty percent (LTP) group. The UTP subjects were significantly older ($p < .001$) and heavier ($p = .002$) and, in addition, had greater lean body weights ($p = .004$) than did the LTP subjects. No significant differences were observed in height, percentage of body fat, or ponderal index.

TABLE 4. Selected Parameters of Upper- vs. Lower-Twenty Percent of Male Swimmers

	Upper-Twenty			Lower-Twenty			ANOVA	
	<u>n</u>	<u>$\bar{x}$</u>	<u>s</u>	<u>n</u>	<u>$\bar{x}$</u>	<u>s</u>	<u>F</u>	<u>P</u>
Age (months)	12	236	16	9	206	16	17.37	<.001
Height (cm)	12	184.0	6.0	9	179.1	5.4	3.58	.07
Weight (kg)	12	78.3	4.7	9	70.0	6.2	12.43	.002
Lean Body Weight (kg)	12	70.5	4.7	9	63.7	4.7	10.48	.004
Percent Body Fat	12	10.0	2.6	9	8.7	2.5	1.34	.26
Ponderal Index	12	23.27	.63	9	23.00	.82	.73	.40

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Isokinetic Data

Actual values and ANOVA results for each joint action and angular velocity are presented in Appendix B, Table B19 through B23.

Cybex data obtained during elbow extension are presented in Figures 25 through 27. A significant difference was observed between the absolute values at 30 $^{\circ}$ /s ($p = .047$). All other comparisons were not significant. Both groups demonstrated increasing power with increased velocity. The UTP group had higher mean values than the LTP group in absolute values and values relative to height and ponderal index at each velocity. When values relative to body weight and lean body weight were considered, the curves were indistinguishable.

Strength and power values during shoulder joint extension are graphed in Figures 28 through 30. No significant differences were obtained in any absolute or relative comparisons. The LTP group demonstrated greater declines in power values at 300 $^{\circ}$ /s than did the UTP group. The UTP group curves were higher than the LTP group in absolute value and power relative to height and ponderal index. In the power curves relative to body weight and lean body weight, the LTP group had higher mean values than did the UTP group at 30 $^{\circ}$ /s, 180 $^{\circ}$ /s, and 240 $^{\circ}$ /s.

Cybex data during shoulder joint inward rotation are shown in Figures 31 through 33. No significant differences were observed. Both groups demonstrated maximal power values at 300 $^{\circ}$ /s. The UTP

Figure 25.--Elbow Extension: Absolute Peak Torque-Velocity and Power-Velocity Relationships for the Upper- vs. Lower-Twenty Percent of Male Swimmers and for the Upper- vs. Lower-Twenty Percent of Female Swimmers.

Torque (N · m)

Figure

- Upper-Twenty Percent Female (n = 13)
- Lower-Twenty Percent Female (n = 14)
- △—△ Upper-Twenty Percent Male (n = 12)
- ×—× Lower-Twenty Percent Male (n = 9)

For Females: All contrasts nonsignificant

For Males: $p < .05$ at 30°/s

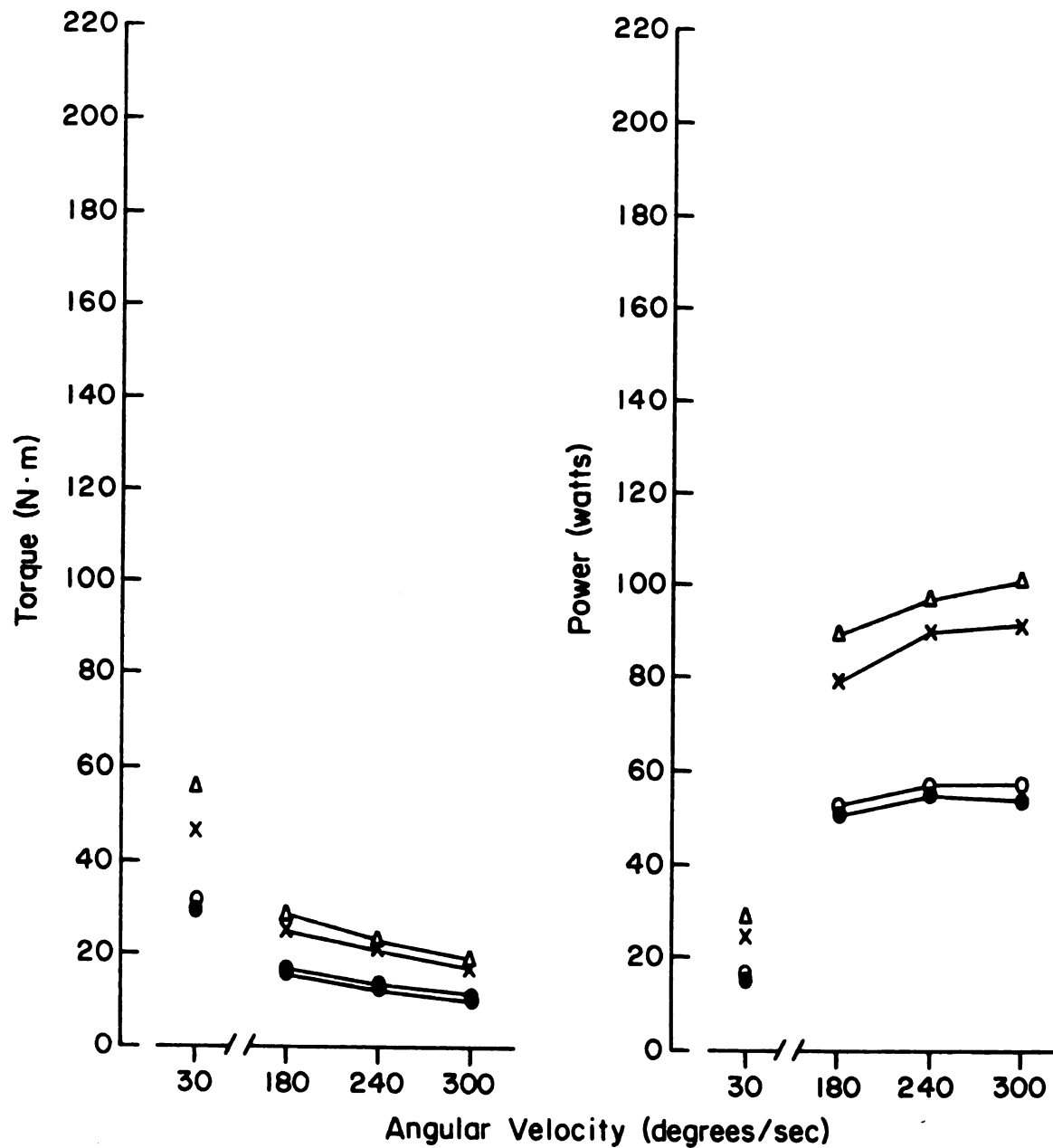


Figure 25

Figure 26.--Elbow Extension: Relative (by Body Weight) Peak Torque-Velocity and Power-Velocity Relationships for the Upper- vs. Lower-Twenty Percent of Male Swimmers and for the Upper- vs. Lower-Twenty Percent of Female Swimmers.

- Upper-Twenty Percent Female (n = 13)
- Lower-Twenty Percent Female (n = 14)
- △—△ Upper-Twenty Percent Male (n = 12)
- x—x Lower-Twenty Percent Male (n = 9)

For Females: All contrasts nonsignificant

For Males: All contrasts nonsignificant

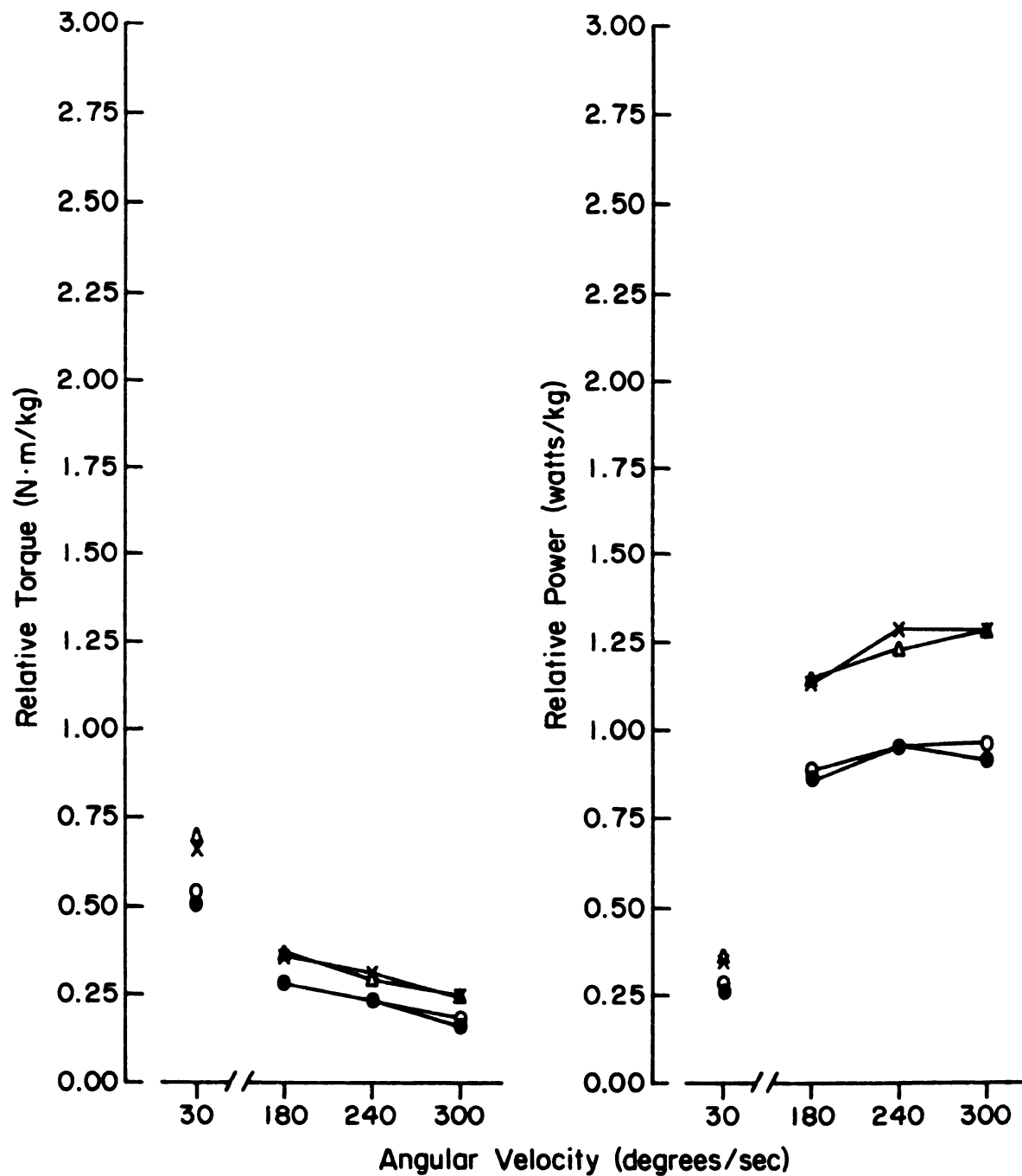


Figure 26

Figure 27.--Elbow Extension: Relative (by Lean Body Weight)
Peak Torque-Velocity and Power-Velocity Relationships for the Upper- vs. Lower-Twenty Percent of Male Swimmers and for the Upper vs. Lower-Twenty Percent of Female Swimmers.

- Upper-Twenty Percent Female (n = 13)
- Lower-Twenty Percent Female (n = 14)
- △—△ Upper-Twenty Percent Male (n = 12)
- ×—× Lower-Twenty Percent Male (n = 9)

For Females: All contrasts nonsignificant

For Males: All contrasts nonsignificant

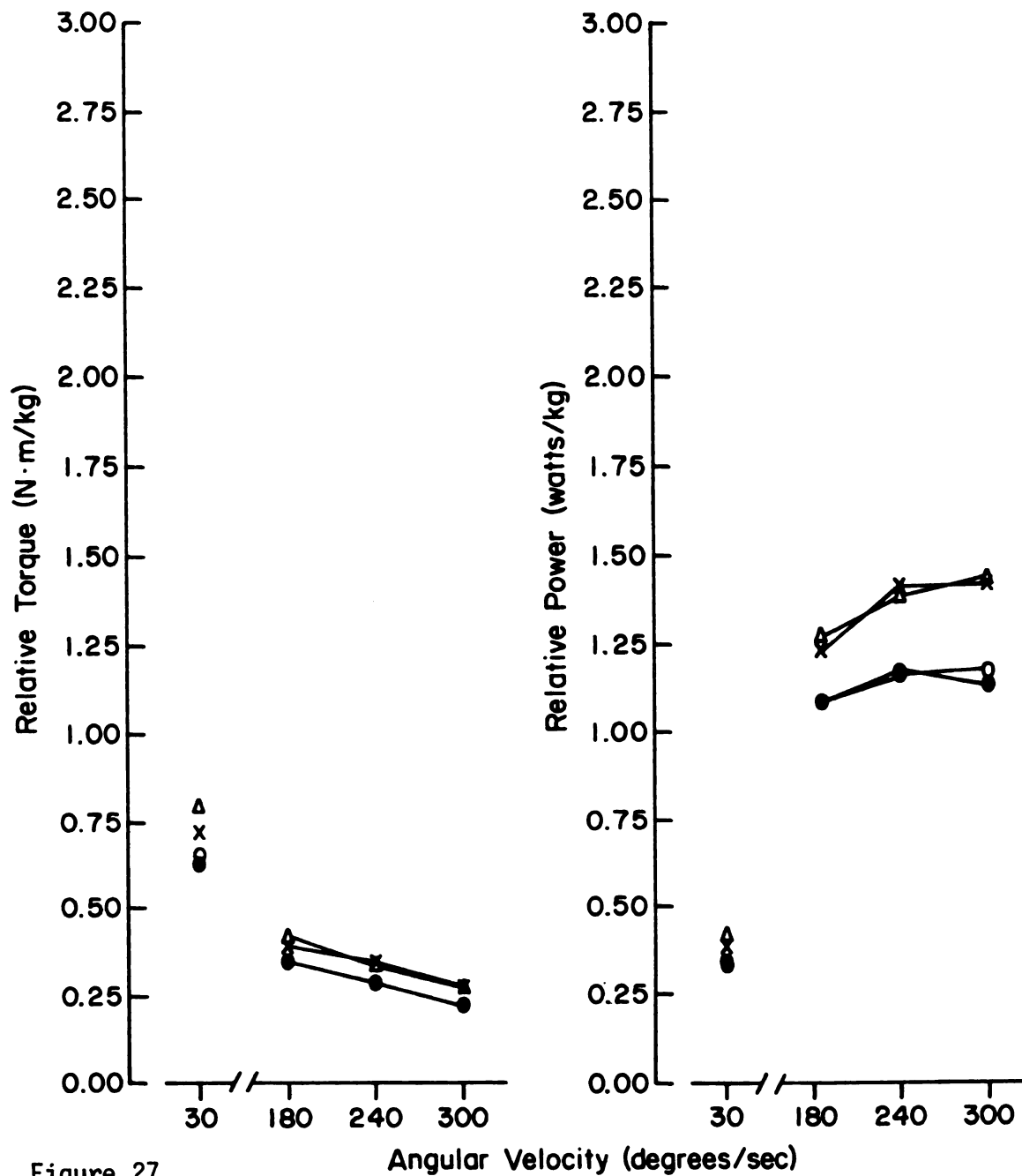


Figure 27

Figure 28.--Shoulder Joint Extension: Absolute Peak Torque-Velocity and Power-Velocity Relationships for the Upper- vs. Lower-Twenty Percent of Male Swimmers and for the Upper- vs. Lower-Twenty Percent of Female Swimmers.

- Upper-Twenty Percent Female (n = 13)
- Lower-Twenty Percent Female (n = 14)
- △—△ Upper-Twenty Percent Male (n = 11)
- ×—× Lower-Twenty Percent Male (n = 9)

For Females: $p < .05$ at $300^\circ/\text{s}$

For Males: All contrasts nonsignificant

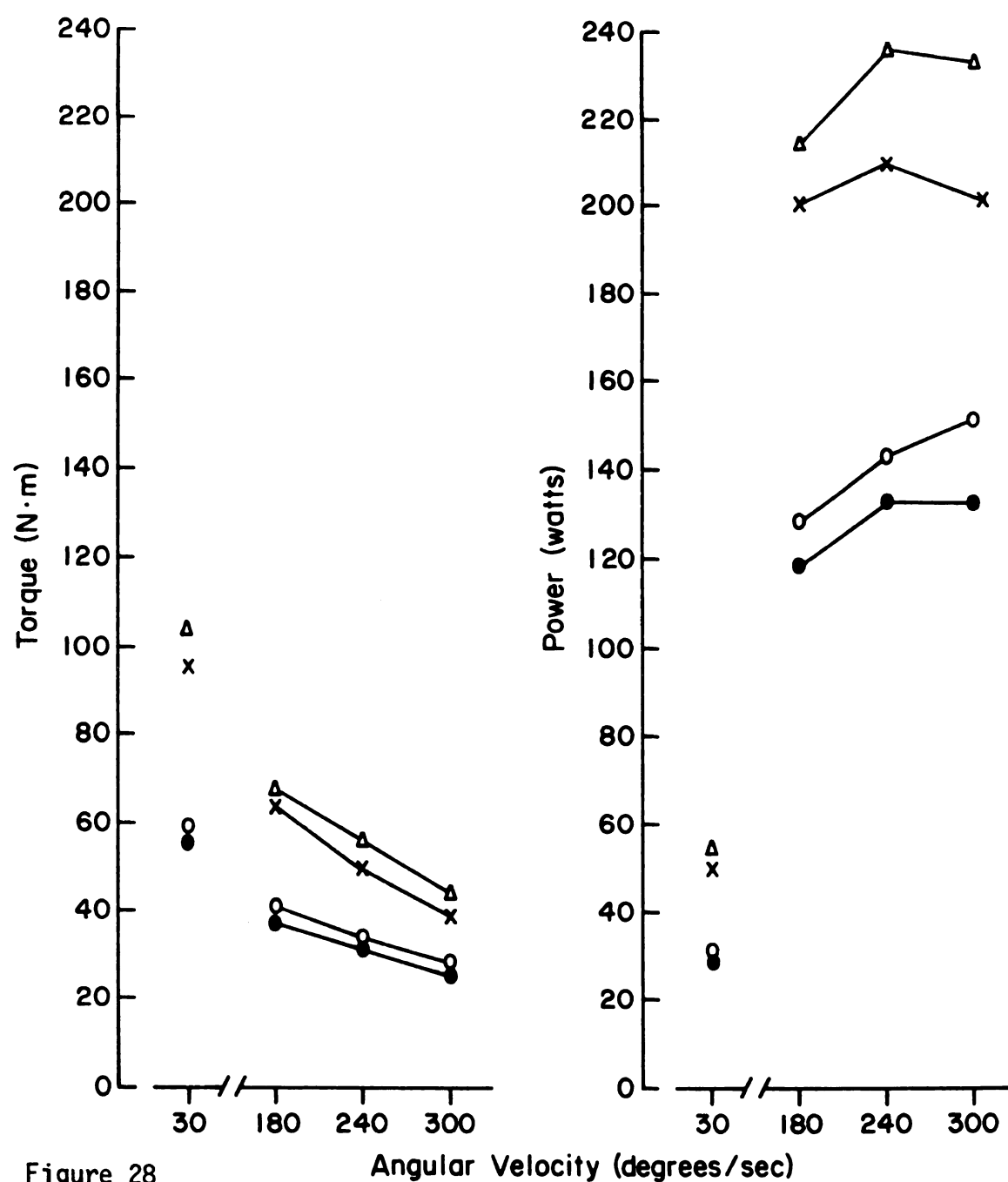


Figure 28

Figure 29.--Shoulder Joint Extension: Relative (by Body Weight)
Peak Torque-Velocity and Power-Velocity Relationships for the Upper- vs. Lower-Twenty Percent of Male Swimmers and for the Upper- vs. Lower-Twenty Percent of Female Swimmers.

