Comparison of kinematic and kinetic data of the shoulder during internal rotation and transverse flexion

by Robert Mitchell Higgs

A thesis submitted in partial fulfillment of the requirements for the degree of Master of Science in Physical Education
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Abstract:
The velocity of a projected object and the accuracy of its placement are important in determining the success of overarm throwlike motions. When performers execute an overarm throwlike motion they are attempting to achieve a high end point linear velocity.

With the end point linear velocity being important to the success of an overarm throwlike motion, it is of interest to know which motion, internal rotation or transverse flexion, of the arm at the shoulder allows for a greater linear velocity to be achieved, and if a kinetic link model, can be formulated to predict the relationship between the linear velocities of a three segment system in a wheel-axle configuration and a lever configuration.

Twenty male subjects were randomly selected. The subjects performed internal rotation and transverse flexion of the arm about an axis through the shoulder joint. Kinematic and kinetic data were obtained by way of videography, electromyography, electrogoniometry and a force transducer. The statistical tool used to compare the data was the paired t-test. Linear regression equations were also fitted to the data.

A significant difference at $p<.OOl$ was present between the linear velocities, the angular velocities, and the angular accelerations for internal rotation and transverse flexion. The end point linear velocity for transverse flexion was significantly greater. The angular velocity and the angular acceleration for internal rotation were significantly greater. The kinetic link model formulated did not predict the relationship between the end point linear velocities of the two configurations.

A force-velocity relationship may explain, in part, the results of this study. Because of the small rotational inertia of the wheel-axle configuration, the muscles internally rotating the arm may not have been able to contract fast enough to further accelerate the upper extremity once a certain velocity was obtained.

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ABSTRACT

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CHAPTER 1

INTRODUCTION

The ability to throw a ball in the strike zone with the largest possible velocity is what most often differentiates professional pitchers from amateurs. Likewise, the tennis player's ability to serve the ball into the service court with the largest possible velocity is what sets many tennis players apart. The velocity of a projected object and the accuracy of its placement are both important aspects in determining the success of the baseball pitch and the tennis serve.

The velocity at the time of release, or moment of impact, has been identified as being very important to the success of an overarm throwlike skill(Atwater, 1979, Komi & Mero, 1985, and Ikegami, Miura, Matsui, and Hashimoto, 1979). When a performer executes a throwlike motion, whether it is an overarm or a kicking motion, the performer is attempting to achieve a high end point velocity(Kreighbaum & Barthels, 1990). Furthermore, when executing throwlike motions, the performer is trying to achieve the overall performance objective of the event, which is "... to either project an object for the greatest horizontal or vertical distance, or to project an object for accuracy where the velocity of the object enhances its effectiveness" (Kreighbaum & Barthels, 1990 p. 600).

The term "overarm" has been defined as a movement pattern in which the trunk laterally flexes away from the throwing arm(Atwater, 1977). The term "throwlike", as quoted from Kreighbaum & Barthels (1990), "... is characterized by movements used to project an object that is allowed to lag back behind the proximal segments that have finished their backswings and are now moving forward"(p. 599). Moreover, the open kinetic link system, represented by throwlike motions, has three characteristics(Kreighbaum & Barthels, 1990). The three characteristics of a kinetic link system are: (1) The system of links has a base, or fixed end and a free, or open, end; (2) the more massive segments are at the proximal, fixed end and the less massive segments are at the free end; (3) an external torque is applied to the base segment to initiate the system's motion and give the entire system angular momentum (Kreighbaum & Barthels, 1990). These characteristics, when executing a throwlike motion of an open kinetic system, allow for a sequential pattern of motion to occur producing a large end point velocity(Kreighbaum & Barthels, 1990).

The proper sequencing of motion about the upper extremity allows for a maximum resultant linear velocity to be achieved at the end point during the tennis serve(Elliott, Marsh, and Blanksby, 1986 and Van Gheluwe & Hebbelinck, 1983). Furthermore, proper sequencing of body motion is important to the performance of the baseball pitch(Atwater, 1979).

With linear velocity being important to the success of overarm throwing motions, the wheel-axle system, whereby motion occurs about a longitudinal axis, should allow for a greater linear velocity to be achieved than can be achieved by the lever system, wherein motion occurs about an anterior/posterior axis or a medial/lateral axis (Kreighbaum & Barthels, 1990). However, other than the theory presented by Kreighbaum & Barthels (1990), little information exists on the kinetic and kinematic comparisons of the wheel-axle and lever systems.