- Upper-Twenty Percent Female (n = 13)
- Lower-Twenty Percent Female (n = 14)
- △—△ Upper-Twenty Percent Males (n = 11)
- ×—× Lower-Twenty Percent Males (n = 9)

For Females: $p < .05$ at 300°/s

For Males: All contrasts nonsignificant

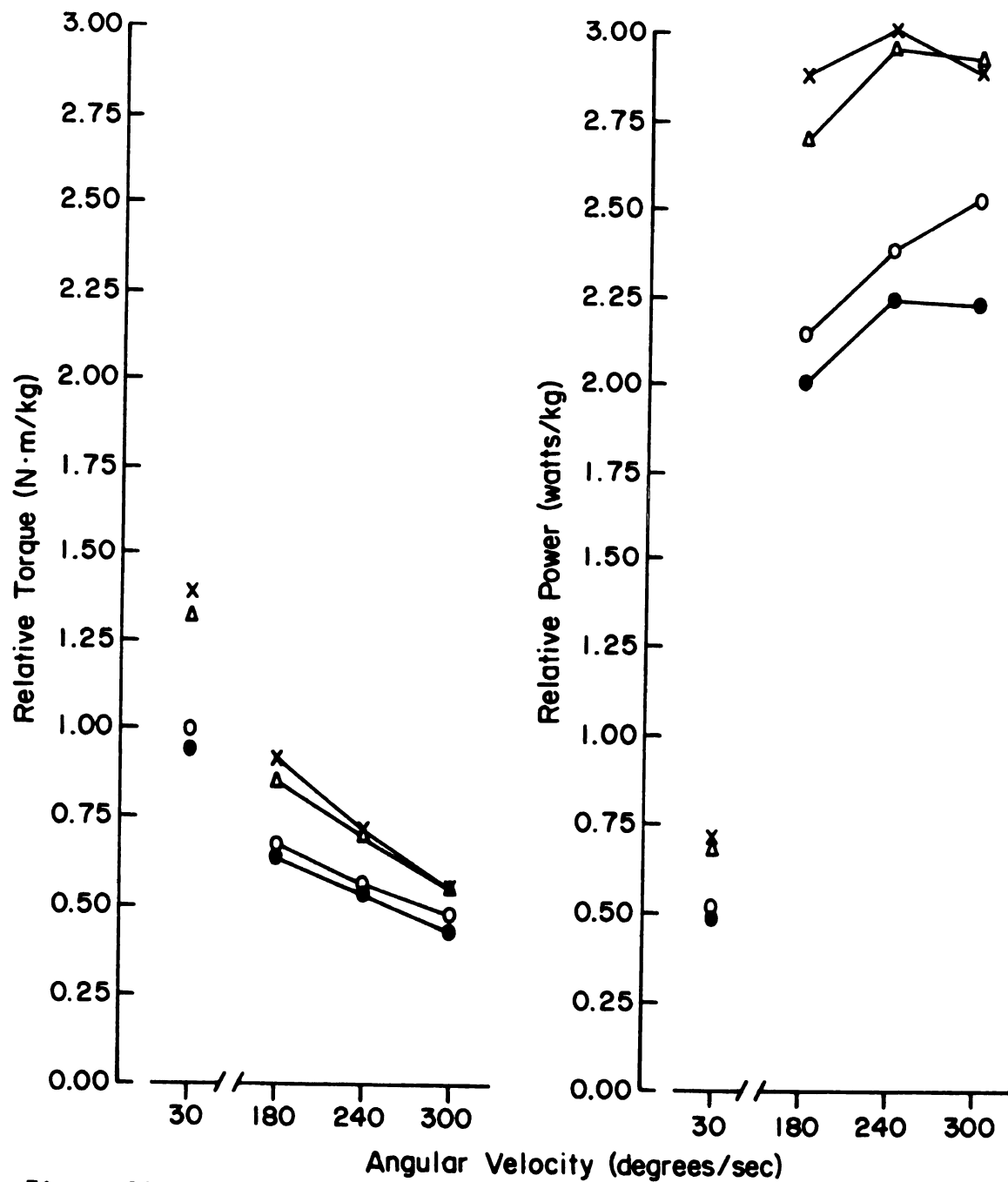


Figure 29

Figure 30.--Shoulder Joint Extension: Relative (by Lean Body Weight) Peak Torque-Velocity and Power-Velocity Relationships for the Upper- vs. Lower-Twenty Percent of Male Swimmers and for the Upper- vs. Lower-Twenty Percent of Female Swimmers.

- Upper-Twenty Percent Female (n = 13)
- Lower-Twenty Percent Female (n = 14)
- △—△ Upper-Twenty Percent Males (n = 11)
- x—x Lower-Twenty Percent Males (n = 9)

For Females: $p < .05$ at $300^\circ/\text{s}$

For Males: All contrasts nonsignificant

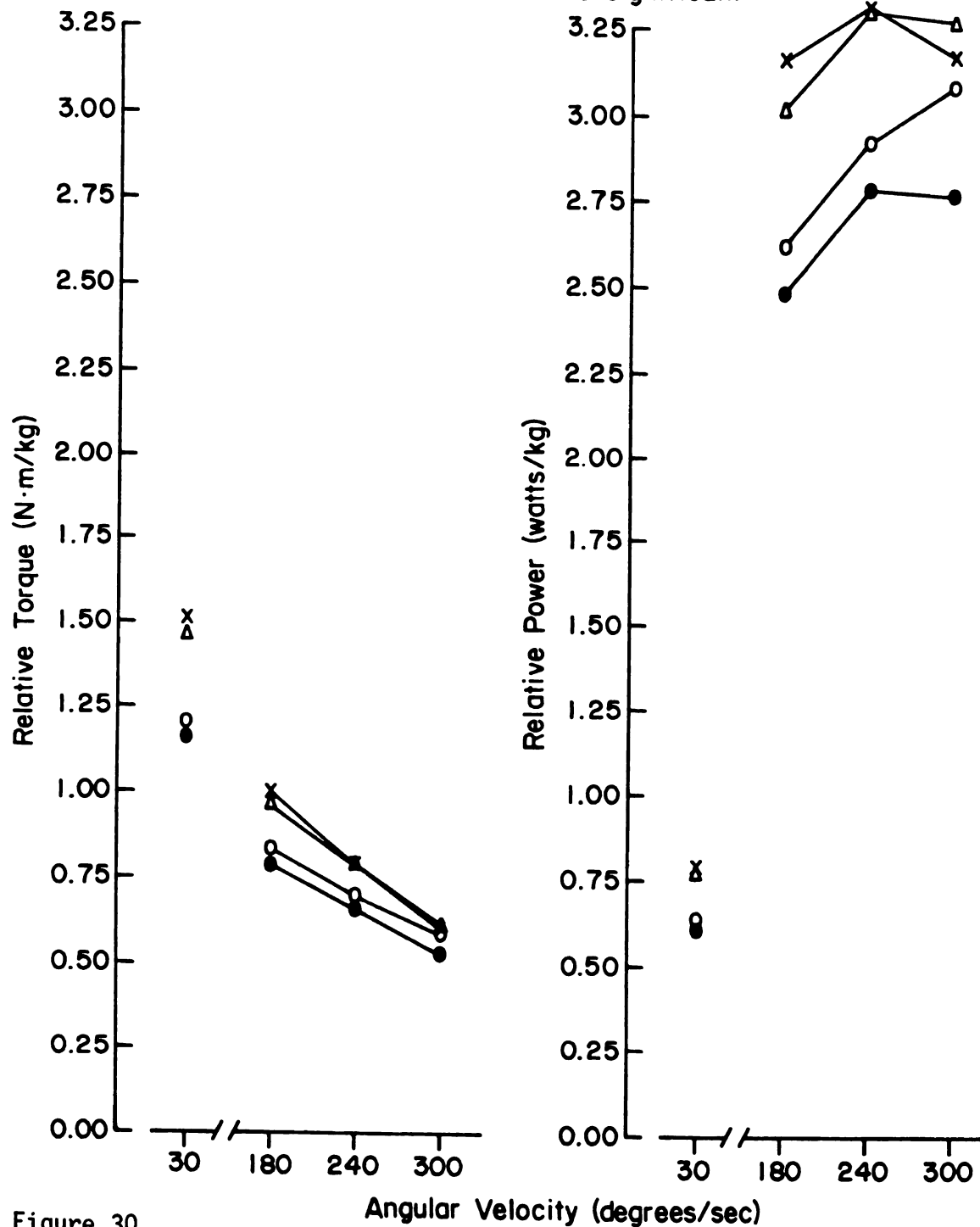


Figure 30

Figure 31.--Shoulder Joint Inward Rotation: Absolute Peak Torque-Velocity and Power-Velocity Relationships for the Upper- vs. Lower Twenty-Percent of Male Swimmers and for the Upper- vs. Lower-Twenty Percent of Female Swimmers.

- Upper-Twenty Percent Female (n = 14)
- Lower-Twenty Percent Female (n = 14)
- △—△ Upper-Twenty Percent Male (n = 12)
- ×—× Lower-Twenty Percent Male (n = 8-9)

For Females: All contrasts nonsignificant

For Males: All contrasts nonsignificant

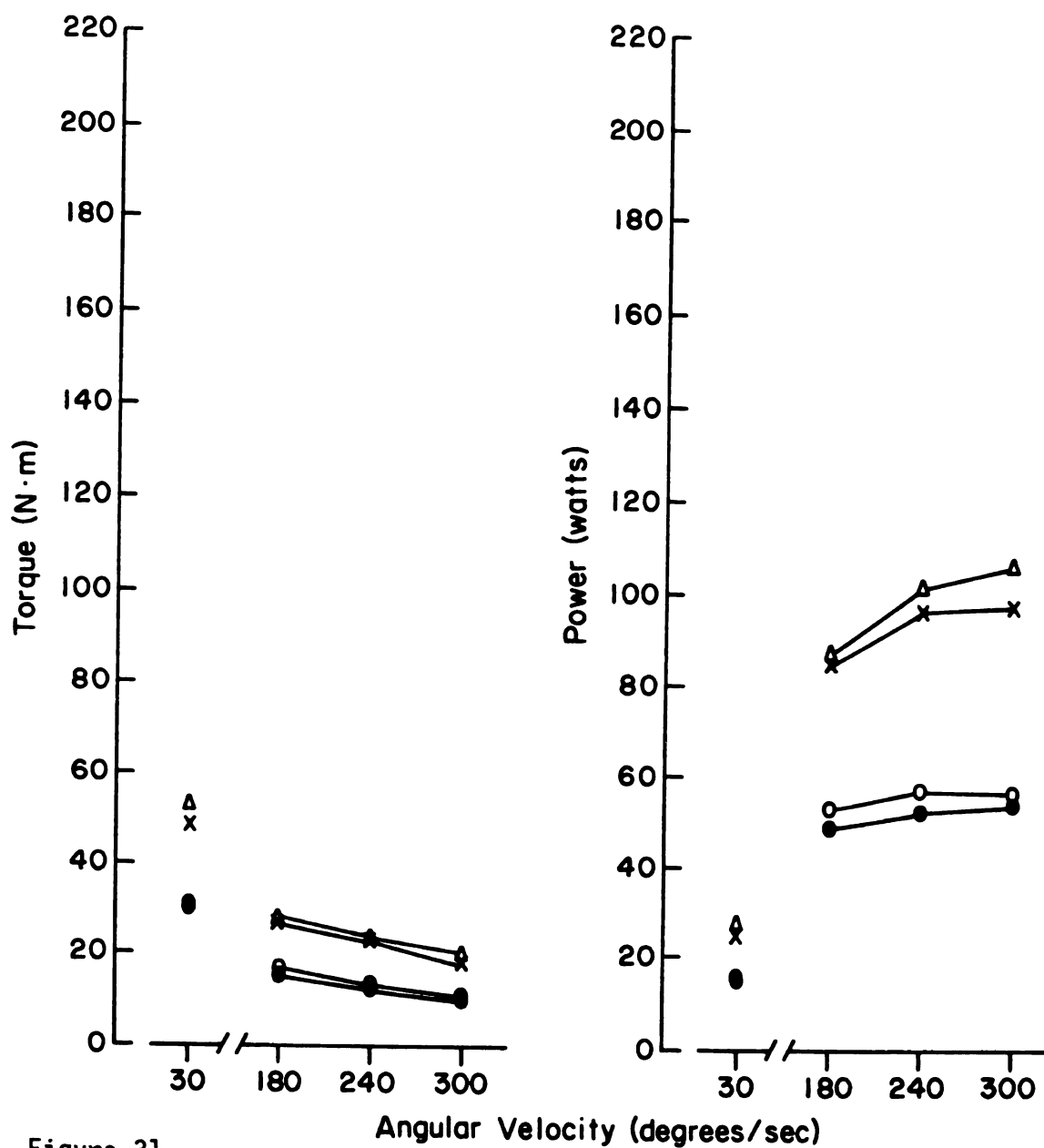


Figure 31

Figure 32.--Shoulder Joint Inward Rotation: Relative (by Body Weight) Peak Torque-Velocity and Power-Velocity Relationships for the Upper- vs. Lower-Twenty Percent of Male Swimmers and for the Upper- vs. Lower-Twenty Percent of Female Swimmers.

- Upper-Twenty Percent Female (n = 14)
- Lower-Twenty Percent Female (n = 14)
- △—△ Upper-Twenty Percent Male (n = 12)
- ×—× Lower-Twenty Percent Male (n = 8-9)

For Females: All contrasts nonsignificant

For Males: All contrasts nonsignificant

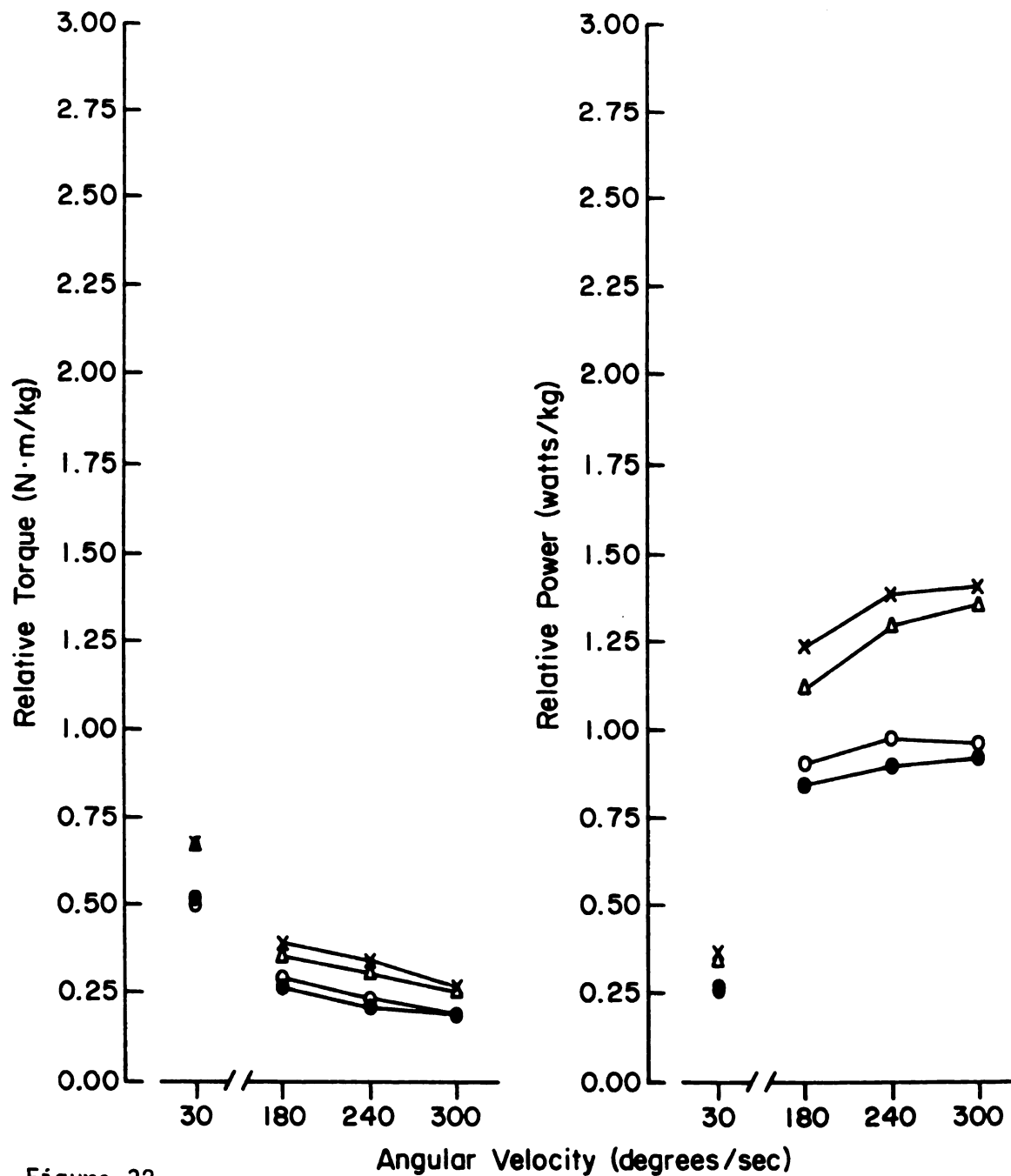


Figure 32

Figure 33.--Shoulder Joint Inward Rotation: Relative (by Lean Body Weight) Peak Torque-Velocity and Power-Velocity Relationships for the Upper- vs. Lower-Twenty Percent of Male Swimmers and for the Upper- vs. Lower-Twenty Percent of Female Swimmers.