Theoretical Framework

It has been hypothesized that the segmental link system used in a wheel-axle configuration allows one to achieve a much greater end point linear velocity than does the same segmental system used in a lever configuration. In a wheel-axle system, one large base segment rotates around its longitudinal axis and thus a smaller rotational inertia is present (Kreighbaum & Barthels, 1990). This hypothesis has been based on the assumption that the torque producing capabilities of the muscles used in each system were equal(Kreighbaum & Barthels, 1990). A system with a smaller rotational inertia should display a greater angular acceleration in response to the application of the same amount of torque. A larger end point velocity would thus be achieved by way of a wheel-axle system because of a greater angular velocity at the contact point(Kreighbaum & Barthels, 1990). However, even though the rotational inertia is larger for the lever system, it also has a larger radius of rotation. Therefore, if it is hypothesized that the torque producing capabilities of the lever system are large enough to accelerate the larger inertial lever system so that it can achieve an angular velocity equal to that of the wheel-axle system, a larger linear velocity would be developed by the lever system. With the angular velocity of the lever system being equal to the angular velocity of the wheel-axle system, a larger end point linear velocity would thus be achieved by the lever system due to its larger radius of rotation. Furthermore, Kreighbaum & Barthels(1990, pp. 611-614) used the equation: $\frac{V(wa)}{V(l)} = \frac{r(wa)\omega(wa)}{r(l)\omega(l)}$, where wa represents the wheel-axle system and l represents the lever system; V = the linear velocity, r = the radius of rotation, and ω = the angular velocity as determined from the rotational inertia value, to predict the advantage one system would have over the other in terms of the end point linear velocity.

Statement of Problem

The relationship between the linear velocity of a projected object and the success achieved in overarm throwlike motions, as expressed by Atwater (1979), Komi & Mero (1985), and Ikegami et al. (1979) is an important one. However, little research exists on which segmental configuration, the wheel-axle or the lever, generates a larger linear velocity. If one system produces a significantly greater linear velocity than the other, then performers should find it advantageous to use that system when performing certain overarm throwlike motions. Thus, the problem is to determine where differences exist between segmental links using each system in terms of the angular velocity, angular acceleration, and the torque each system is able to produce about the shoulder.

Purpose of Study

The purpose of this study was twofold: to determine if a kinetic link model for the upper limb as a wheel-axle system and the upper limb as a lever system predicts the relationship between the linear velocities produced by the two systems; and to determine if there is a significant difference between the linear velocities produced at the end points of segmental links acting in a wheel-axle and a lever configuration.

Internal rotation of the humerus at the glenohumeral joint represented the wheel-axle system; transverse flexion of the humerus at the glenohumeral joint represented the lever system. Thus, the linear velocity of the end point, generated during transverse flexion of the upper extremity at the shoulder joint and during internal rotation of the upper extremity at the shoulder joint, were examined.

Hypotheses

The hypotheses for this study are stated in the null: 1. A kinetic link model for the upper limb as a wheel-axle system and the upper limb as a lever system does not predict the relationship between the end point linear velocities produced by the two systems. The alternative hypothesis is that the kinetic link model for the upper limb as a wheel-axle system and the upper extremity as a lever system predicts the relationship between the linear velocities produced by the two systems. 2. There is no difference between the linear velocities produced at the end points of the segmental links acting in a wheel-axle and a lever configuration. The alternative hypothesis is that there is a difference between the linear velocities produced at the end points of the segmental links acting in a wheel-axle and a lever configuration.

Assumptions

The following assumptions were made in regard to this study:

1. Videography functioning at 30 hertz and a shutter speed of 1/1000 of a second provided an accurate method of recording the movements of subjects performing transverse flexion and medial rotation with no hand held inertia.
2. Digitizing was reliable and accurate.
3. Filmdata, a software program, accurately determined the angular acceleration of the system, the kinematic moment about the axis of rotation of the system, the linear velocity of the end point of the system.
4. The anthropometric data base used was appropriate for the subjects.
5. The template used accurately determined the three dimensional data to be analyzed from two dimensional data.
6. Anatomical locations were correctly identified.
7. The pectoralis major was at an equal mechanical advantage in each system.
8. The anterior deltoid and the latissimus dorsi were major contributors to their respective movements.

Delimitations

The following are delimitations of this study:

1. A total of 20 male subjects, 18 years and older were selected for this research.
2. Only two superficial muscles for each system were analyzed by way of electromyography. The electrical activity of the anterior deltoid and the pectoralis major for transverse flexion and the pectoralis major and the latissimus dorsi for internal rotation were analyzed.

Limitations

The following were identified as possible limitations of this study:

1. The motivation of each subject was not controlled.
2. A template was needed to determine 3-dimensional movement from 2-dimensional recording.
3. The electromyographic data were dependent on the positioning of the surface electrodes between subjects.
4. Filming and Electromyographic data were collected at different times. Thus, the motions of internal rotation and transverse flexion may not have been exactly the same when gathering the data for these movements.

5. The relative involvement of the number of fast and slow twitch muscle fibers when recording the electrical activity was not controllable and thus, may have influenced the recorded electrical activity between subjects.

Operational Definitions

Wheel & Axle System - system where segmental rotation occurs about a segment's longitudinal axis and the wheel is represented by the next adjoining segment(Kreighbaum & Barthels, 1990).

Lever System - system where rotation occurs about a segment's medial/lateral or an anterior/posterior axis(Kreighbaum & Barthels, 1990).

Kinematic moment - the torque which is present as calculated by way of time and space factors(Hull & Jorge, 1985).

Rotational Inertia - the resistance of a body to angular acceleration(Kreighbaum & Barthels, 1990).

Offset Voltage - for an operational amplifier, the particular value of dc bias voltage required at the input to produce zero output voltage(Turner & Gibilisco, 1991).