- Upper-Twenty Percent Female (n = 14)
- Lower-Twenty Percent Female (n = 14)
- △—△ Upper-Twenty Percent Male (n = 12)
- ×—× Lower-Twenty Percent Male (n = 8-9)

For Females: All contrasts nonsignificant

For Males: All contrasts nonsignificant

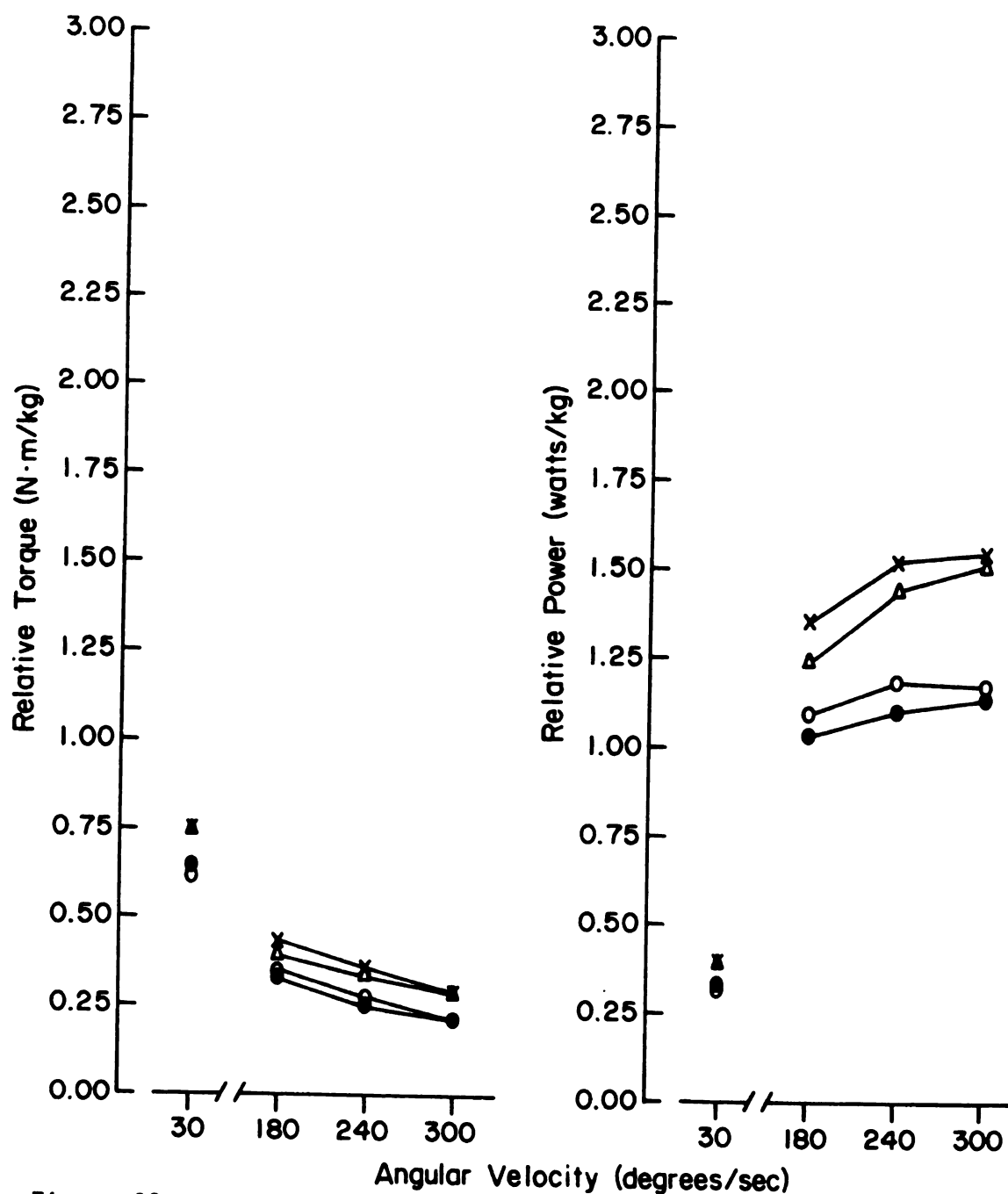


Figure 33

power curves were higher than the LTP power curves in absolute values and values relative to both height and ponderal index. The position of the curves were reversed in comparisons of power values relative to body weight and lean body weight.

Cybex data obtained during knee extension are presented in Figures 34 through 36. No statistically significant differences were obtained. Both groups demonstrated maximal power values at 180 °/s. The UTP curves were higher than the LTP curves in absolute values and values relative to height and ponderal index. The power curves of values relative to body weight of the two groups were similar. Higher mean values for the UTP group than the LTP group were observed in values relative to lean body weight at 180 °/s, 240 °/s, and 300 °/s.

Modified Vertical Power Jump

Actual values and ANOVA results are presented in Appendix B, Table B24.

No significant differences were observed in the absolute heights achieved during the vertical jump or in any relative comparisons.

No significant differences were obtained in the amount of work performed during the jump or in any relative values. However, the mean values for the UTP group were consistently higher than those for the LTP group.

Figure 34.--Knee Extension: Absolute Peak Torque-Velocity and Power-Velocity Relationships for the Upper- vs. Lower-Twenty Percent of Male Swimmers and for the Upper- vs. Lower-Twenty Percent of Female Swimmers.

- Upper-Twenty Percent Female (n = 13)
- Lower-Twenty Percent Female (n = 14)
- △—△ Upper-Twenty Percent Male (n = 11)
- ×—× Lower-Twenty Percent Male (n = 9)

For Females: All contrasts nonsignificant

For Males: All contrasts nonsignificant

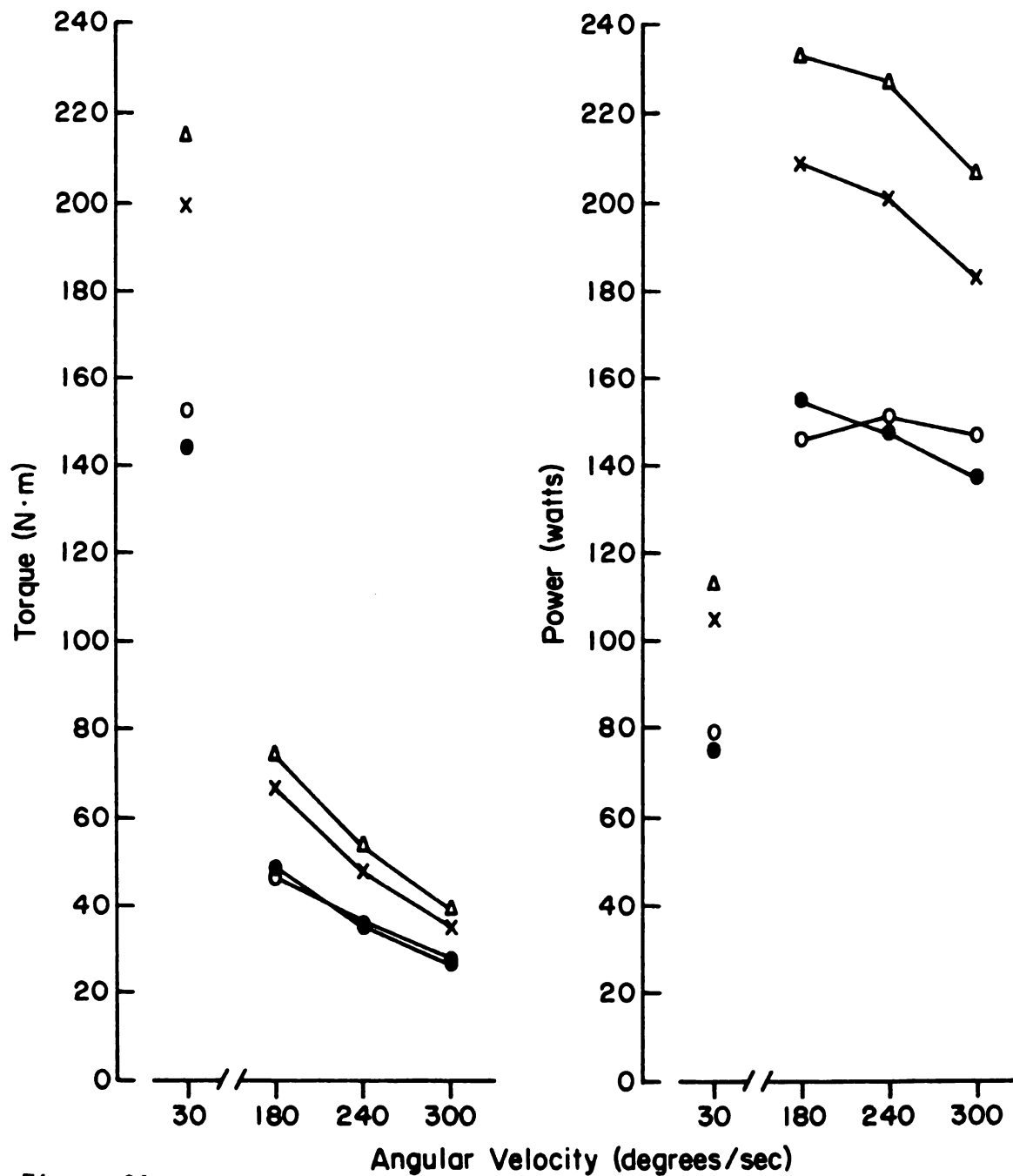


Figure 34

Figure 35.--Knee Extension: Relative (by Body Weight) Peak Torque-Velocity and Power-Velocity Relationships for the Upper- vs. Lower-Twenty Percent of Male Swimmers and for the Upper- vs. Lower-Twenty Percent of Female Swimmers.

- Upper-Twenty Percent Female (n = 13)
 ○—○ Lower-Twenty Percent Female (n = 14)
 △—△ Upper-Twenty Percent Male (n = 11)
 ×—× Lower-Twenty Percent Male (n = 9)

For Females: All contrasts nonsignificant

For Males: All contrasts nonsignificant

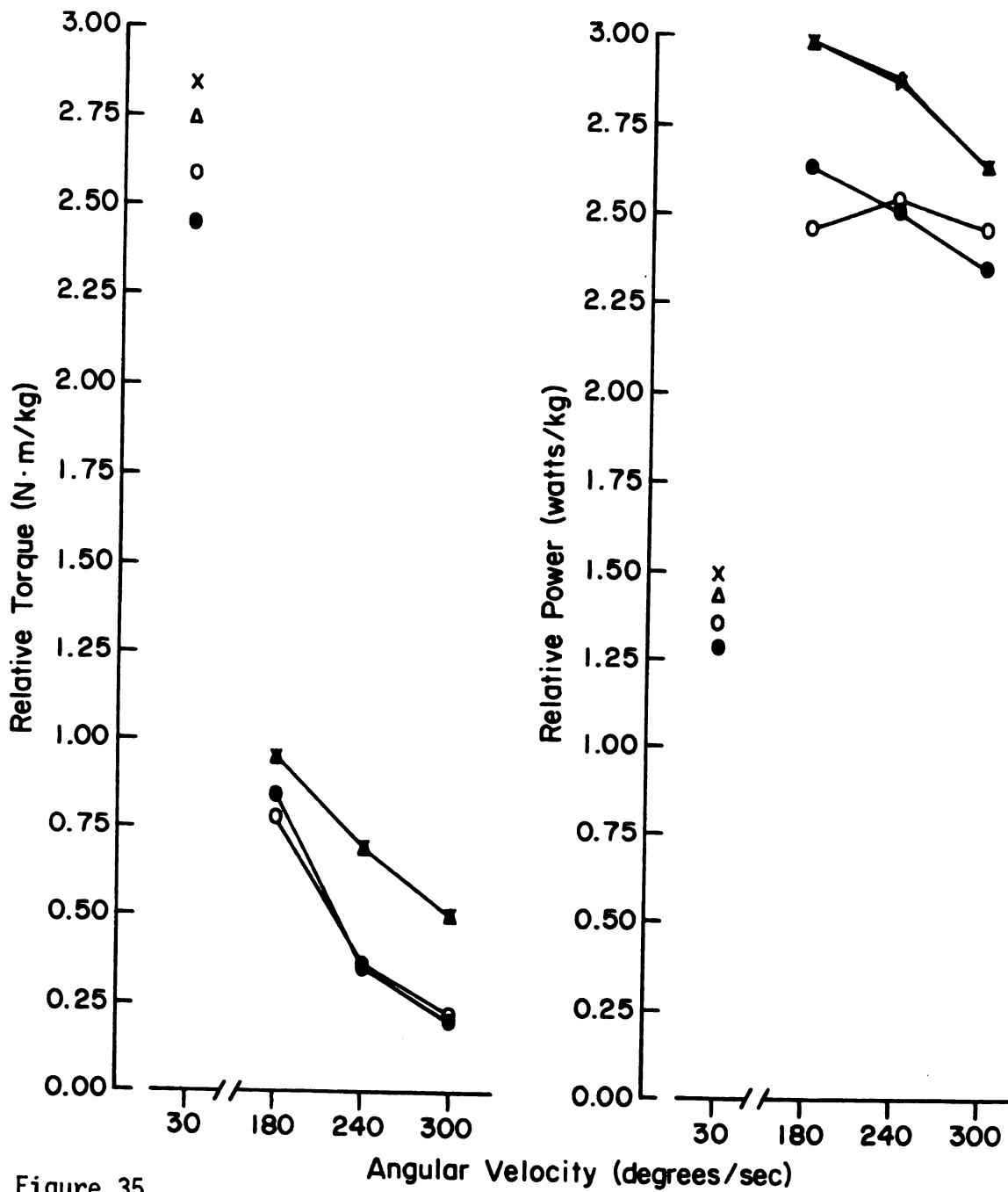


Figure 35

Figure 36.--Knee Extension: Relative (by Lean Body Weight)
Peak Torque-Velocity and Power-Velocity Relationships for the Upper- vs. Lower-Twenty Percent of Male Swimmers and for the Upper- vs. Lower-Twenty Percent of Female Swimmers.

- Upper-Twenty Percent Female (n = 13)
- Lower-Twenty Percent Female (n = 14)
- △—△ Upper-Twenty Percent Male (n = 11)
- ×—× Lower-Twenty Percent Male (n = 9)

For Females: All contrasts nonsignificant

For Males: All contrasts nonsignificant

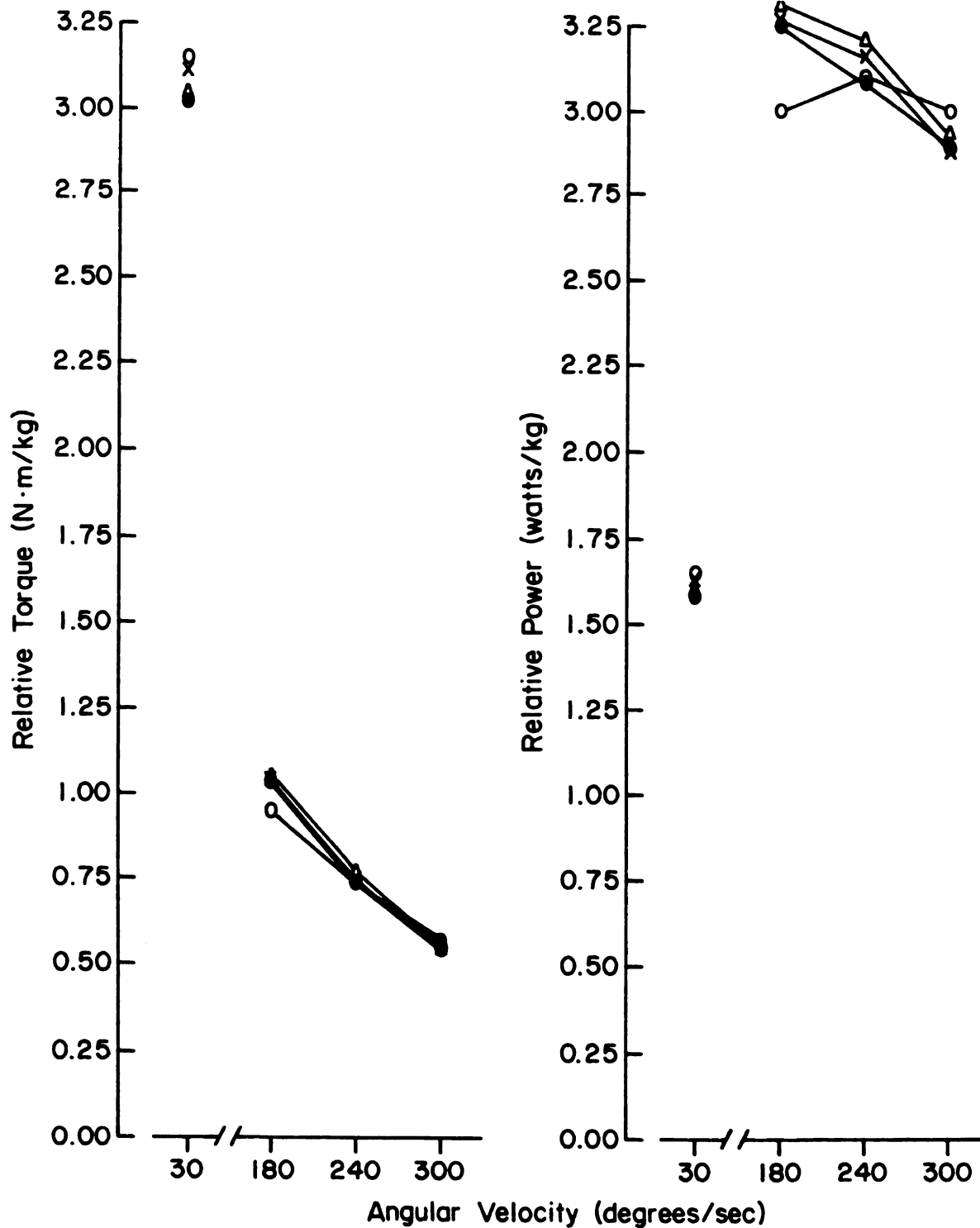


Figure 36

No significant differences were seen in the power generated during the jump or in any relative comparisons. Again, the UTP group had higher mean values than did the LTP group.