Significance of Study

The results of this study may lead to changes in the way performers execute certain overarm throwlike motions so that they may more effectively achieve the overall performance objective of the skill they are executing. Contributions to our overall knowledge of human body segmental interactions may be also be achieved. From a safety standpoint, injury prevention could also result. The significance of variables involved in generating end point linear velocity may further expand our knowledge of overarm throwlike motions.

CHAPTER 2

REVIEW OF LITERATURE

The biomechanical factors of numerous overarm throwlike skills have been identified. The kinetic and kinematic data obtained from these studies have been reviewed by researchers to help identify where improvements can be made in individual performances. Several researchers have stated that the success of the skill is highly dependent on the velocity of the object being thrown or the velocity of the implement being used to contact an oncoming object(Atwater, 1979, Komi & Mero, 1985, and Ikegami, Miura, Matsui, and Hashimoto, 1979). Elliott, Marsh, and Blanksby (1986) and Van Gheluwe & Hebbelinck (1983), have further stated that for an object or implement to have obtained a high linear velocity, the performer must execute the overarm motion precisely through a sequential movement pattern.

The review of literature related to overarm throwlike motions has been divided into four areas: (1) Data Collection Methods, (2) Phases of Overarm Throwlike Motions, (3) Kinematics of Motion, (4) Kinetics Related to Overarm Throwlike Motions, and (5) Summary.

Data Collection Methods

Cinematography and Videography

Data collection on overarm throwing skills has largely been recorded through the use of high speed filming. Javelin throws have been recorded with film rates of 200 frames per second by Komi & Mero (1985). Jobe, Tibone, Perry, and Moynes (1983) used a camera speed of 500 frames per second to film baseball pitchers. Elliot, Grove, Gibson & Thurston (1986) used film speeds of 200 and 300 frames per second with shutter speeds of 1/2400 of a second to analyze fastball and curveball pitches. Elliot, Marsh, & Planksby (1986) used a camera speed of 200 fields per second and a shutter speed of 1/2400 of a second when filming tennis serves. Gregor & Pink (1985) used a high-speed video camera functioning at 200 fields per second to video Tom Petranoff's world record javelin throw.

Goniometry

Goniometry is a commonly used method for measuring joint motion. A goniometer is a protractor with two reference arms. By including a rotational transducer at the place where the arms of the goniometer are attached, an electronic readout can be obtained(Chaffin & Andersson, 1991a). The electronic readout is often recorded on a chart strip recorder(Kreighbaum & Barthels, 1990) or more recently on a computer through the use of specialized software. An electrogoniometer or ELGON, as it is often called, thus allows simple planar motions of body segments to be examined (Chaffin & Andersson, 1991a).

Electromyography

Electromyographic (EMG) analyses of muscular activity have also been done to determine which muscles are active during each part of a skill. Nuber, Jobe, Perry, Moynes, and Antonelli (1986) synchronized EMG signals with high speed photography to gain further insight on the muscular activity of swimmers.

Isokinetic Dynamometer

Kinetic data were obtained by Otis, Warren, Backus, Santner, and Mabrey (1990) through the use of a Cybex II isokinetic dynamometer. Otis et al. (1990) used a Cybex II isokinetic dynamometer to determine the amount of torque produced by the muscles acting about the shoulder during abduction, internal rotation, and external rotation. Mean results of the dominant arm for the thirty-six subjects tested at an angular velocity of 48 degrees per second were 49.6, 42.4, and 26.6 Newton-meters for abduction, internal rotation, and external rotation respectively(Otis et at., 1990).

Hinton (1988) and Otis et al. (1990) both used Cybex II isokinetic dynamometers to determine the torque production of shoulder muscles in young male baseball pitchers. Hinton (1988) recorded toques of high school baseball pitchers performing internal and external rotation of the humerus with the arm abducted and the elbow flexed at 90 degrees at speeds of 90 and 240 degrees per second. At an angular velocity of 90 degrees per second, a mean torque of 30.7, and 18.5 foot-pounds for internal rotation and external rotation, respectively, were measured. Mean torque values of 22.5 and 12.2 foot-pounds for internal rotation and external rotation, respectively, were measured at an angular velocity of 240 degrees per second(Hinton, 1988).

Phases of Overarm Throwlike Motions

Overarm throwlike motions can be divided into three phases: preparation, acceleration, and follow-through. The preparation phase is characterized as being highly unique to each individual and consists of motions that allow the extremity to be placed in a position so that it is ready to execute the other stages. The preparation phase is characterized by external rotation, abduction, and transverse extension of the humerus. The acceleration stage is characterized by slight horizontal flexion and internal rotation of the humerus. This stage ends when the object to be propelled is released or contacted by the end point body segment or implement. The follow-through stage is characterized by the continuation of horizontal flexion and internal rotation of the humerus. The extremity is decelerating throughout this stage(Moynes et al., 1986, Ryu et al., 1988, and Jobe et al., 1985).

Kinematics of Motion

Feltner & Dapena (1986), Elliot, Grove, Gibson, & Thurston (1986), and Pappas et al. (1985) conducted studies on the kinematics of the baseball pitch. Feltner & Dapena (1986) concluded that, for intercollegiate varsity baseball pitchers, the elbow's maximum angular velocity during extension was 2200 degrees per second shortly before release. The mean maximum angular velocity for forearm extension during a baseball pitch, as stated by Pappas et al. (1985), was found to be 4,595 degrees per second. Feltner and Dapena (1986) confirmed that a peak angular velocity for internal rotation at the shoulder occurred at the instant the ball was released and was measured at 6100 degrees per second. Pappas et al. (1985) measured peak average angular velocities of 6,180 degrees per second for internal rotation of the shoulder. Hinton (1988) further confirmed such large angular velocities at the shoulder joint by stating that velocities over 6,000 degrees per second have been found. Elliot et al. (1986) studied the angular velocities of the wrist and determined maximum wrist angular velocities to be approximately 188 degrees per second at time of ball release for a baseball pitch.

Komi & Mero (1987), Gregor & Pink (1985) and Ikegami et al. (1987) all agreed the most important factor influencing the performance of the javelin throw was the velocity of the javelin at release. Ikegami et al. (1987) confirmed that there was a significant relationship between the release velocities of the javelin and the distances thrown. Atwater (1979) stated that Terauds (1978) found there was a correlation of .72 between distance of the javelin and release velocity for javelin throwers in the 1976 Olympics. The height of release and the angle of release are also of importance for the distance the javelin will travel and may account for the non-perfect correlation. Furthermore, Gregor & Pink (1985) declared that Tom Petranoff's world record throw had one of the highest recorded release velocities of 32.3 meters per second. Ikegami, Miura, Matsui, and Hashimoto (1987) stated that the velocity of the total body's center of gravity is important also to the performance of the javelin throw.

Whiting, Puffer, Finerman, Gregor, and Maletis (1985) examined the kinematics of throwing by elite water polo players. Peak extension angular velocities of the forearm at the elbow were found to average 1,137 degrees per second (Whiting et al., 1985).

Elliot et al. (1986b) and Elliot (1988) studied the resultant linear velocities of the hip, shoulder, elbow, wrist, and racket end for the tennis serve. Elliot (1988) stated that there was a synchronization of the motion of the shoulder to the end of the racket as the moment of impact neared and that an increase in the resultant velocity of each successive segment occurred until just prior to contact with the ball. Thus, the coordination of the body segments occurred in a sequential pattern which has been referred to as a kinetic chain(Elliot, 1988).

Putnam (1991) completed a study on segmental sequencing and agreed and disagreed with some of the statements that have been made about the kinetic link system. Putnam (1991) stated that the way in which segments interact provides an explanation of the proximal-to-distal sequencing pattern but that this explanation is too general because of the way in which different orientations of the segments affect the sequencing. Putnam (1991) agreed that the summation of speed principle was a valid means of explaining the sequential segment motion patterns, but that the summation of force principle and the way in which a negative thigh angular acceleration positively affects a positive leg angular acceleration are not a valid way of explaining the motion patterns that are seen. A final statement by Putnam (1991) was that it is difficult to identify the exact roles that muscles play in producing the proximal-to-distal sequential patterns which are seen.

The movement pattern for most overarm throwing motions, as stated by Atwater (1979), takes less than one second. Atwater (1979) further stated that the throwing motion, from the time upward and forward motion of the arm is initiated until the time of release, takes approximately 400 milliseconds. Pappas, Zawacki, and Sullivan (1985) stated that for baseball pitching, the acceleration stage occurs in approximately 50 milliseconds, the cocking stage takes approximately 1500 milliseconds, and the follow-through stage occurs in approximately 350 milliseconds.

Kinematics Related to Overarm Throwlike Motions

Atwater (1979) stated that high velocities and accelerations in the throwing motion may be caused by large internal forces. Moments determined from kinematic data have often been called kinematic moments. Hull & Jorge (1985) defined moments derived from motion parameters as kinematic moments and moments resulting from direct forces as kinetic moments. Gainor, Piotrowski, Puhl, Allen, and Hagen (1980) stated there was an internal torque of 14,000 inch-lbs on the humerus just before ball release after analyzing the cinematographic data. Gainor et al. (1980) arrived at this kinematic moment value by way of recording the angular acceleration and the rotational inertia present during a pitching motion and then applying the formula, $T=I\alpha$, torque = rotational inertia x angular acceleration.

Feltner & Dapena (1986) concluded there was 110 Newton-meters of horizontal adductor torque on the shoulder just prior to ball release. Peak abduction and internal rotational torques on the shoulder were 70 Newton-meters and 90 Newton-meters at the instant of maximum external rotation. Near maximum external rotation of the arm at the shoulder, a peak extension torque of 20 Newton-meters about the elbow was recorded (Feltner & Dapena, 1986). Gainor et al. (1990) and Feltner & Dapena (1986) both used kinematic data as a way of determining their torque measurements. Kreighbaum & Barthels (1990) stated angular acceleration is directly related to a body's rotational inertia as well as a body's ability to produce torque and that a larger angular acceleration, due to a decrease in rotational inertia or an increase in torque, or both, results in a higher angular velocity. Furthermore, a larger angular velocity results in a larger linear velocity if the radius of rotation for an object remains constant (linear velocity = radius of rotation x angular velocity). However, Kreighbaum & Barthels (1990) further stated that if an increase of the radius of rotation is used to achieve a larger linear velocity, an increase in rotational inertia usually results and thus a decrease in angular acceleration will be present.