Upper- vs. Lower-Twenty Percent of Female Swimmers

This section has three parts. The subjects' characteristics are discussed first. This is followed by a description of the isokinetic results. Finally, data from the modified vertical power jump are reviewed.

Subject Characteristics

Selected parameters of the subjects are presented in Table 5. Approximately fourteen subjects were in each group. No significant differences were observed in age, height, weight, lean body weight, percentage of body fat, or ponderal index.

Isokinetic Data

Actual values and ANOVA results for each joint action and angular velocity are presented in Appendix B, Table B25 through B29.

Cybex data obtained during elbow extension are presented in Figures 25 through 27. No significant differences were observed in any absolute or relative comparisons. Absolute values and values relative to ponderal index were slightly higher in the UTP group than in the LTP group.

Strength and power values obtained during shoulder joint extension are shown in Figures 28 through 30. Significant

TABLE 5. Selected Parameters of Upper- vs. Lower-Twenty Percent of Female Swimmers

	Upper-Twenty			Lower-Twenty			ANOVA	
	<u>n</u>	<u>x</u>	<u>s</u>	<u>n</u>	<u>x</u>	<u>s</u>	<u>F</u>	<u>P</u>
Age (months)	14	205	22	14	205	12	.01	.94
Height (cm)	14	169.9	3.6	13	168.5	5.4	.62	.44
Weight (kg)	14	60.0	5.9	14	59.1	5.0	.20	.66
Lean Body Weight (kg)	14	49.0	3.6	14	47.7	2.9	1.02	.32
Percent Body Fat	14	18.1	2.4	14	19.0	2.4	.99	.33
Ponderal Index	14	23.02	.76	13	23.08	.85	.04	.84

differences were observed in absolute values at 300 °/s ($p = .03$), in values relative to body weight at 300 °/s ($p = .02$), in values relative to lean body weight at 300 °/s ($p = .03$), and in values relative to ponderal index at 300 °/s ($p = .03$). The UTP group demonstrated increased power with increased velocity, with maximal values occurring at 300 °/s. The LTP group had lower mean values than did the UTP group, and these values appeared to plateau between 240 °/s and 300 °/s.

Cybox data during shoulder joint inward rotation are graphed in Figures 31 through 33. No significant differences were noted in any comparisons. The UTP group had higher mean values than did the LTP group in all comparisons at 180 °/s, 240 °/s, and 300 °/s. The curve shapes in both groups appeared to be similar.

Strength and power data from knee extension are presented in Figures 34 through 36. No significant differences were observed in any absolute or relative means. The UTP group demonstrated unique curves, which differed not only from the curves of the LTP group but also from the power curves of both male groups. The UTP power curve for the absolute and all relative values peaked at 240 °/s. Values relative to lean body weight of the UTP group were lower at 180 °/s than were the corresponding values for the female LTP group and both male groups. At 300 °/s, the UTP group mean was higher than that of the other three groups.

Modified Vertical Power Jump

Actual values and ANOVA results are presented in Appendix B, Table B30.

No statistically significant differences were observed in the absolute vertical distances attained during the vertical jump or in any relative comparisons. The UTP group had higher mean values than the LTP group in all cases.

The UTP group performed greater work during the vertical jump than did the LTP group (410 vs. 360 joules, $p = .04$). Values relative to ponderal index also were significant ($p = .04$).

While the UTP group had higher absolute and relative mean power values than did the LTP group, no significant differences were observed in any comparisons.

Discussion

This section is presented in three parts. A discussion of the findings in male versus female swimmers will be presented first. Second, the important differences between sprinters and middle-distance swimmers will be presented. Finally, data of the upper- versus lower-twenty percent of swimmers will be discussed.

Male vs. Female Swimmers

Comparative values of various physical characteristics of swimmers from other studies are given in Table 6 for females and Table 7 for males. The female swimmers in this study were generally taller and leaner than other swimmers and also taller and leaner

TABLE 6. Comparative Physical Characteristics of Female Swimmers

<u>Type</u>	<u>n</u>	<u>Age</u>	<u>Height (cm)</u>	<u>Weight (kg)</u>	<u>Percent Body Fat</u>	<u>Method*</u>	<u>References</u>
1980 Junior Olympic	64	16.1	168.2	58.5	19.8	UW	Housh (47)
Prominent German Team	8	14.6	158.1	48.2	17.0	TBW	Novak (82)
1972 Olympics	7	17.7	167.0	60.1	18.9	TBW	Novak (84)
"State" Czech. Team	10	19.5	166.2	63.9	19.2	UW	Sprynarova (96)
College Swimmers	9	-	168.0	63.8	26.3	SKF	Conger (21)
Swim Club and College	13	16.4	168.8	57.9	15.6	UW	Melenski (72)
College Team	15	18.6	166.1	62.1	19.6	UW	Wade (106)
This Study	66	16.8	169.7	60.4	18.8	SKF	
Reference Group		16.6	162.3	54.4	25.8		Thorland (99)

*Methods Used: UW = Underwater Weighing, SKF = Skinfold, TBW = Total Body Water.

TABLE 7. Comparative Physical Characteristics of Male Swimmers.

<u>Type</u>	<u>n</u>	<u>Age</u>	<u>Height (cm)</u>	<u>Weight (kg)</u>	<u>Percent Body Fat</u>	<u>Method*</u>	<u>References</u>
1972 Olympics	14	19.9	179.5	74.9	7.5	TBW	Novak (81)
1980 Junior Olympics	39	17.3	180.7	72.7	12.1	UW	Thorland (100)
College Team	7	20.6	182.9	78.9	4.95	TBW	Novak (83)
Elite Czech Swimmers	13	21.8	182.3	79.1	8.45	UW	Sprynarova (97)
This Study	55	18.0	180.7	72.9	9.1	SKF	
Reference Group		17.5	175.9	67.5	11.4		Thorland (99)

*Method Used: TBW = Total Body Water, UW = Underwater Weighing, SKF = Skinfold.

than a reference group developed by Thorland (99). The reference group represented data summarized from several studies on subjects who were of similar age but who were not athletes.

The males in this study were similar to other groups of swimmers. Compared to the reference group, they were taller, heavier, and leaner.

It is difficult to make direct comparisons of the isokinetic strength and power results of this study with those obtained in earlier research. First, gravitational corrections were not performed in this study. More importantly, the test position and methods of stabilization may have differed. Finally, other studies reported angle-specific torque values or tested different angular velocities.

The isokinetic data in this study indicated that male swimmers are significantly stronger and more powerful than female swimmers, both in absolute and in relative measurements. One exception to this statement was noted. No significant differences were observed between male and female swimmers in torque relative to lean body weight at 30, 240, and 300 $^{\circ}$ /s during knee extension.

The relationship of muscle strength in untrained men and women has been studied extensively. Laubach (65) reviewed nine studies comparing static and dynamic strength differences. He reported the following: (a) static upper-body strength measurements in females are 35 to 79% of those of males ($\bar{X} = 55.8$); (b) in static lower-body measurements, women are 57 to 86% as strong as men

($\bar{X}$ = 71.9); (c) in static trunk strength, women's values range from 37 to 70% of men's values ($\bar{X}$ = 63.8); and (d) in dynamic upper-body measurements, women are 59 to 84% as strong as men ($\bar{X}$ = 68.6).

Differences in isokinetic strength measurements also have been reported. In sedentary adults, mean female torques were 65% of male torques during plantar flexion (32). In West Point cadets, the females were 50.1% and 74.0% as strong as their male counterparts in the bench press and leg press respectively (45).

Most past studies of sex differences in strength have not included athletes. Morrow (77) compared untrained men with intercollegiate women basketball and volleyball players. The females were 71% and 50% as strong as the males in an isokinetic leg press and bench press respectively. Using a MANCOVA analysis to control for weight, height, biacromium width and bi-iliac width, the women were 75% and 56% as strong as the males.

The current study made comparisons between highly trained male and female athletes. Lower body strength differences similar to past studies were observed. In absolute values of knee extension, the female swimmers were 71.4% as strong as the males. Differences in upper-body measurements were slightly less than in previous studies. The mean percent difference between female and male swimmers was 61.6%.

As observed in this study, several authors have reported that women's leg strength is closer to men's than is their arm strength (45, 65, 80, 110). Furthermore, as in this study, some

relative strength measurements of lower-body segments have shown no significant differences between men and women (5, 45, 61, 110). Some authors have suggested that these observations reflect similar usage of leg muscles by each sex and that differences in upper-body strength are due to differences in physical activities. This theory is not supported by the current data. The female swimmers were extensively trained in upper-body movements and they still exhibited greater strength differences in that area than in lower-body measurements.

It is not known if differences in strength between the sexes are due to intrinsic differences in muscle characteristics. Several factors confound direct comparisons of strength values. Body size is known to be related to strength in both men and women (2, 15, 16, 64, 107). Because males are generally heavier, taller, and leaner than females, measurements relative to various anthropometric variables have been analyzed to control for body size. With the exception of relative values of knee extension, significant differences in strength, while less, still are present (45, 61, 110). This was observed in the present study also.

There are some limitations in the use of anthropometric measurements for controlling differences in body sizes. The use of body weight as a relative measurement does not reflect the percentage of body fat in a subject. Strength values per unit of weight may be useful in comparing the ability of a subject to move his/her body; but in strength comparisons between the sexes,

differences will be observed simply because of the greater percentage of body fat in females.

Measurements relative to lean body weight have been used to overcome this problem. However, the use of lean body weight may have limitations. Lean body weight has been observed to be related to circumferences and bone diameters in both males and females (54). Men and women differ more in the shoulder region than in the hips and thigh, with a greater proportion of lean body weight being distributed in the shoulders in males. When ratios using lean body weight are used in comparisons between sexes, lower body measurements will appear closer in value while upper body measurements will be farther apart. This was observed in the current study.

The correlation of body size to strength may be dependent more upon muscle mass than upon currently used anthropometric measures. Strength in animal muscle is known to be related to the transverse cross-sectional area of the muscle (20). The development of ultrasound technology and CT scanning has allowed the measurement of cross-sectional areas of human muscles. Significant positive correlations have been observed between the cross-sectional areas of the biceps brachii or the knee extensors and isometric strength in both males and females (50, 69, 70, 113). No significant differences between male and female subjects have been observed in strength per unit of cross-sectional area.

It has not been determined yet if there are intrinsic differences between the muscles of men and women. While differences in muscle-fiber composition, the metabolic and contractile profile of fibers, fiber size, elastic behavior of muscle, and neuromotor efficiency have been reported (5, 60, 61), the studies have not controlled for differences in physical fitness between the sexes.

Hill (40) stated that the maximal power output of an excised muscle is achieved when the velocity of contraction is 25-30% of its maximum value. Using this criteria with maximum leg extension velocities measured by Thorstensson (102), maximum power during knee extension should occur between 180 and 240 $^{\circ}/s$ (data for the present study were obtained in this range.) MacIntosh and Brownmen (68) calculated power outputs from observed torque-velocity curves and determined that maximum value should be obtained from 203 to 316 $^{\circ}/s$. Other authors have reported peak power outputs at 210 and 240 $^{\circ}/s$ (7, 53, 88).

All comparisons in the modified vertical power jump were significant, except for the vertical distance jumped relative to lean body weight. Greater differences were observed in power values than in vertical distance jumped or in work performed.

Gray (35) reported a mean value of 1,218 watts for male college students during a revised vertical jump. The value is somewhat lower than that observed in this study. Several reasons may exist to explain the difference. First, the subjects were not trained athletes. More importantly, in Gray's study the jump was performed in an awkward position.

Davies (27) reported maximum instantaneous power output means of 3,902 watts for males and 2,340 watts for females. These values are much higher than those obtained by the revised vertical jump; however, the difference can be explained easily. Davies' values represent peak power outputs, while the modified vertical jump determines average power production.

Bosco (7) devised a test for the measurement of mechanical power during a series of vertical rebound jumps. The average mechanical power generated in a 60s jumping test by males and male athletes was 20 watt/kg of body weight. In a later study, Bosco reported values of 19 to 23 watts/kg of body weight in track athletes. It is not surprising that these values are somewhat lower than the values observed in this study because they represent power output over a series of jumps.

Sprinters vs. Middle-Distance Swimmers

In this study, male middle-distance swimmers were similar to the sprinters in height and weight, but they had a larger percentage of body fat. Increased body fat may be beneficial in longer distances by increasing buoyancy.

In the females, the sprinters and middle-distance swimmers were of similar height, weight, and percentage of body fat. It may be that female middle-distance swimmers do not need an increase in the percentage of body fat. Perhaps at existing levels for female swimmers, any increase in buoyancy would be offset by the added work necessary to move the additional mass through the water.

Similar findings were reported by Housh (47). Female Junior Olympic sprinters were similar in weight and percent body fat to middle-distance swimmers.

The isokinetic results showed that both male and female sprinters had higher mean torque and power values than their respective middle-distance counterparts at each angular velocity in all joint actions. While the analyses used indicated that only 34 of 160 individual comparisons were statistically significant, clearly the probability that these curves represent the same population is low. The data strongly imply that sprinters are stronger and more powerful than middle-distance swimmers.

Similar relationships have been observed in runners (12, 48, 69, 103). Housh (48) measured knee extension torques and reported that female sprinters at an Olympic track and field development camp had higher absolute and relative values at $180^{\circ}/s$ than did middle-distance runners; however, no comparisons were statistically significant. Campbell (12) observed that male college track sprinters generated higher mean torques than did endurance runners during knee extension tests at both 60 and $210^{\circ}/s$. Thorstensson et al. (103) reported that male sprinters and jumpers had significantly higher relative torques in knee extension at 0, 15, 30, 60, 90, and $180^{\circ}/s$ than did endurance athletes (race walkers and orienteers). Maughan, Watson, and Weir (69) reported that elite male sprinters had significantly greater absolute and relative isometric strengths during knee extension than did marathon runners.

An important finding was that the sprinters had greater strength per unit of cross-sectional muscle area than did the endurance runners. This suggests that there may be genetic and/or trained differences in the contractile proteins of the muscles of these athletes.

Bloomfield and Sigereth (6) did not observe a significant difference between sprinters and middle-distance university swimmers in isometric shoulder flexion and extension or in hip flexion and extension. However, the mean values for sprinters were consistently higher than those for the middle-distance swimmers.

Hopper (46) developed an "in-pool" power test for swimmers. While the number of subjects used was small, he observed $1\frac{1}{2}$ to 2 fold more power in elite male sprinters than in elite male middle-distance swimmers. The middle-distance men had power values only slightly higher than those obtained in women sprinters. Smaller differences in power were observed between women middle-distance swimmers and sprinters than between corresponding groups of male swimmers. The same pattern was observed in this study and may represent hormonal limitations to strength development in women.

King, Sharp, and Costill (57) examined arm power on a Biokinetic Swim Bench in male and female national-caliber swimmers. Significantly higher peak power values were found in sprinters and middle-distance swimmers than in distance swimmers. Sprinters had somewhat higher peak power values than did middle-distance swimmers, but the difference was not significant.

In contrast to the previously cited studies, Gregor (37) observed nonsignificant but consistent differences in relative torques favoring elite female distance runners over elite female sprinters during knee extension tests at 0, 67, and 192 °/s. At 288 °/s, the sprinters had slightly higher torque values. Conclusions from the study should be limited as the data on sprinters were obtained from only two athletes.

The current study as well as those reviewed indicate that athletes who compete in short events are stronger and more powerful than are athletes who participate in longer events. The reasons for these strength differences are not known, but several explanations can be offered which include theories concerning muscle fiber composition, biomechanical systems, and neuromotor efficiency. The latter two concepts have not been studied extensively.

Differences in muscle fiber composition have been observed between athletes. Highly trained sprinters have a greater proportion of fast-twitch fibers than do distance runners (4, 22, 23, 33, 103).