Electromyography

The electrical activity of a muscle that functions to produce motion at the shoulder joint has been recorded to determine its involvement and how it's activity contributes to the force producing the designated motion. Several researchers, including: Scheving & Pauly (1959), de Sousa et al. (1969), and Jonsson et al. (1972), have disagreed on whether or not the pectoralis major functions to produce medial rotation at the shoulder. Scheving & Pauly (1959) stated that there must be some resistance against medial rotation for the pectoralis major to function as a medial rotator, that is, it may be recruited to assist. de Sousa et al. (1969) disagreed with this and stated that the clavicular head of the pectoralis major is active when medial rotation occurs freely or against a resistance. Jonsson et al. (1972) agreed with de Sousa et al.(1969). The pectoralis major functions to medially rotate the humerus while it adducts and/or flexes the humerus(Hollinshead & Jenkins, 1981). Furthermore, the electrical activity of muscles acting to produce motion about the shoulder joint has been examined during individual phases of overarm throwlike motions. The phases that have been examined include the preparation, the acceleration, and the follow-through and are described below.

Preparation Phase

The preparation phase of the tennis serve, which begins with the initiation of motion, ends when the serving shoulder reaches maximum external rotation (Moynes et al., 1986). In the preparation phase of the tennis serve, the biceps, supraspinatus, serratus anterior, and subscapularis all showed moderate activity (Moynes et al., 1986). Ryu et al. (1988) stated that the infraspinatus was also moderately active in the preparation phase.

Shoulder abduction and external rotation characterized the preparation phase for the baseball pitch. Jobe et al. (1984) stated that the biceps and brachialis muscles were moderately active during the preparation phase. Jobe et al. (1984) also commented that the pectoralis major and latissimus dorsi muscles became active late in the preparation phase as external rotation reached its maximum. The deltoid showed strong activity early in this stage to abduct the humerus. Activity of the infraspinatus, in the preparation phase, was significant near maximum external rotation. The biceps muscle demonstrated its largest activity during elbow flexion in the preparation phase. Prior to maximum external rotation, the serratus anterior and pectoralis major showed their greatest activity (Moynes et al. 1986).

Acceleration Phase

Ryu et al. (1988) stated that the pectoralis major and subscapularis demonstrated the most activity, during horizontal adduction and internal rotation of the humerus during the acceleration stage of the tennis serve. The serratus anterior and latissimus dorsi had a high amount of activity present in the acceleration stage of the tennis serve. The serratus anterior upwardly rotates the scapula and the latissimus dorsi internally rotates the humerus. Extension occurs at the elbow during the acceleration stage. Internal rotation of the humerus at the shoulder characterized the acceleration stage (Moynes et al., 1986). Ryu et al. (1988) stated that extension of the elbow was also present in the acceleration stage of the tennis serve.

In the acceleration stage of the baseball pitch, Jobe et al. (1983) found through the use of intramuscular electrodes that the electrical activity of the deltoid, supraspinatus, infraspinatus, teres minor, and subscapularis was very small. Monyes et al. (1986) agreed with Jobe's et al. (1983) assessment. Jobe et al. (1984) stated that the triceps, which initially demonstrated activity in the cocking stage, showed high activity in the acceleration stage and that the pectoralis major and latissimus dorsi continued their activity through the acceleration stage. Jobe et al. (1984) commented that triceps activity led to elbow extension in the acceleration stage. Moynes et al. (1986) agreed with Jobe et al. (1984) and stated that the action of the pectoralis major was to horizontally flex the humerus. However, Kreighbaum & Barthels (1990) stated that there is little horizontal flexion present during skilled throwing. Activity by the subscapularis and latissimus dorsi muscles caused the humerus to medially rotate (Moynes et al. 1986).

Follow-Through Phase

The follow-through stage started after the tennis ball had been hit and ended when the serving shoulder had stopped internally rotating (Moynes et al., 1986). Moynes et al. (1986) and Ryu et al. (1988) agreed there was a moderate amount of activity demonstrated by all the muscles in the follow-through stage of the tennis serve.

Jobe et al. (1984) stated that the triceps, pectoralis major, and latissimus dorsi were all active in the follow-through stage of the baseball pitch by way of EMG analysis. The deltoid, supraspinatus, infraspinatus, teres minor, and subscapularis muscles all showed significant activity during the follow-through stage (Jobe et al. 1983). Moynes et al. (1986) stated there was activity in the deltoid, supraspinatus, infraspinatus, and teres minor muscles. The latissimus dorsi and biceps muscles were also active during the follow-through (Moynes et al. 1986). Jobe et al. (1983), Jobe et al. (1984), and Moynes et al. (1986) all agreed that the activity by the lateral rotators, during the follow-through stage, was to help negatively accelerate internal rotation of the humerus. Activity by the biceps in this stage was present to decelerate the extending arm (Jobe et al. 1984).

Recruitment of Motor Units

As stated by Winter (1990a), each muscle has a finite number of motor units and each of these motor units is innervated by a separate nerve ending. When excitation of the motor unit occurs, the muscle responds with an all-or-nothing outcome. As further stated by Winter (1990a), the electrical indication of excitation is an action potential and the mechanical result is a twitch of tension. An increase in tension has been shown to result from either an increase in the stimulation rate of the motor unit or by the recruitment of additional motor units(Winter, 1990a).

Motor units are recruited according to the size principle. Depending on the tension needed to be achieved, the smallest motor unit is recruited first and the largest motor unit is recruited last. When a decrease in tension is required the recruitment or derecruitment pattern proceeds in the opposite direction(Winter, 1990a).

Signal Processing

Winter (1990a) stated that once the EMG signal has been amplified it is necessary to process it with the use of an on-line processing procedure. Raw EMG data is often not suitable for recording or correlation with other parameters. The following are some of the more common types of on-line processing: (1) Half- or full-wave rectification, (2) Linear envelope detector, (3) Integration of the full-wave rectified signal over the entire period of muscle contraction, (4) Integration of the full-wave rectified signal for a fixed time, or reset to zero, and then the integration cycle repeated, and (5) Integration of the full-wave rectified signal to a preset level, or reset to zero, and then the integration repeated(Winter, 1990b).

Chaffin & Andersson (1991b) stated that the main reason for recording and processing myoelectric signals in kinesiology is to try and determine the tension that is produced by a muscle. However, the relationship of EMG activity to the force of a muscle has been found to depend on several factors which include; the size of the electrode used, the proximity of the electrode to the muscle, the electrical impedance, the type of electrode used (surface vs. indwelling, bipolar vs. monopolar), the spacing between bipolar electrodes, the state of fatigue, the muscle temperature, the specificity of muscle tested, the strength-training of the muscle, the muscle's length, and the speed of shortening while testing(Chaffin & Andersson, 1991b). Although the relationship appears to be monotonic, in the sense that an increase in myoelectric activity has resulted when an increase in tension has been present, it has been non-linear under many circumstances. Nonlinear results, that result in an increase in the general effect of the EMG/Load ratio, have been shown to be present when the electrodes were too large, the electrodes are placed in close proximity to the muscle, a prolonged contraction and resulting fatigue has been executed, and when a high speed of shortening is used. A decrease in the general effect of the EMG/Load ratio that has been shown to account for nonlinear results occurs when high electrode impedance is present, the muscles temperature has been elevated, and when a muscle has been highly strength-trained. Furthermore, while reasonably reproducible relationships have been found for isometric contractions, it has not been the case for dynamic contractions(Chaffin & Andersson, 1991b). Chaffin & Andersson (1991b) attributed the lack of reproducability in dynamic contractions to a muscle's length-tension relationship and also to differences in recruitment patterns. The alteration of an electrode's position in terms of the location of active motor units may also affect the signal's amplitude(Chaffin & Andersson, 1991b).

A procedure that has been used to minimize the errors when using myoelectrical activity to determine force is one in which a "calibration" is done by "normalization" of the EMG to a single maximum reference contraction. The most common method of normalization that has been done is to record the myoelectrical activity during one isometric maximal voluntary contraction and express the measured myoelectrical activity during subsequently recorded activities as a percentage of the myoelectrical activity that occurred during the isometric maximal voluntary contraction(Chaffin & Andersson, 1991b).

Bouisset (1990) stated that relationships between integrated surface EMG and various biomechanical quantities, which characterize the mechanical performance of a muscle, do exist specifically when using surface EMG as an index of a muscle's level of excitation. However, even though surface EMG can be an appropriate index for the level of excitation of a muscle, it appears rather hazardous to associate it with a simple mechanical significance when examining complex motor activities(Bouisset, 1990).

Summary

Many researchers have studied the biomechanics of overarm motions and have concluded that linear velocity of the end point is an important contributor to the success of the performance. The use of cinematography or videography is a good way of obtaining kinematic data. The angular acceleration of a segment has been determined through the use of cinematography. Kinematic data that is obtained through cinematography has also been used to determine kinetic data. High end point velocity may be achieved through increasing muscle forces and torques.

EMG analysis can be a useful way of determining which muscles are active during overarm throwlike motions. However, the use of EMG as a way of determining force or torque production for a specific movement is limited.

Kinetic data has been obtained through the use of isokinetic dynamometers. The Cybex II isokinetic dynamometer has specifically been used to collect kinetic data.

CHAPTER 3

METHODS

The procedures used in this study are presented in the following sections: (1) Subjects, (2) Filming Procedures, (3) Method of Calculating Predicted Variables from the Kinetic Link Model, (4) Electromyography and Electrogoniometry, (5) Data Retrieval Procedures, and (6) Statistical Analysis Procedures.

Subjects

Twenty men served as subjects. The subjects' ages ranged from 18 to 50 years, with the mean age being 28 years. All subjects' weights and heights were recorded for use in the Filmdata software program and for determining the location of each segment's center of mass. Subjects were randomly assigned a number that was used as a means of identification for their test results. Written consent, by way of a human subject form, was received, signed, and returned from all subjects before testing procedures were conducted(See Appendix A).