Fast-twitch fibers are known to have contractile and metabolic characteristics that favor high force production and glycolytic metabolism. Slow-twitch fibers favor aerobic metabolism and sustained lower force production. While it is appealing to assume that muscles with a greater proportion of fast-twitch fibers produce more force per unit area, that assumption has not been verified in either animals or humans (see Chapter II for a discussion of muscle

fiber composition and T-V curves). Sprinters may be stronger because of greater muscle mass, better lever systems, and/or more efficient motor unit activity.

Angular velocities at the shoulder during sprint swimming have been estimated to exceed $300^{\circ}/s$, while during longer distances the angular velocities are approximately $240^{\circ}/s$. It would seem that maximum differences in power between sprinters and middle-distance swimmers would be observed at the higher velocity. The data from this study do not support that premise. Greater differences during shoulder joint extension in both males and females were observed at $240^{\circ}/s$. A possible explanation for this observation is that sprinters in swimming, in addition to doing high intensity work, perform a great amount of endurance work.

In the modified vertical power jump, the data indicate significant differences in jumping ability between sprinters and middle-distance swimmers. The vertical distance jumped was statistically greater for both male and female sprinters. However, the power generated during the jump was a better discriminator for the females. The reasons for this observation are not apparent.

Counsilman (24) developed a vertical jump protocol to help classify male swimmers into events. Ballow (1) later extended the procedure to female swimmers. The theoretical basis for the test was that the height attained during a vertical jump will reflect the muscle composition of an individual. This, in turn, will affect that subject's ability to perform in a given event. Later studies

showed that low correlations exist between muscle fiber composition and the height of a standard vertical jump (89). It is interesting to note that the data from the current study indicate that the modified vertical power jump does discriminate elite sprinters from elite middle-distance swimmers. However, this should not be interpreted to mean that the test necessarily has good predictive value.

The isokinetic data tend to support the differences noted in the vertical jump. Angular velocities of the knee joint during a jump have been observed to be approximately $350^{\circ}/s$ (29). Distinct, but nonsignificant, differences were found between female sprinters and female middle-distance swimmers in this study at $300^{\circ}/s$.

Upper- vs. Lower-Twenty Percent of Swimmers

All but two comparisons indicated that there were no significant differences in strength and power between the upper- versus lower-twenty percent of either male or female swimmers. This is surprising, especially in the male swimmers, because the upper group was significantly older and heavier than the lower group. These findings suggest that variations in strength and power do not differentiate performances at this level of competition.

There are limitations of this study that may weaken the foregoing conclusion. First, the number of subjects were limited. More importantly, sprinters and middle-distance swimmers were pooled together. It is clear from the data that strength and power

are more important in sprinters than in middle-distance swimmers. By having both types of swimmers in the same analyses, the ability of muscular strength to differentiate successful performance is weakened.

King (57) has reported a lack of relationship between strength and performance in elite swimmers. No significant relationships were observed between peak or mean power obtained on a Biokinetic Swim Bench and freestyle performances of male and female swimmers at the 1982 U.S. National Championships.

These findings do not imply that strength is not important in reaching this level of competition. Several studies have reported significant correlations between arm power and swim time in less-accomplished swimmers (74, 93). In addition, the elite swimmers in King's studies generated greater power than did the less-proficient swimmers (93).

These studies do suggest that other factors may differentiate elite swimmers. Areas that should be investigated include differences in stroke mechanics, cardiovascular fitness, anaerobic fitness, biomechanical factors (e.g., lever length, drag), and psychological factors.

CHAPTER V

SUMMARY, CONCLUSIONS, AND RECOMMENDATIONS

Summary

This study was undertaken to provide descriptive data related to strength and power in elite swimmers. Sixty-six females and 55 males participated in the study. Five comparisons were defined as follows: (a) male vs. female; (b) male sprinters vs. male middle-distance swimmers; (c) female sprinters vs. female middle-distance swimmers; (d) upper-twenty vs. lower-twenty percent of male swimmers; and (e) upper-twenty vs. lower-twenty percent of female swimmers. Isokinetic absolute and relative torque and power measurements during elbow extension, shoulder joint extension, shoulder joint inward rotation and knee extension at angular velocities of 30, 180, 240 and 300 $^{\circ}$ /s were obtained. Absolute and relative average power, work, and vertical distance achieved during a modified vertical power jump were analyzed also.

Analysis of variance indicated that the male swimmers were significantly stronger than the female swimmers in all joint actions, at each angular velocity, in both absolute and relative terms with one exception. No significant differences between the sexes were observed in torque per unit of lean body weight during knee extension at 30, 240, and 300 $^{\circ}$ /s. In the modified vertical jump,

significant differences were observed for all absolute and relative values of distance jumped, work, and power except in the relative measure of distance jumped per unit of lean body weight.

Both male and female sprinters had mean torque and power values which were consistently higher than those recorded for male and female middle-distance swimmers respectively. Analysis of variance revealed that 34 of 160 comparisons were statistically significant. In the modified vertical power jump, male sprinters were significantly different from male middle-distance swimmers in all absolute and relative values of vertical distance jumped and in values relative to weight and lean body weight of work performed during the jump. With two exceptions, female sprinters were significantly different from female middle-distance swimmers in all absolute and relative measurements of vertical distance jumped, work, and power. No significant differences were observed in values relative to weight and lean body weight in the vertical distance attained.

Analysis of variance indicated that there were no significant differences in the majority of comparisons between the upper-twenty versus lower-twenty percent of either male or female swimmers. Significant differences were observed in male swimmers during elbow extension at $30^{\circ}/s$ and in female swimmers during shoulder joint extension at $300^{\circ}/s$ in absolute values and in values relative to body weight, lean body weight, and ponderal index. In the modified vertical power jump, significant differences were noted only for

female swimmers in absolute values and in values relative to ponderal index of work performed.

Conclusions

The results of this study have led to the following conclusions:

- 1) Elite male swimmers are stronger and more powerful than are elite female swimmers. These differences are still apparent when body size and shape are considered.
- 2) Differences in strength and power between elite male and female swimmers are greater in upper body movements than in lower body movements.
- 3) Elite male and female sprinters are stronger and more powerful than elite male and female middle-distance swimmers respectively.
- 4) Strength and power measurements do not differentiate successful elite swimmers from less successful elite swimmers.

Recommendations

The following discussion will provide suggestions for future studies of strength in swimmers.

When isokinetic instrumentation is used, gravitational corrections should be made on the raw data. Peak measurements should not involve the overshoot phenomenon. Full torque-velocity curves should be obtained with the use of both peak and angle-specific torques.

In strength studies, testing positions and methods of stabilization should be fully specified. Male and female subjects should not be pooled into single analyses because they represent separate populations. The level of physical training should be specified, and comparisons should be made only when the physical fitness of the subjects is known.

Studies involving strength measurements per unit of muscle cross-sectional area in swimmers are needed. Biomechanical factors, such as lever length, and neuromotor efficiency should be investigated in swimmers. Further studies are needed to identify the factors governing success in elite swimmers.

APPENDICES

Appendix A

Derivation Used in the Measurement of Leg Power

Appendix A

Derivation Used in the Measurement of Leg Power

An easily administered test of leg power which, unlike the Sargent Jump, would yield measurements in power units was needed for inclusion in a battery of tests to assess the physical capabilities of athletes.

Gray, Start, and Glencross (35) attempted to provide such a test in 1962. However, both conceptual and practical problems were associated with their approach. First, the initial jumping position was awkward. The subject jumped from a stationary full squat position with one arm raised above the head and the other arm behind the back. This position does not yield a maximum leg power value and does not approximate joint angles used in sport skills. Second, Gray et al. made the unwarranted assumption that leg force remains constant throughout the acceleration phase of the vertical jump. That assumption is not needed if acceleration time is calculated using Newton's second law instead of the laws of uniformly accelerated motion. The final result is an expression for average power ($\bar{P}$), not constant power (P) as was implied by Gray et al. (35).

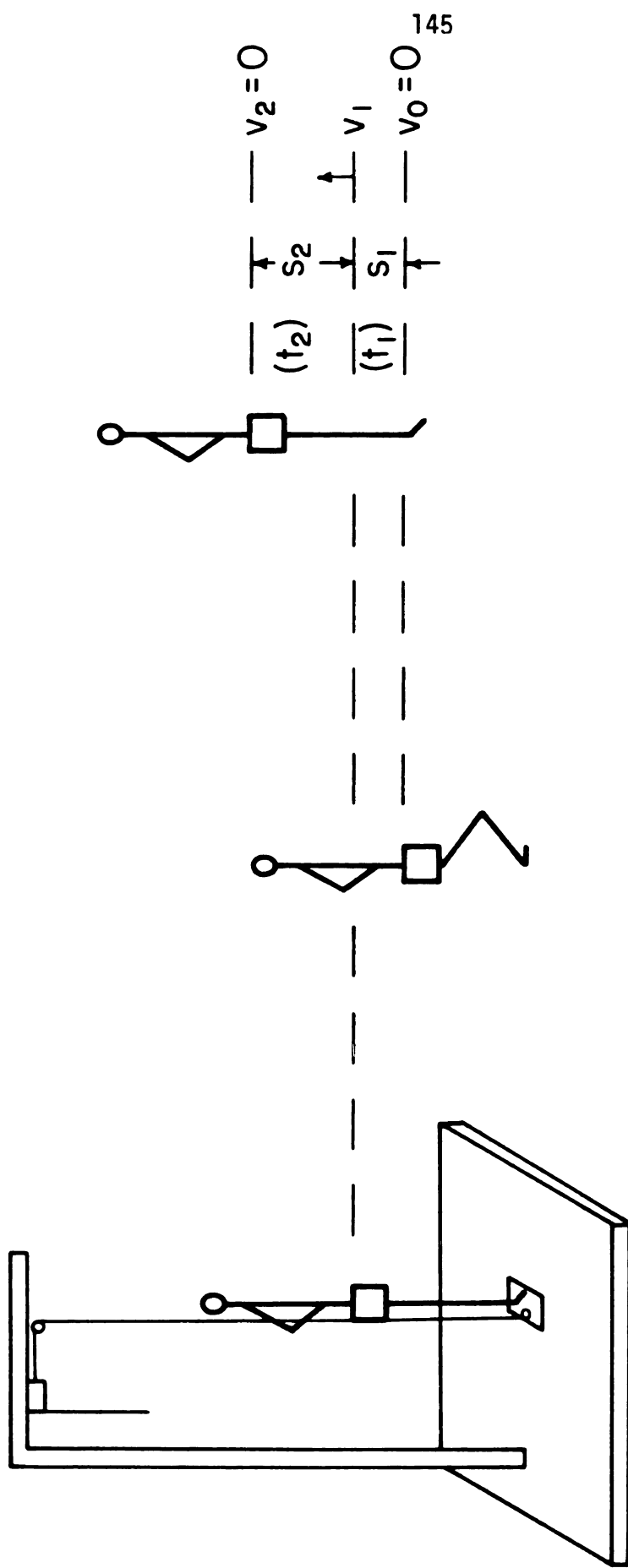


Figure A1. General Testing Situation.

An expression for the average leg power ($\bar{P}$) which is generated during the acceleration phase of the jump was derived by Heusner¹ as follows:

A definitional formula for the average leg power generated during the vertical jump is:

$$\bar{P} = W/t_1 \quad (1)$$

where t_1 is the acceleration time.

Work can be calculated as:

$$W = R \cdot S$$

where R = resistance

S = total distance through which resistance is moved.

Therefore, in the vertical jump:

$$W = w(s_1 + s_2) \quad (2)$$

where w = body weight

s_1 = squat displacement

s_2 = jump displacement.

Substituting the value of W in Eq. 2 into Eq. 1 yields:

$$\bar{P} = \frac{w (s_1 + s_2)}{t_1} \quad (3)$$

Acceleration time (t_1) is derived from Newton's second law:

$$\bar{F} \cdot \Delta t = m \cdot \Delta v \quad (4)$$

where $\bar{F}$ = average net force

Δt = interval of time that force operates

m = mass

Δv = change in velocity during t_1 due to $\bar{F}$ operating.

¹Unpublished report, Michigan State University.

Substituting the following values into Eq. 4,

$$\bar{F} = \bar{F} - w$$

$$\Delta t = t_1$$

$$m = w/g$$

$$\Delta v = v_1 - v_0$$

$$= v_1 - 0$$

$$= v_1$$

where $\bar{F}$ = average total force

g = acceleration due to gravity,

v_1 = take-off velocity

v_0 = final velocity at top of jump,

we obtain:

$$(\bar{F} - w) t_1 = \frac{w}{g} v_1$$

$$t_1 = \frac{w}{g} \frac{v_1}{\bar{F} - w} \quad (5)$$

The take-off velocity (v_1) can be obtained from the free-flight phase of the jump as follows:

$$v_2 = \sqrt{v_1^2 + 2gs_2}$$

$$0 = \sqrt{v_1^2 + 2(-g)s_2}$$

$$0 = \sqrt{v_1^2 - 2gs_2} \quad (6)$$

where g = acceleration due to gravity.

Squaring both sides of Eq. 6, yields:

$$\begin{aligned}
 0 &= v_1^2 - 2 g s_2 \\
 v_1^2 &= 2 g s_2 \\
 v_1 &= \sqrt{2gs_2}
 \end{aligned} \tag{7}$$

Substituting the value of v_1 obtained in Eq. 7 into Eq. 5 yields:

$$t_1 = \frac{w}{g} \frac{\sqrt{2gs_2}}{\bar{F} - w} \tag{8}$$

The only term in Eq. 8 which cannot be measured directly is $\bar{F}$, but this can be calculated from the alternate formula for work:

$$\begin{aligned}
 W &= \bar{F} \cdot s_1 \\
 \bar{F} &= W/s_1
 \end{aligned} \tag{9}$$

Substituting the value of work obtained from Eq. 2 into Eq. 9 yields:

$$\bar{F} = \frac{w(s_1 + s_2)}{s_1} \tag{10}$$

By substituting the value of $\bar{F}$ from Eq. 10 into Eq. 8, the acceleration time (t_1) can be obtained directly from measured variables:

$$\begin{aligned}
 t_1 &= \frac{w}{g} \frac{\sqrt{2gs_2}}{\frac{w(s_1 + s_2)}{s_1} - w} \\
 &= \frac{w}{g} \frac{\sqrt{2gs_2}}{\frac{w(s_1 + s_2) - ws_1}{s_1}}
 \end{aligned}$$

$$= \frac{w}{g} \frac{\sqrt{2gs_2}}{\frac{ws_1 + ws_2 - ws_1}{s_1}}$$

$$= \frac{w}{g} \frac{\sqrt{2gs_2}}{\frac{ws_2}{s_1}}$$

$$= \frac{w}{g} \sqrt{2gs_2} \frac{s_1}{ws_2}$$

$$= s_1 \sqrt{2} \frac{\sqrt{g}}{g} \frac{\sqrt{s_2}}{s_2}$$

$$\therefore t_1 = s_1 \sqrt{\frac{2}{gs_2}} \quad (11)$$

Returning to Eq. 3 with the value of t_1 in Eq. 11, yields an expression for average leg power:

$$\bar{p} = \frac{w(s_1 + s_2)}{s_1 \sqrt{2/g s_2}}$$

$$\therefore \bar{p} = \frac{w(s_1 + s_2)}{s_1} \sqrt{\frac{gs_2}{2}} \quad (12)$$

The right-hand side of Eq. 12 is identical to the expression for $\bar{P}$ that was developed by Gray, Start, and Glencross (35). From just three measured variables (body weight, squat displacement, and jump displacement) the average leg power generated during a vertical jump can be obtained. Furthermore, if the individual terms on the right-hand side of Eq. 12 are measured in the mks system, the units of $\bar{P}$ will be watts.

In addition to assuming that the leg force remains constant throughout the acceleration phase of the vertical jump, Gray et al. made the assumption that the position of the center of gravity, relative to the fingertips of the raised arm, remains constant during all phases of the jump. The second assumption is not reasonable. Taking a squatting position raises the relative position of the center of gravity in the body. Thus the effective value of the squat displacement (s_1) is less than the measured value. The net result is that $\bar{P}$ is underestimated by some unknown amount.

Eight actual and twelve theoretical subjects were used to evaluate the potential magnitude of the errors caused by assuming the center of gravity remains stationary relative to the raised fingertips. The inclusion of theoretical subjects allowed comparative calculations to be made over a wide range of assumed values:

$$w = 36 \text{ through } 109 \text{ Kg}$$

$$s_1 = 15 \text{ through } 61 \text{ cm}$$

$$s_2 = 15 \text{ through } 76 \text{ cm}$$

The segmental method of locating the center of gravity was used as described by Dempster (28). Muscular, thin, and median body types were assumed for each combination of w , s_1 , and s_2 values. In each case ($n = 60$) the height of the center of gravity was calculated for the standing and squatting-positions. The difference between the corrected and the true s_1 value was used as a correction factor, Δs_1 .

The use of the measured s_1 values resulted in underestimates of $\bar{P}$ ranging from -3.17 through -10.23%. There was no relationship with body size as measured by either body weight or height. Body type was shown to have an effect on $\bar{P}$, but the maximum change in $\bar{P}$ was limited to $\pm 0.59\%$ when $s_2 = \text{jump displacement}$ with partialled out.

A correlational analysis then was conducted which revealed that there is an almost perfect relationship ($r = 0.98$) between the measured value of $s_1 = \text{squat displacement}$ and Δs_1 , the correction factor. Therefore, a regression equation was calculated to predict the corrected squat displacement $\tilde{s}_1$ from $\tilde{s}_2$:

$$\tilde{s}_1 = .8644s_1 + .0046$$

This equation was used to estimate a value of s_1 for each of the 60 actual and theoretical cases. Correcting s_1 by regression reduced the errors in $\bar{P}$ to only -0.18 through -0.34%.

Incorporating the regression based correction s_1 into Equation 12, the final equation for average leg power is:

$$\bar{P} = \frac{w(.8644s_1 + .0046 + s_1)}{.8644s_1 + .0046} \sqrt{\frac{gs_2}{2}}$$

Appendix B
Tables

Table B1. Absolute Torque and Power Results for Male vs. Female Swimmers

Joint Action and Velocity	Torque (N · m)				Power (watts)				ANOVA					
	Females		Males		Females		Males		F	P				
	n	$\bar{X}$	s	n	$\bar{X}$	s	n	$\bar{X}$			s			
Elbow Extension	64	30.7	5.2	54	49.9	11.9	64	16.0	2.7	54	26.1	6.2	135.72	<.001
	64	16.7	3.3	54	26.7	5.1	64	52.6	10.3	54	84.0	15.9	166.93	<.001
	64	13.5	2.6	54	21.7	4.1	64	56.5	10.9	54	90.9	17.1	175.46	<.001
	64	10.9	2.2	54	18.0	3.7	64	57.0	11.4	54	94.0	19.2	168.16	<.001
Shoulder Joint Extension	62	58.2	8.9	53	94.9	15.4	62	30.5	4.7	53	49.7	8.1	253.22	<.001
	62	40.2	5.9	53	61.9	11.0	62	126.2	18.7	53	194.3	34.7	178.65	<.001
	62	32.9	4.6	53	49.8	9.8	62	137.6	19.2	53	208.4	40.9	147.25	<.001
	62	26.7	4.5	53	39.7	7.5	62	139.6	23.6	53	207.6	39.4	130.08	<.001
Shoulder Joint Inward Rotation	66	30.4	6.6	54	49.6	8.7	66	15.9	3.5	54	26.0	4.6	188.57	<.001
	63	16.6	4.1	53	27.6	5.9	63	52.0	12.8	53	86.8	18.5	141.87	<.001
	65	13.1	3.3	53	22.8	5.4	65	54.8	13.7	53	95.6	22.6	146.82	<.001
	65	10.5	2.8	54	19.5	4.2	65	54.7	14.5	54	102.1	22.2	195.77	<.001
Knee Extension	65	149.7	22.3	54	207.1	32.4	65	78.3	11.7	54	108.4	17.0	130.15	<.001
	65	47.9	7.3	53	69.2	10.5	65	150.4	22.9	53	217.4	33.0	169.10	<.001
	64	35.5	5.9	54	49.6	9.3	64	148.7	24.5	54	207.9	38.9	100.93	<.001
	65	26.5	5.2	54	36.4	6.1	65	138.8	27.1	54	190.7	31.9	92.30	<.001

Table B2. Relative (by Body Weight) Torque and Power Results for Male vs. Female Swimmers

Joint Action and Velocity	Torque (N · m/kg)				Power (watts/kg)				ANOVA	
	Females		Males		Females		Males		F	p
	n	$\bar{X}$	s	n	$\bar{X}$	s	n	$\bar{X}$		
Elbow Extension										
30°/s	64	.51	.09	54	.68	.14	54	.36	63.86	<.001
180°/s	64	.28	.05	54	.37	.06	54	1.15	77.02	<.001
240°/s	64	.22	.04	54	.30	.05	54	1.25	73.37	<.001
300°/s	64	.18	.04	54	.25	.04	54	1.29	80.91	<.001
Shoulder Joint Extension										
30°/s	62	.96	.12	53	1.30	.18	53	.68	144.11	<.001
180°/s	62	.66	.08	53	.85	.12	53	2.66	99.33	<.001
240°/s	62	.54	.07	53	.68	.11	53	2.85	66.34	<.001
300°/s	62	.44	.07	53	.54	.08	53	2.84	53.81	<.001
Shoulder Joint Inward Rotation										
30°/s	66	.50	.10	54	.68	.10	54	.36	92.21	<.001
180°/s	63	.28	.07	53	.38	.07	53	1.19	65.89	<.001
240°/s	65	.22	.05	53	.31	.06	53	1.31	81.94	<.001
300°/s	65	.17	.04	54	.27	.05	54	1.40	121.49	<.001
Knee Extension										
30°/s	65	2.49	.33	54	2.84	.37	54	1.49	25.73	<.001
180°/s	65	.80	.12	53	.95	.12	53	2.99	49.70	<.001
240°/s	64	.59	.09	54	.68	.10	54	2.85	24.23	<.001
300°/s	65	.44	.08	54	.50	.07	54	2.62	18.02	<.001

Table B3. Relative (by Lean Body Weight) Torque and Power Results for Male vs. Female Swimmers

Joint Action and Velocity	Torque (N · m/kg)				Power (watts/kg)				ANOVA	
	Females		Males		Females		Males		F	p
	n	$\bar{X}$	s	n	$\bar{X}$	s	n	$\bar{X}$		
Elbow Extension										
30°/s	64	.63	.11	54	.75	.15	54	.39	26.94	<.001
180°/s	64	.34	.06	54	.40	.06	54	1.27	28.13	<.001
240°/s	64	.28	.05	54	.33	.05	54	1.37	27.62	<.001
300°/s	64	.22	.04	54	.27	.05	54	1.42	33.75	<.001
Shoulder Joint Extension										
30°/s	62	1.19	.15	53	1.43	.19	53	.75	62.40	<.001
180°/s	62	.82	.09	53	.93	.13	53	2.92	31.14	<.001
240°/s	62	.67	.08	53	.75	.12	53	3.14	18.34	<.001
300°/s	62	.54	.08	53	.60	.09	53	3.13	12.13	<.001
Shoulder Joint Inward Rotation										
30°/s	66	.62	.12	54	.75	.11	54	.39	36.00	<.001
180°/s	63	.34	.08	53	.42	.08	53	1.31	28.65	<.001
240°/s	65	.27	.06	53	.34	.07	53	1.44	39.90	<.001
300°/s	65	.21	.05	54	.29	.05	54	1.54	67.43	<.001
Knee Extension										
30°/s	65	3.07	.44	54	3.13	.41	54	1.64	.56	.46
180°/s	65	.98	.14	53	1.04	.13	53	3.28	6.50	.01
240°/s	64	.73	.11	54	.75	.11	54	3.13	.91	.34
300°/s	65	.54	.09	54	.55	.08	54	2.89	.23	.63

Table B4. Relative (by Height) Torque and Power Results for Male vs. Female Swimmers

Joint Action and Velocity	Torque (N · m/cm)				Power (watts/cm)				ANOVA	
	Females		Males		Females		Males		F	p
	n	$\bar{X}$	s	n	$\bar{X}$	s	n	$\bar{X}$		
Elbow Extension	63	.18	.03	53	.28	.06	63	.09	113.53	<.001
	63	.10	.02	53	.15	.03	63	.31	133.30	<.001
	63	.08	.02	53	.12	.02	63	.33	134.08	<.001
	63	.06	.01	53	.10	.02	63	.34	133.01	<.001
Shoulder Joint Extension	61	.34	.05	53	.52	.08	61	.18	210.95	<.001
	61	.24	.03	53	.34	.06	61	.74	148.23	<.001
	61	.19	.03	53	.27	.05	61	.81	117.34	<.001
	61	.16	.03	53	.22	.04	61	.82	100.81	<.001
Shoulder Joint Inward Rotation	65	.18	.04	53	.27	.05	65	.09	153.38	<.001
	62	.10	.02	53	.15	.03	62	.31	114.00	<.001
	64	.08	.02	53	.13	.03	64	.32	121.37	<.001
	64	.06	.02	53	.11	.02	64	.32	168.93	<.001
Knee Extension	64	.88	.13	53	1.14	.17	64	.46	90.55	<.001
	64	.28	.04	52	.38	.06	64	.89	118.66	<.001
	63	.21	.03	53	.27	.05	63	.88	65.87	<.001
	64	.16	.03	53	.20	.03	64	.82	56.65	<.001

Table B5. Relative (by Panderal Index) Torque and Power Results for Male vs. Female Swimmers

Joint Action and Velocity	Torque (N · m/p.i.)				Power (watts/p.i.)				ANOVA	
	Females		Males		Females		Males		F	p
	n	$\bar{X}$	s	n	$\bar{X}$	s	n	s		
Elbow Extension										
30°/s	63	1.33	.23	53	2.15	.52	63	.69	.12	.53
180°/s	63	.73	.14	53	1.15	.21	63	2.28	.45	.53
240°/s	63	.59	.11	53	.94	.17	63	2.46	.47	.53
300°/s	63	.47	.09	53	.77	.15	63	2.48	.49	.53
Shoulder Joint Extension										
30°/s	61	2.52	.37	53	4.11	.65	61	1.32	.20	.53
180°/s	61	1.74	.25	53	2.69	.47	61	5.46	.79	.53
240°/s	61	1.42	.19	53	2.15	.41	61	5.96	.82	.53
300°/s	61	1.16	.19	53	1.72	.32	61	6.05	1.00	.53
Shoulder Joint Inward Rotation										
30°/s	65	1.32	.28	53	2.14	.38	65	.69	.15	.53
180°/s	62	.72	.18	53	1.20	.25	62	2.26	.55	.53
240°/s	64	.57	.14	53	.99	.23	64	2.38	.59	.53
300°/s	64	.45	.12	53	.83	.17	64	2.37	.62	.53
Knee Extension										
30°/s	64	6.49	.99	53	8.92	1.34	64	3.40	.52	.53
180°/s	64	2.08	.31	52	2.99	.43	64	6.53	.97	.52
240°/s	63	1.54	.25	53	2.14	.38	63	6.45	1.03	.53
300°/s	64	1.15	.22	53	1.57	.24	64	6.02	1.15	.53

Table B6. Modified Vertical Power Jump Results for Male vs. Female Swimmers

	Females			Males			ANOVA	
	n	$\bar{X}$	s	n	$\bar{X}$	s	F	p
Distance (cm)	66	34.6	5.2	54	45.8	6.5	109.81	<.001
By Weight (kg)	66	.58	.11	54	.63	.11	7.13	.01
By Lean Body Weight (kg)	66	.71	.12	54	.69	.11	6.53	.42
By Height (cm)	65	.20	.03	53	.25	.04	60.31	<.001
By Ponderal Index	65	1.50	.23	53	1.98	.28	102.11	<.001
Work (joules)	66	383	58	54	551	93	145.11	<.001
By Weight (kg)	66	6.35	.83	54	7.56	1.01	51.55	<.001
By Lean Body Weight (kg)	66	7.82	.96	54	8.30	1.06	6.86	.01
By Height (cm)	65	2.26	.32	53	3.05	.49	109.18	<.001
By Ponderal Index	65	16.60	2.49	53	23.84	3.98	145.98	<.001
Power (watts)	66	1663	281	54	2664	449	222.27	<.001
By Weight (kg)	66	27.58	3.99	54	36.60	5.55	106.95	<.001
By Lean Body Weight (kg)	66	33.97	4.82	54	40.22	5.83	41.31	<.001
By Height (cm)	65	9.77	1.61	53	14.73	2.48	171.00	<.001
By Ponderal Index	65	71.76	11.46	53	115.11	18.95	235.06	<.001

Table B7. Absolute Torque and Power Results for Male Sprinters vs. Middle-Distance Swimmers

Joint Action and Velocity	Torque (N · m)				Power (watts)				Middle-Distance				ANOVA F	P
	Sprinter		Middle-Distance		Sprinter		Middle-Distance		Sprinter		Middle-Distance			
	n	$\bar{X}$	s	n	$\bar{X}$	s	n	$\bar{X}$	s	n	$\bar{X}$	s		
Elbow Extension	37	51.1	12.8	17	47.1	9.4	37	26.8	6.7	17	24.7	5.0	1.34	.25
	37	27.4	5.5	17	25.2	3.6	37	86.2	17.3	17	79.2	11.3	2.30	.14
	37	22.3	4.3	17	20.5	3.2	37	93.2	18.1	17	85.9	13.8	2.20	.14
	37	18.5	4.0	17	16.7	2.5	37	97.0	20.9	17	87.6	13.1	2.87	.10
Shoulder Joint Extension	37	97.2	14.7	16	89.7	16.1	37	50.9	7.7	16	46.9	8.4	2.78	.10
	37	64.1	10.7	16	56.8	10.5	37	201.2	33.5	16	178.3	32.9	5.24	.03
	37	51.7	9.0	16	45.3	10.3	37	216.5	37.8	16	189.7	43.1	5.16	.03
	37	40.9	7.7	16	36.7	6.3	37	214.3	40.5	16	192.1	32.7	3.72	.06
Shoulder Joint Inward Rotation	37	50.7	8.7	17	47.3	8.7	37	26.5	4.5	17	24.8	4.5	1.78	.19
	37	28.5	6.2	16	25.8	4.7	37	89.4	19.6	16	80.9	14.7	2.42	.13
	37	23.7	5.6	16	20.9	4.4	37	99.1	23.5	16	87.7	18.5	2.98	.09
	37	20.3	4.3	17	17.8	3.7	37	106.2	22.5	17	93.4	19.5	4.09	.048
Knee Extension	37	209.7	32.1	17	201.5	33.5	37	109.8	16.8	17	105.5	17.6	.75	.39
	36	70.4	10.8	17	66.8	9.6	36	221.1	34.0	17	209.7	30.0	1.40	.24
	37	50.7	9.5	17	47.4	8.5	37	212.2	39.9	17	198.4	35.7	1.49	.23
	37	37.4	6.5	17	34.4	4.8	37	195.6	33.8	17	180.2	25.1	2.80	.10

Table B8. Relative (by Body Weight) Torque and Power Results for Male Sprinters vs. Middle-Distance Swimmers

Joint Action and Velocity	Torque (N · m/kg)				Power (watts/kg)				ANOVA	
	Sprinter		Middle-Distance		Sprinter		Middle-Distance		F	p
	n	$\bar{X}$	s	n	$\bar{X}$	s	n	s		
Elbow Extension										
30°/s	37	.70	.16	17	.64	.10	37	.08	2.03	.16
180°/s	37	.38	.06	17	.35	.05	37	.19	3.35	.07
240°/s	37	.31	.05	17	.28	.05	37	.22	2.74	.10
300°/s	37	.25	.05	17	.23	.03	37	.24	4.07	.049
Shoulder Joint										
Extension										
30°/s	37	1.34	.18	16	1.22	.14	37	.09	5.73	.02
180°/s	37	.88	.12	16	.77	.09	37	.36	11.87	.001
240°/s	37	.71	.10	16	.61	.10	37	.42	10.58	.002
300°/s	37	.56	.09	16	.50	.06	37	.45	7.35	.009
Shoulder Joint										
Inward Rotation										
30°/s	37	.69	.10	17	.65	.10	37	.05	2.66	.11
180°/s	37	.39	.07	16	.35	.06	37	.22	3.89	.054
240°/s	37	.32	.06	16	.28	.05	37	.26	5.14	.03
300°/s	37	.28	.05	17	.24	.05	37	.24	5.40	.02
Knee Extension										
30°/s	37	2.88	.36	17	2.76	.39	37	.19	1.43	.24
180°/s	36	.97	.12	17	.91	.10	36	.38	2.81	.10
240°/s	37	.70	.11	17	.65	.08	37	.45	3.06	.09
300°/s	37	.51	.07	17	.47	.06	37	.39	4.40	.04

Table B9. Relative (by Lean Body Weight) Torque and Power Results for Male Sprinters vs. Middle-Distance Swimmers

Joint Action and Velocity	Torque (N · m/kg)				Power (watts/kg)				ANOVA	
	Sprinter		Middle-Distance		Sprinter		Middle-Distance		F	p
	n	$\bar{X}$	s	n	$\bar{X}$	s	n	s		
Elbow Extension	37	.77	.16	17	.72	.11	37	.40	1.29	.26
	37	.41	.06	17	.38	.05	37	1.29	2.16	.15
	37	.33	.06	17	.31	.05	37	1.40	1.75	.19
	37	.28	.05	17	.26	.03	37	1.45	2.83	.10
Shoulder Joint Extension	37	1.47	.19	16	1.36	.16	37	.77	3.98	.051
	37	.96	.12	16	.86	.10	37	3.02	8.98	.004
	37	.78	.11	16	.68	.12	37	3.25	8.11	.006
	37	.62	.09	16	.56	.07	37	3.22	5.31	.03
Shoulder Joint Inward Rotation	37	.76	.10	17	.72	.11	37	.40	1.58	.21
	37	.43	.08	16	.39	.07	37	1.34	2.92	.09
	37	.36	.07	16	.32	.06	37	1.49	4.03	.051
	37	.30	.05	17	.27	.06	37	1.59	4.06	.049
Knee Extension	37	3.16	.40	17	3.07	.43	37	1.65	.55	.46
	36	1.06	.13	17	1.02	.11	36	3.32	1.33	.25
	37	.76	.12	17	.72	.09	37	3.19	1.77	.19
	37	.56	.08	17	.52	.06	37	2.94	2.88	.10

Table B10. Relative (by Height) Torque and Power Results for Male Sprinters vs. Middle-Distance Swimmers

Joint Action and Velocity	Torque (N · m/cm)				Power (watts/cm)				ANOVA	
	Sprinter		Middle-Distance		Sprinter		Middle-Distance		F	p
	n	$\bar{X}$	s	n	$\bar{X}$	s	n	s		
Elbow Extension										
30°/s	36	.28	.07	17	.26	.05	36	.15	.04	.27
180°/s	36	.15	.03	17	.14	.02	36	.47	.09	.17
240°/s	36	.12	.02	17	.11	.02	36	.51	.10	.17
300°/s	36	.10	.02	17	.09	.01	36	.53	.11	.11
Shoulder Joint										
Extension										
30°/s	37	.54	.08	16	.49	.08	37	.28	.04	.08
180°/s	37	.35	.06	16	.31	.05	37	1.11	.18	.02
240°/s	37	.29	.05	16	.25	.05	37	1.20	.20	.02
300°/s	37	.23	.04	16	.20	.03	37	1.18	.21	.04
Shoulder Joint										
Inward Rotation										
30°/s	36	.28	.05	17	.26	.04	36	.15	.02	.19
180°/s	37	.16	.03	16	.14	.02	37	.49	.10	.11
240°/s	37	.13	.03	16	.12	.02	37	.55	.13	.08
300°/s	36	.11	.02	17	.10	.02	36	.58	.11	.07
Knee Extension										
30°/s	36	1.15	.16	17	1.12	.17	36	.60	.09	.49
180°/s	35	.39	.06	17	.37	.05	35	1.22	.19	.28
240°/s	36	.28	.05	17	.26	.04	36	1.17	.22	.26
300°/s	36	.21	.04	17	.19	.03	36	1.08	.19	.15