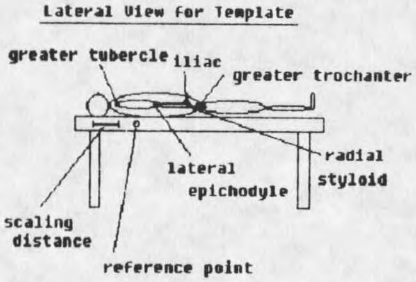
Filming Procedures

All filming was done in the Athletic Training Room at Montana State University. A Panasonic AG450 SVHS video camera, functioning at 33.3 mm/sec. was used to film the subjects. The shutter speed was set at 1/1000 of a second. A filming light was used to illuminate the subjects so that the video was clear. For all filming, the camera was placed on a counter top that was ten feet from a table where the subjects were positioned. For digitizing purposes a 3/4" red adhesive dot with a 1/2" white adhesive dot centered on it was placed on anatomical landmarks, as specified by Dempster (1955). The dots identified each joint's center or axis of rotation.

To film transverse flexion of the arm at the shoulder, dots were placed on the radial side of the wrist at the midpoint of the line between the radial styloid and the center of the pisiform bone, at a point 8 mm. above the radiohumeral junction at the elbow, at the midregion of palpable bony mass of the head and the tuberosities of the humerus at the shoulder, and at the most lateral point of the iliac crest, and the greater trochanter of the femur. For filming internal rotation of the shoulder dots were placed on the ulnar side of the wrist at the midpoint of the line between the radial styloid and the center of the pisiform bone, at the olecranon process of the ulna while the forearm was flexed to 90° at the elbow, at the midregion of palpable bony mass of the head and tuberosities of the humerus at the shoulder, and at the most lateral point of the iliac crest, and the greater trochanter of the femur.

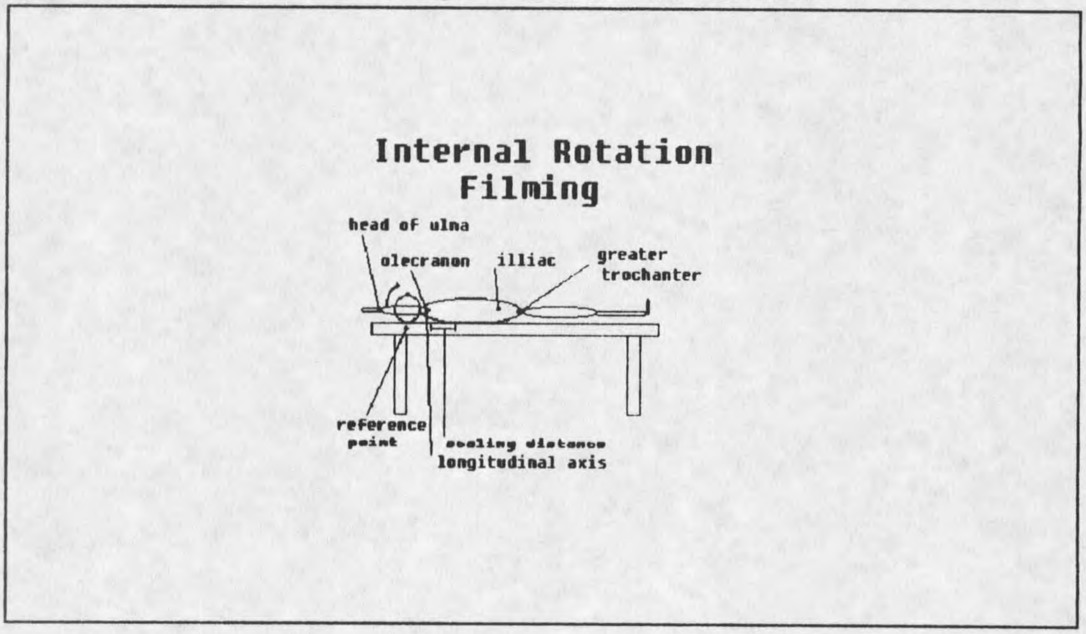
Before each subject was filmed performing transverse flexion or internal rotation, a lateral view of the subject was taken(Figure 1). Two white strips of tape, .3048 meters apart, were placed on the side of the bench where the subjects were positioned and used as a scaling distance. A white dot was also placed on the side of the table and used as a reference point.

Figure 1. Lateral View of Subject.