Table B11. Relative (by Ponderal Index) Torque and Power Results for Male Sprinters vs. Middle-Distance Swimmers

Joint Action and Velocity	Torque (N · m/p.i.)				Power (watts/p.i.)				ANOVA	
	Sprinter		Middle-Distance		Sprinter		Middle-Distance		F	p
	n	$\bar{X}$	s	n	$\bar{X}$	s	n	s		
Elbow Extension										
30°/s	36	2.21	.56	17	2.03	.39	36	1.16	1.39	.24
180°/s	36	1.18	.23	17	1.09	.15	36	3.71	2.30	.14
240°/s	36	.96	.18	17	.88	.14	36	4.02	2.27	.14
300°/s	36	.80	.17	17	.72	.11	36	4.18	2.94	.09
Shoulder Joint Extension										
30°/s	37	4.21	.61	16	3.88	.69	37	2.21	3.15	.08
180°/s	37	2.78	.45	16	2.45	.44	37	8.72	5.90	.02
240°/s	37	2.24	.38	16	1.96	.44	37	9.38	5.73	.02
300°/s	37	1.77	.33	16	1.59	.26	37	9.29	4.09	.048
Shoulder Joint Inward Rotation										
30°/s	36	2.19	.37	17	2.04	.38	36	1.14	1.67	.20
180°/s	37	1.23	.26	16	1.11	.21	37	3.88	2.62	.11
240°/s	37	1.02	.23	16	.90	.19	37	4.29	3.29	.08
300°/s	36	.86	.16	17	.77	.16	36	4.52	4.06	.049
Knee Extension										
30°/s	36	9.02	1.29	17	8.69	1.45	36	4.72	.69	.41
180°/s	35	3.04	.44	17	2.88	.40	35	9.54	1.59	.21
240°/s	36	2.19	.39	17	2.04	.36	36	9.15	1.68	.20
300°/s	36	1.61	.26	17	1.48	.19	36	8.42	3.25	.08

Table B12. Modified Vertical Power Jump Results for Male Sprinters vs. Middle-Distance Swimmers

	Sprinters				Middle-Distance			ANOVA	
	n	$\bar{X}$	s		n	$\bar{X}$	s	F	P
Distance (cm)	37	47.4	6.2		17	42.2	5.9	8.44	.005
By Weight (kg)	37	.66	.11		17	.58	.08	7.09	.01
By Lean Body Weight (kg)	37	.72	.11		17	.64	.09	5.95	.02
By Height (cm)	36	.26	.04		17	.23	.03	7.31	.009
By Ponderal Index	36	2.06	.27		17	1.82	.24	9.61	.003
Work (joules)	37	566	95		17	519	83	3.10	.08
By Weight (kg)	37	7.78	1.04		17	7.07	.77	6.26	.02
By Lean Body Weight (kg)	37	8.50	1.09		17	7.87	.86	4.35	.04
By Height (cm)	36	3.13	.51		17	2.87	.42	3.25	.08
By Ponderal Index	36	24.55	4.05		17	22.36	3.49	3.65	.06
Power (watts)	37	2727	413		17	2528	504	2.34	.13
By Weight (kg)	37	37.58	5.23		17	34.46	5.76	3.87	.05
By Lean Body Weight (kg)	37	41.07	5.50		17	38.36	6.27	2.59	.11
By Height (cm)	36	15.06	2.28		17	14.02	2.81	2.05	.16
By Ponderal Index	36	118.1	17.8		17	108.8	20.3	2.86	.10

Table B13. Absolute Torque and Power Results for Female Sprinters vs. Middle-Distance Swimmers

Joint Action and Velocity	Torque (N · m)				Power (watts)				ANOVA	
	Sprinter		Middle-Distance		Sprinter		Middle-Distance		F	P
	n	$\bar{X}$	s	n	$\bar{X}$	s	n	s		
Elbow Extension										
30°/s	43	31.5	5.3	21	28.8	4.6	21	2.4	3.89	.053
180°/s	43	17.2	3.4	21	15.8	2.9	21	9.1	2.75	.10
240°/s	43	13.9	2.9	21	12.7	1.7	21	7.0	2.94	.09
300°/s	43	11.1	2.4	21	10.4	1.7	21	8.7	1.72	.19
Shoulder Joint Extension										
30°/s	43	59.4	9.5	19	55.5	6.7	19	3.5	2.63	.11
180°/s	43	41.1	6.6	19	38.0	3.4	19	10.7	3.88	.05
240°/s	43	33.7	4.9	19	30.9	3.3	19	13.7	5.36	.02
300°/s	43	27.4	4.8	19	24.9	3.3	19	17.5	4.19	.045
Shoulder Joint Inward Rotation										
30°/s	45	31.2	7.1	21	28.7	5.1	21	2.7	2.10	.15
180°/s	43	17.1	4.5	20	15.4	2.9	20	9.0	2.36	.13
240°/s	44	13.5	3.6	21	12.3	2.4	21	10.1	1.73	.19
300°/s	44	10.9	2.9	21	9.5	2.1	21	11.2	3.69	.06
Knee Extension										
30°/s	45	154.0	22.0	20	140.0	20.2	20	10.6	5.86	.02
180°/s	45	49.2	7.3	20	45.0	6.5	20	20.5	4.74	.03
240°/s	44	36.3	5.7	20	33.7	5.9	20	24.8	2.91	.09
300°/s	45	27.1	5.2	20	25.1	5.1	20	26.6	2.09	.15

Table B14. Relative (by Body Weight) Torque and Power Results for Female Sprinters vs. Middle-Distance Swimmers

Joint Action and Velocity	Torque (N · m/kg)				Power (watts/kg)				ANOVA	
	Sprinter		Middle-Distance		Sprinter		Middle-Distance		$\bar{F}$	P
	n	$\bar{X}$	s	n	$\bar{X}$	s	n	s		
Elbow Extension										
30°/s	43	.52	.09	21	.49	.08	43	.27	.05	.25
180°/s	43	.28	.05	21	.27	.05	43	.89	.16	.38
240°/s	43	.23	.04	21	.22	.04	43	.95	.19	.38
300°/s	43	.18	.04	21	.18	.04	43	.96	.19	.63
Shoulder Joint Extension										
30°/s	43	.97	.12	19	.94	.12	43	.51	.06	.30
180°/s	43	.67	.08	19	.64	.07	43	2.11	.25	.14
240°/s	43	.55	.07	19	.52	.07	43	2.32	.29	.11
300°/s	43	.45	.06	19	.42	.07	43	2.35	.34	.14
Shoulder Joint Inward Rotation										
30°/s	45	.51	.11	21	.49	.08	45	.27	.06	.33
180°/s	43	.28	.07	20	.26	.05	43	.88	.23	.29
240°/s	44	.22	.06	21	.21	.04	44	.93	.23	.42
300°/s	44	.18	.04	21	.16	.04	44	.94	.23	.15
Knee Extension										
30°/s	45	2.54	.38	20	2.40	.36	45	1.33	.20	.17
180°/s	45	.81	.11	20	.77	.13	45	2.54	.35	.26
240°/s	44	.60	.09	20	.58	.10	44	2.51	.38	.35
300°/s	45	.45	.08	20	.43	.08	45	2.33	.41	.47

Table B15. Relative (by Lean Body Weight) Torque and Power Results for Female Sprinters vs. Middle-Distance Swimmers

Joint Action and Velocity	Torque (N m/kg)				Power (watts/kg)				ANOVA	
	Sprinter		Middle-Distance		Sprinter		Middle-Distance		F	P
	n	$\bar{X}$	s	n	$\bar{X}$	s	n	$\bar{X}$		
Elbow Extension										
30°/s	43	.64	.11	21	.60	.09	43	.33	.06	.21
180°/s	43	.35	.06	21	.33	.06	43	1.09	.20	.20
240°/s	43	.28	.06	21	.27	.04	43	1.18	.23	.31
300°/s	43	.23	.04	21	.22	.04	43	1.18	.23	.32
									.40	.53
Shoulder Joint Extension										
30°/s	43	1.20	.15	19	1.15	.14	43	.63	.08	.25
180°/s	43	.83	.10	19	.79	.07	43	2.61	.31	.10
240°/s	43	.68	.08	19	.64	.07	43	2.86	.34	.07
300°/s	43	.55	.08	19	.52	.07	43	2.90	.41	.10
Shoulder Joint Inward Rotation										
30°/s	45	.63	.13	21	.60	.10	45	.33	.07	.29
180°/s	43	.35	.09	20	.32	.06	43	1.09	.27	.27
240°/s	44	.27	.07	21	.26	.05	44	1.14	.28	.38
300°/s	44	.22	.05	21	.20	.05	44	1.15	.29	.13
Knee Extension										
30°/s	45	3.13	.44	20	2.94	.41	45	1.64	.23	.11
180°/s	45	1.00	.14	20	.95	.14	45	3.13	.43	.17
240°/s	44	.74	.11	20	.71	.11	44	3.09	.45	.27
300°/s	45	.55	.09	20	.53	.10	45	2.88	.49	.38

Table B16. Relative (by Height) Torque and Power Results for Female Sprinters vs. Middle-Distance Swimmers

Joint Action and Velocity	Torque (N · m/cm)				Power (watts/cm)				ANOVA	
	Sprinter		Middle-Distance		Sprinter		Middle-Distance		F	p
	n	$\bar{X}$	s	n	$\bar{X}$	s	n	s		
Elbow Extension										
30°/s	42	.18	.03	21	.17	.03	21	.02	3.48	.07
180°/s	42	.10	.02	21	.09	.02	21	.05	2.55	.12
240°/s	42	.08	.02	21	.07	.01	21	.04	2.86	.10
300°/s	42	.07	.01	21	.06	.01	21	.05	1.80	.19
Shoulder Joint Extension										
30°/s	42	.35	.05	19	.33	.41	19	.02	2.62	.11
180°/s	42	.24	.04	19	.22	.19	19	.06	4.39	.04
240°/s	42	.20	.03	19	.18	.02	19	.08	5.78	.02
300°/s	42	.16	.03	19	.15	.02	19	.11	4.65	.04
Shoulder Joint Inward Rotation										
30°/s	44	.18	.04	21	.17	.03	21	.02	1.94	.17
180°/s	42	.10	.03	20	.09	.02	20	.05	2.39	.13
240°/s	43	.08	.02	21	.07	.01	21	.06	1.64	.20
300°/s	43	.06	.02	21	.06	.01	21	.07	3.45	.07
Knee Extension										
30°/s	44	.91	.12	20	.83	.11	20	.06	5.94	.02
180°/s	44	.29	.04	20	.27	.04	20	.12	4.82	.03
240°/s	43	.21	.03	20	.20	.03	20	.14	2.79	.10
300°/s	44	.16	.03	20	.15	.03	20	.15	2.06	.16

Table B17. Relative (by Ponderal Index) Torque and Power Results for Female Sprinters vs. Middle-Distance Swimmers

Joint Action and Velocity	Torque (N · m/p.i.)				Power (watts/p.i.)				ANOVA	
	Sprinter		Middle-Distance		Sprinter		Middle-Distance		F	p
	n	$\bar{X}$	s	n	$\bar{X}$	s	n	s		
Elbow Extension										
30°/s	42	1.36	.24	21	1.26	.21	21	.11	3.07	.09
180°/s	42	.74	.15	21	.69	.13	21	.41	2.31	.13
240°/s	42	.60	.12	21	.55	.08	21	.32	2.80	.10
300°/s	42	.48	.10	21	.45	.08	21	.40	1.68	.20
Shoulder Joint Extension										
30°/s	42	2.56	.40	19	2.42	.29	19	.15	2.07	.16
180°/s	42	1.78	.28	19	1.66	.16	19	.50	3.24	.08
240°/s	42	1.46	.21	19	1.35	.14	19	.60	4.71	.03
300°/s	42	1.19	.20	19	1.09	.15	19	.76	3.98	.051
Shoulder Joint Inward Rotation										
30°/s	44	1.35	.30	21	1.25	.22	21	.12	1.83	.18
180°/s	42	.74	.19	20	.67	.12	20	.39	2.31	.13
240°/s	43	.58	.16	21	.54	.10	21	.43	1.64	.21
300°/s	43	.47	.13	21	.41	.09	21	.49	3.45	.07
Knee Extension										
30°/s	44	6.67	.99	20	6.10	.90	20	.47	4.92	.03
180°/s	44	2.13	.30	20	1.96	.29	20	.92	4.40	.04
240°/s	43	1.57	.23	20	1.47	.26	20	1.09	2.56	.11
300°/s	44	1.17	.22	20	1.10	.23	20	1.19	1.78	.19

Table B18. Modified Vertical Power Jump Results for Female Sprinters vs. Middle-Distance Swimmers

	Sprinters			Middle-Distance			ANOVA	
	n	$\bar{X}$	s	n	$\bar{X}$	s	F	p
Distance (cm)	45	35.7	5.3	21	32.2	3.9	7.22	.01
By Weight (kg)	45	.59	.11	21	.55	.11	1.75	.19
By Lean Body Weight (kg)	45	.73	.12	21	.68	.12	2.44	.12
By Height (cm)	44	.21	.03	21	.19	.03	5.85	.02
By Ponderal Index	44	1.55	.25	21	1.40	.18	5.74	.02
Work (joules)	45	396	62	21	356	38	7.34	.01
By Weight (kg)	45	6.50	.89	21	6.04	.58	4.51	.04
By Lean Body Weight (kg)	45	8.01	1.02	21	7.42	.67	5.78	.02
By Height (cm)	44	2.33	.34	21	2.10	.21	7.81	.01
By Ponderal Index	44	17.14	2.64	21	15.47	1.64	7.03	.01
Power (watts)	45	1734	298	21	1513	161	10.07	.002
By Weight (kg)	45	28.43	4.17	21	25.74	2.91	7.13	.01
By Lean Body Weight (kg)	45	35.07	5.00	21	31.61	3.43	8.21	.01
By Height (cm)	45	10.16	1.70	21	8.95	1.01	9.09	.004
By Ponderal Index	44	74.63	12.28	21	65.75	6.34	9.69	.003

Table B19. Absolute Torque and Power Results for Upper- vs. Lower-Twenty Percent of Male Swimmers

Joint Action and Velocity	Torque (N · m)				Power (watts)				ANOVA	
	Upper-Twenty		Lower-Twenty		Upper-Twenty		Lower-Twenty		F	p
	n	$\bar{X}$	s	n	$\bar{X}$	s	n	s		
Elbow Extension										
30°/s	12	56.2	13.8	9	45.9	4.5	9	7.2	4.50	.047
180°/s	12	28.6	6.1	9	25.1	3.9	9	19.2	2.32	.14
240°/s	12	23.2	4.6	9	21.5	4.2	9	19.1	.84	.37
300°/s	12	19.3	4.3	9	17.4	3.9	9	22.2	1.15	.30
Shoulder Joint Extension										
30°/s	11	105.0	19.5	9	95.5	13.3	9	10.2	1.54	.23
180°/s	11	68.4	12.0	9	63.7	6.1	9	37.6	1.13	.30
240°/s	11	56.3	10.9	9	50.0	5.4	9	45.7	2.49	.13
300°/s	11	44.6	8.8	9	38.4	4.7	9	46.3	3.58	.07
Shoulder Joint Inward Rotation										
30°/s	12	53.4	12.9	8	48.2	7.0	8	6.7	1.08	.31
180°/s	12	28.1	8.3	9	27.3	4.3	9	26.2	.07	.80
240°/s	12	24.5	8.1	9	23.0	3.4	9	34.1	.28	.60
300°/s	12	20.4	5.1	9	18.7	2.7	9	26.6	.89	.36
Knee Extension										
30°/s	11	215.3	33.4	9	199.3	37.8	9	17.5	1.02	.33
180°/s	11	74.3	9.0	9	66.3	11.9	9	28.3	2.95	.10
240°/s	11	54.1	7.3	9	47.9	11.3	9	30.5	2.20	.16
300°/s	11	39.4	4.8	9	35.0	5.0	9	25.3	4.14	.06

Table B20. Relative (by Body Weight) Torque and Power Results for Upper- vs. Lower-Twenty Percent of Male Swimmers

Joint Action and Velocity	Torque (N · m/kg)				Power (watts/kg)				ANOVA	
	Upper-Twenty		Lower-Twenty		Upper-Twenty		Lower-Twenty		F	P
	n	$\bar{X}$	s	n	$\bar{X}$	s	n	s		
Elbow Extension										
30°/s	12	.71	.14	9	.66	.08	12	.37	.98	.33
180°/s	12	.37	.07	9	.36	.05	12	1.15	.07	.80
240°/s	12	.30	.05	9	.31	.05	12	1.24	.22	.65
300°/s	12	.25	.05	9	.25	.05	12	1.29	.004	.95
Shoulder Joint Extension										
30°/s	11	1.32	.20	9	1.38	.25	11	.69	.32	.58
180°/s	11	.86	.12	9	.92	.11	11	2.71	1.09	.31
240°/s	11	.71	.11	9	.72	.11	11	2.97	.06	.81
300°/s	11	.56	.09	9	.56	.08	11	2.94	.05	.83
Shoulder Joint Inward Rotation										
30°/s	12	.68	.13	8	.68	.10	12	.35	.01	.91
180°/s	12	.36	.09	9	.39	.06	12	1.12	.98	.33
240°/s	12	.31	.09	9	.33	.05	12	1.30	.35	.56
300°/s	12	.26	.06	9	.27	.04	12	1.36	.15	.70
Knee Extension										
30°/s	11	2.75	.37	9	2.84	.42	11	1.44	.28	.60
180°/s	11	.95	.10	9	.95	.15	11	2.98	<.001	.99
240°/s	11	.69	.08	9	.69	.15	11	2.89	.004	.95
300°/s	11	.50	.06	9	.50	.08	11	2.63	.001	.98

Table B21. Relative (by Lean Body Weight) Torque and Power Results for Upper-vs. Lower-Twenty Percent of Male Swimmers

Joint Action and Velocity	Torque (N · m/kg)				Power (watts/kg)				ANOVA	
	Upper-Twenty		Lower-Twenty		Upper-Twenty		Lower-Twenty		F	p
	n	$\bar{X}$	s	n	$\bar{X}$	s	n	$\bar{X}$		
Elbow Extension										
30°/s	12	.79	.15	9	.72	.08	9	.38	1.49	.24
180°/s	12	.41	.07	9	.39	.05	9	1.23	.20	.66
240°/s	12	.33	.05	9	.34	.06	9	1.41	.10	.75
300°/s	12	.27	.05	9	.27	.06	9	1.42	.003	.96
Shoulder Joint Extension										
30°/s	11	1.47	.19	9	1.51	.27	11	.77	.17	.69
180°/s	11	.96	.11	9	1.00	.12	11	3.01	.82	.38
240°/s	11	.79	.11	9	.79	.11	11	3.30	.002	.97
300°/s	11	.62	.09	9	.61	.09	11	3.27	.21	.65
Shoulder Joint Inward Rotation										
30°/s	12	.75	.14	8	.75	.11	12	.39	<.001	.99
180°/s	12	.40	.10	9	.43	.07	12	1.24	.81	.38
240°/s	12	.34	.09	9	.36	.06	12	1.44	.26	.62
300°/s	12	.29	.06	9	.29	.04	12	1.51	.07	.80
Knee Extension										
30°/s	11	3.05	.36	9	3.12	.53	9	1.60	.13	.72
180°/s	11	1.05	.10	9	1.04	.18	11	3.31	.04	.85
240°/s	11	.77	.08	9	.75	.18	11	3.21	.05	.83
300°/s	11	.56	.06	9	.55	.09	11	2.93	.07	.79

Table B22. Relative (by Height) Torque and Power Results for Upper- vs. Lower-Twenty Percent of Male Swimmers

Joint Action and Velocity	Torque (N · m/cm)				Power (watts/cm)				ANOVA			
	Upper-Twenty		Lower-Twenty		Upper-Twenty		Lower-Twenty		F	P		
	n	$\bar{X}$	s	n	n	$\bar{X}$	s	n			$\bar{X}$	s
Elbow Extension	12	.30	.07	.03	12	.16	.04	9	.13	.02	3.72	.07
	12	.16	.03	.02	12	.49	.10	9	.44	.07	1.50	.24
	12	.13	.02	.02	12	.53	.10	9	.50	.10	.35	.56
	12	.10	.02	.02	12	.55	.11	9	.51	.12	.63	.44
Shoulder Joint Extension	11	.57	.10	.08	11	.30	.05	9	.28	.04	.58	.46
	11	.37	.06	.04	11	1.16	.19	9	1.12	.11	.31	.58
	11	.30	.05	.03	11	1.27	.23	9	1.17	.13	1.36	.26
	11	.24	.04	.03	11	1.26	.23	9	1.12	.14	2.32	.15
Shoulder Joint Inward Rotation	12	.29	.06	.04	12	.15	.03	8	.14	.02	.52	.48
	12	.15	.04	.03	12	.48	.13	9	.48	.08	.001	.98
	12	.13	.04	.02	12	.56	.17	9	.54	.08	.08	.78
	12	.11	.03	.02	12	.58	.14	9	.55	.08	.44	.52
Knee Extension	11	1.17	.17	.21	11	.61	.09	9	.58	.11	.44	.52
	11	.40	.05	.06	11	1.27	.15	9	1.16	.20	1.81	.20
	11	.29	.04	.06	11	1.23	.15	9	1.12	.26	1.37	.26
	11	.21	.03	.03	11	1.12	.13	9	1.02	.15	2.49	.13

Table B23. Relative (by Ponderal Index) Torque and Power Results for Upper-vs. Lower-Twenty Percent of Male Swimmers

Joint Action and Velocity	Torque (N·m/p.i.)				Power (watts/p.i.)				ANOVA	
	Upper-Twenty		Lower-Twenty		Upper-Twenty		Lower-Twenty		F	P
	n	$\bar{X}$	s	n	$\bar{X}$	s	n	s		
Elbow Extension										
30°/s	12	2.42	.60	9	2.00	.17	12	1.26	4.05	.06
180°/s	12	1.23	.27	9	1.09	.15	9	3.87	2.13	.16
240°/s	12	1.00	.20	9	.93	.17	9	4.18	.72	.41
300°/s	12	.83	.19	9	.75	.16	9	4.35	1.06	.32
Shoulder Joint Extension										
30°/s	11	4.53	.85	9	4.15	.57	11	2.37	1.31	.27
180°/s	11	2.95	.53	9	2.77	.27	11	9.28	.88	.36
240°/s	11	2.43	.48	9	2.18	.25	11	10.19	2.08	.17
300°/s	11	1.93	.39	9	1.67	.21	11	10.09	3.11	.09
Shoulder Joint Inward Rotation										
30°/s	12	2.30	.57	8	2.08	.27	12	1.20	1.06	.32
180°/s	12	1.21	.37	9	1.19	.18	12	3.80	.03	.86
240°/s	12	1.06	.36	9	1.00	.15	9	4.42	.20	.66
300°/s	12	.88	.22	9	.81	.12	12	4.60	.69	.42
Knee Extension										
30°/s	11	9.27	1.47	9	8.65	1.52	11	4.85	.84	.37
180°/s	11	3.20	.40	9	2.88	.51	11	10.05	2.45	.14
240°/s	11	2.33	.33	9	2.08	.48	11	9.76	1.83	.19
300°/s	11	1.70	.21	9	1.52	.22	11	8.88	3.22	.09

Table B24. Modified Vertical Power Jump Results for Upper-vs. Lower-Twenty Percent of Male Swimmers

	Upper-Twenty			Lower-Twenty			ANOVA	
	n	$\bar{X}$	s	n	$\bar{X}$	s	F	p
Distance (cm)	11	46.4	6.4	9	46.0	5.5	.02	.88
By Weight (kg)	11	.59	.08	9	.66	.12	2.48	.13
By Lean Body Weight (kg)	11	.69	.08	9	.73	.12	2.34	.14
By Height (cm)	11	.25	.03	9	.26	.03	.12	.74
By Ponderal Index	11	2.00	.29	9	2.00	.26	.00	.97
Work (joules)	11	599	102	9	533	84	2.44	.14
By Weight (kg)	11	7.62	.99	9	7.66	1.24	.01	.94
By Lean Body Weight (kg)	11	8.46	.97	9	8.39	1.32	.02	.88
By Height (cm)	11	3.25	.49	9	2.98	.46	1.58	.22
By Ponderal Index	11	25.82	4.59	9	23.19	3.60	1.95	.18
Power (watts)	11	2900	381	9	2535	380	4.56	.05
By Weight (kg)	11	37.08	5.37	9	36.19	3.78	.18	.68
By Lean Body Weight (kg)	11	41.20	5.44	9	39.67	4.16	.48	.50
By Height (cm)	11	15.77	2.22	9	14.16	2.06	2.79	.11
By Ponderal Index	11	124.72	16.06	9	110.10	15.3	4.28	.05

Table B25. Absolute Torque and Power Results for Upper- vs. Lower-Twenty Percent of Female Swimmers

Joint Action and Velocity	Torque (N · m)				Power (watts)				ANOVA	
	Upper-Twenty		Lower-Twenty		Upper-Twenty		Lower-Twenty		F	p
	n	$\bar{X}$	s	n	$\bar{X}$	s	n	s		
Elbow Extension										
30°/s	13	31.6	3.9	14	29.8	4.3	14	2.1	1.28	.27
180°/s	13	16.8	3.0	14	16.3	3.3	14	9.4	.14	.71
240°/s	13	13.5	2.4	14	13.3	3.1	14	9.9	.05	.83
300°/s	13	10.9	1.8	14	10.3	2.4	14	9.6	.53	.47
Shoulder Joint Extension										
30°/s	13	59.4	8.7	14	55.3	6.7	14	4.6	1.93	.18
180°/s	13	40.9	5.2	14	37.7	5.4	14	16.5	2.35	.14
240°/s	13	34.1	5.0	14	31.6	3.8	14	21.1	2.10	.16
300°/s	13	28.8	4.3	14	25.3	3.6	14	22.8	5.45	.03
Shoulder Joint Inward Rotation										
30°/s	14	30.1	5.4	14	30.3	4.8	14	2.8	.03	.87
180°/s	14	16.9	3.2	14	15.6	3.1	14	10.0	1.27	.27
240°/s	14	13.8	2.7	14	12.5	3.1	14	11.2	1.26	.27
300°/s	14	10.9	2.2	14	10.3	2.6	14	11.7	.39	.54
Knee Extension										
30°/s	13	152.1	22.6	14	143.9	20.0	14	11.8	1.01	.32
180°/s	13	46.4	8.6	14	49.2	4.7	14	27.1	1.11	.30
240°/s	13	36.0	7.9	14	35.1	4.4	14	33.0	1.37	.71
300°/s	13	28.0	8.1	14	26.3	3.5	14	42.2	.52	.48

Table B26. Relative (by Body Weight) Torque and Power Results for Upper-vs. Lower-Twenty Percent of Female Swimmers

Joint Action and Velocity	Torque (N · m/kg)				Power (watts/kg)				ANOVA	
	Upper-Twenty		Lower-Twenty		Upper-Twenty		Lower-Twenty		F	P
	n	$\bar{X}$	s	n	$\bar{X}$	s	n	s		
Elbow Extension										
30°/s	13	.54	.10	14	.51	.10	14	.05	.59	.45
180°/s	13	.28	.06	14	.28	.06	14	.15	.07	.80
240°/s	13	.23	.05	14	.23	.05	14	.16	.01	.94
300°/s	13	.18	.03	14	.17	.04	14	.16	.38	.54
Shoulder Joint Extension										
30°/s	13	1.00	.12	14	.94	.11	14	.06	1.61	.22
180°/s	13	.68	.07	14	.64	.06	14	.23	3.14	.09
240°/s	13	.57	.08	14	.54	.05	14	.34	1.93	.18
300°/s	13	.48	.06	14	.43	.05	14	.34	6.41	.02
Shoulder Joint Inward Rotation										
30°/s	14	.50	.10	14	.52	.08	14	.05	.12	.73
180°/s	14	.29	.07	14	.27	.06	14	.21	.73	.40
240°/s	14	.23	.05	14	.21	.05	14	.22	.94	.34
300°/s	14	.18	.04	14	.18	.04	14	.21	.26	.62
Knee Extension										
30°/s	13	2.59	.49	14	2.45	.39	14	.26	.64	.43
180°/s	13	.78	.13	14	.84	.10	14	.41	1.49	.23
240°/s	13	.61	.11	14	.60	.09	14	.47	.04	.84
300°/s	13	.47	.12	14	.45	.07	14	.63	.36	.56

Table B27. Relative (by Lean Body Weight) Torque and Power Results for Upper- vs. Lower-Twenty Percent of Female Swimmers

Joint Action and Velocity	Torque (N · m/kg)				Power (watts/kg)				ANOVA	
	Upper-Twenty		Lower-Twenty		Upper-Twenty		Lower-Twenty		F	p
	n	$\bar{X}$	s	n	$\bar{X}$	s	n	$\bar{X}$	s	
Elbow Extension	13	.65	.11	14	.63	.11	14	.33	.06	
	13	.34	.06	14	.34	.07	14	1.08	.22	.54
	13	.28	.05	14	.28	.07	14	1.17	.28	.94
	13	.22	.04	14	.22	.05	14	1.13	.26	.93
Shoulder Joint Extension	13	1.21	.14	14	1.16	.12	14	.61	.06	.66
	13	.84	.09	14	.79	.08	14	2.48	.26	.28
	13	.70	.09	14	.66	.06	14	2.78	.26	.17
	13	.59	.08	14	.53	.06	14	2.77	.33	.26
Shoulder Joint Inward Rotation	14	.62	.11	14	.64	.10	14	.33	.05	.57
	14	.35	.07	14	.33	.07	14	1.03	.22	.48
	14	.28	.06	14	.26	.06	14	1.10	.27	.43
	14	.22	.05	14	.22	.05	14	1.14	.28	.74
Knee Extension	13	3.15	.55	14	3.02	.44	14	1.58	.23	.53
	13	.95	.16	14	1.03	.12	14	3.25	.37	.15
	13	.74	.14	14	.74	.10	14	3.10	.41	.98
	13	.57	.14	14	.55	.08	14	2.89	.40	.65

Table B28. Relative (by Height) Torque and Power Results for Upper-vs. Lower-Twenty Percent of Female Swimmers

Joint Action and Velocity	Torque (N · m/cm)				Power (watts/cm)				ANOVA	
	Upper-Twenty		Lower-Twenty		Upper-Twenty		Lower-Twenty		F	P
	n	$\bar{X}$	s	n	$\bar{X}$	s	n	s		
Elbow Extension										
30°/s	13	.19	.02	13	.18	.03	13	.01	1.12	.30
180°/s	13	.10	.02	13	.10	.02	13	.06	.06	.81
240°/s	13	.08	.01	13	.08	.02	13	.08	.002	.97
300°/s	13	.06	.01	13	.06	.01	13	.08	.16	.69
Shoulder Joint Extension										
30°/s	13	.35	.05	13	.33	.04	13	.02	1.87	.18
180°/s	13	.24	.03	13	.22	.03	13	.10	2.03	.17
240°/s	13	.20	.03	13	.19	.02	13	.10	1.50	.23
300°/s	13	.17	.02	13	.15	.02	13	.12	4.13	.053
Shoulder Joint Inward Rotation										
30°/s	14	.18	.03	13	.18	.03	13	.02	.07	.80
180°/s	14	.10	.02	13	.09	.02	13	.06	.65	.43
240°/s	14	.08	.02	13	.07	.02	13	.08	.81	.38
300°/s	14	.06	.01	13	.06	.02	13	.09	.23	.64
Knee Extension										
30°/s	13	.90	.13	13	.86	.12	13	.06	.65	.43
180°/s	13	.37	.05	13	.30	.03	13	.09	1.98	.17
240°/s	13	.21	.05	13	.21	.03	13	.12	.03	.86
300°/s	13	.17	.05	13	.16	.02	13	.11	.29	.60

Table B29. Relative (by Panderal Index) Torque and Power Results for Upper-vs. Lower-Twenty Percent of Female Swimmers

Joint Action and Velocity	Torque (N · m/p.i.)				Power (watts/p.i.)				ANOVA	
	Upper-Twenty		Lower-Twenty		Upper-Twenty		Lower-Twenty		F	P
	n	$\bar{X}$	s	n	$\bar{X}$	s	n	s		
Elbow Extension										
30°/s	13	1.38	.20	13	1.28	.20	13	.11	1.56	.22
180°/s	13	.73	.13	13	.71	.15	13	.40	.17	.68
240°/s	13	.59	.10	13	.58	.14	13	.42	.01	.91
300°/s	13	.47	.08	13	.45	.10	13	.41	.36	.56
Shoulder Joint Extension										
30°/s	13	2.58	.34	13	2.38	.29	13	.18	2.60	.12
180°/s	13	1.78	.22	13	1.63	.22	13	.68	2.95	.10
240°/s	13	1.48	.21	13	1.37	.15	13	.89	2.33	.14
300°/s	13	1.25	.18	13	1.10	.14	13	.96	5.60	.03
Shoulder Joint Inward Rotation										
30°/s	14	1.31	.23	13	1.31	.20	13	.12	.01	.93
180°/s	14	.74	.14	13	.68	.13	13	.45	1.07	.31
240°/s	14	.60	.12	13	.55	.13	13	.49	1.17	.29
300°/s	14	.47	.10	13	.45	.11	13	.50	.43	.52
Knee Extension										
30°/s	13	6.63	1.08	13	6.26	.09	13	.56	.88	.36
180°/s	13	2.02	.35	13	2.16	.17	13	1.10	1.74	.20
240°/s	13	1.57	.32	13	1.53	.19	13	1.33	.13	.72
300°/s	13	1.22	.33	13	1.15	.16	13	1.74	.44	.51

Table B30. Modified Vertical Power Jump Results for Upper- vs. Lower-Twenty Percent of Female Swimmers

	Upper-Twenty			Lower-Twenty			ANOVA	
	n	$\bar{X}$	s	n	$\bar{X}$	s	F	p
Distance (cm)	14	37.1	7.0	14	33.1	3.6	3.75	.06
By Weight (kg)	14	.63	.14	14	.57	.10	1.66	.21
By Lean Body Weight (kg)	14	.76	.16	14	.70	.11	1.59	.22
By Height (cm)	14	.22	.04	13	.20	.02	3.00	.10
By Ponderal Index	14	1.62	.32	13	1.43	.18	3.44	.08
Work (joules)	14	410	92	14	360	24	4.79	.04
By Weight (kg)	14	6.85	1.26	14	6.12	.51	3.97	.06
By Lean Body Weight (kg)	14	8.35	1.47	14	7.56	.53	3.67	.07
By Height (cm)	14	2.41	.48	13	2.14	.12	3.95	.06
By Ponderal Index	14	17.79	3.39	13	15.64	1.30	4.60	.04
Power (watts)	14	1680	278	14	1600	274	.60	.45
By Weight (kg)	14	28.04	3.97	14	27.22	5.07	.23	.64
By Lean Body Weight (kg)	14	34.22	4.53	14	33.59	6.05	.10	.76
By Height (cm)	14	9.89	1.61	13	9.36	1.75	.66	.42
By Ponderal Index	14	72.91	11.28	13	68.05	10.54	1.33	.26

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