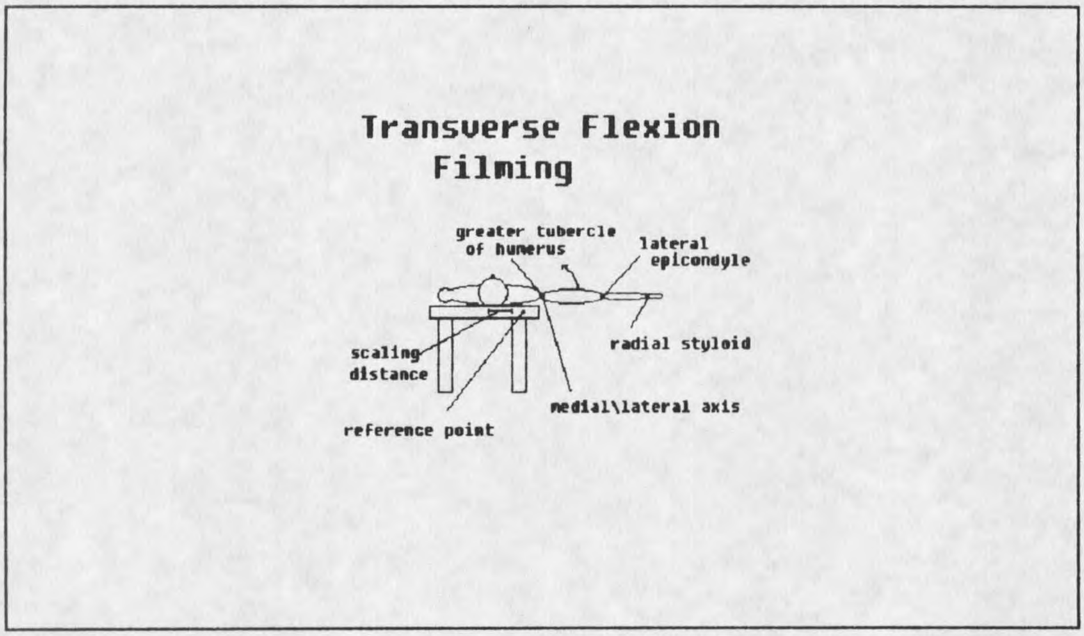
When filming the subjects performing internal rotation of the humerus, all subjects were placed in a supine position with their humeri maximally externally rotated and abducted to 90°, their forearms flexed to 90° at the elbow and their radio-ulnar joints in mid position. The subjects were filmed performing internal rotation of the humerus at the shoulder from a lateral view so that the axis of rotation, which was identified by the olecranon process of the ulna, faced directly into the camera lens(Figure 2).

Figure 2. Subject During Internal Rotation.



In order to film the subjects transversely flexing their humeri the subjects were placed in a supine position on the bench such that their humeri were in a maximum transverse extension. The subjects' humeri were also abducted to 90°, their elbows were fully extended, and their forearms supinated. The subjects were filmed performing transverse flexion from a coronal view so that the medial/lateral axis of the shoulder, which was identified by the greater tuberosity of the humerus, faced directly into the camera lens(Figure 3).

Figure 3. Subject During Transverse Flexion.



After positioning the subjects for filming internal rotation, as previously described, the subjects were shown how they were to move their upper extremity by being led through the movement. Subjects were instructed to keep the forearm at 90° to the upper arm throughout the movement. The subjects were also instructed to perform the movement as fast as possible.

When the filming of internal rotation was finished the subjects were positioned, as previously described, for filming transverse flexion. Each subject was shown the movement they were to perform by being led through the movement. The subjects were instructed to keep their forearms extended while transversely flexing their humeri. The subjects were further instructed to perform the movement as fast as possible.

After being instructed on the motion each subject was to execute, internal rotation or transverse flexion, the subjects performed an unlimited number of practice trials to ensure they understood what they were to do. Subjects were told when they performed the movement correctly and shown how to correct the movement when performed incorrectly. All questions they had about the movements were answered before they performed the movement. When each subject was comfortable with the movement they were to execute filming began. Each subject was filmed twice performing internal rotation and transverse flexion.

Method of Calculating Predicted Variables from Kinetic Link Model

Kreighbaum & Barthels (1990, pp. 611-614) predict angular velocities in a wheel-axle system and a lever system. This model was applied to the upper limb to predict an end point linear velocity value for internal rotation and transverse flexion. Each subject's weight and segmental lengths were recorded. The length of each segment was measured between two consecutive joint markers. These distances which were measured in inches were converted to meters by multiplying by .0245. The mass of each segment was determined after calculating the subject's total weight in pounds by 2.205 so that it was in kilograms. The total weight in kilograms, of each subject was multiplied by mean segment weights expressed as percentages of total body weight from Plagenhoef et al.(1983). The center of gravity location for each segment was then calculated by multiplying the length of the segment specified by segmental center of gravity locations expressed as percentages of segment lengths measured from the proximal ends(Plagenhoef et al., 1983).

The equation, $Icg = 1/2Mr^2$ was used for determining the rotational inertia of a segment, about its own center of gravity for each segment in each system. The radius of rotation for the center of gravity of the arm, forearm, and hand in the lever system were calculated by multiplying the distance measured between the markers by segmental center of gravity locations expressed as percentages of segmental lengths from Plagenhoef et al. (1983). This same procedure was used for the forearm and hand in the wheel-axle system. However, for the arm in the wheel-axle system, the radius of rotation for the center of gravity was identified as being negligible because rotation of the arm occurred about the long axis of the humerus. The mass of each segment was determined as a percent of total body weight from Plagenhoef et al. (1983).

From the previous calculations, the rotational inertia of each segment was calculated using the equation $I=\Sigma mr^2$ +

Icg. The radius of rotation of the arm in the wheel-axle system was treated as zero because rotation occurred about its long axis. The rotational inertia present in each system was calculated by adding each individual segment's rotational inertia.

Each system's radius of rotation was calculated by adding the lengths of each segment in the system. The end point of lever system was identified by the marker on the radial side of the wrist at the midpoint of the line between the radial styloid and the center of the pisiform. The end point of the wheel-axle system was identified by the marker on the ulnar side of the wrist at the midpoint of the line between the radial styloid and the center of the pisiform.

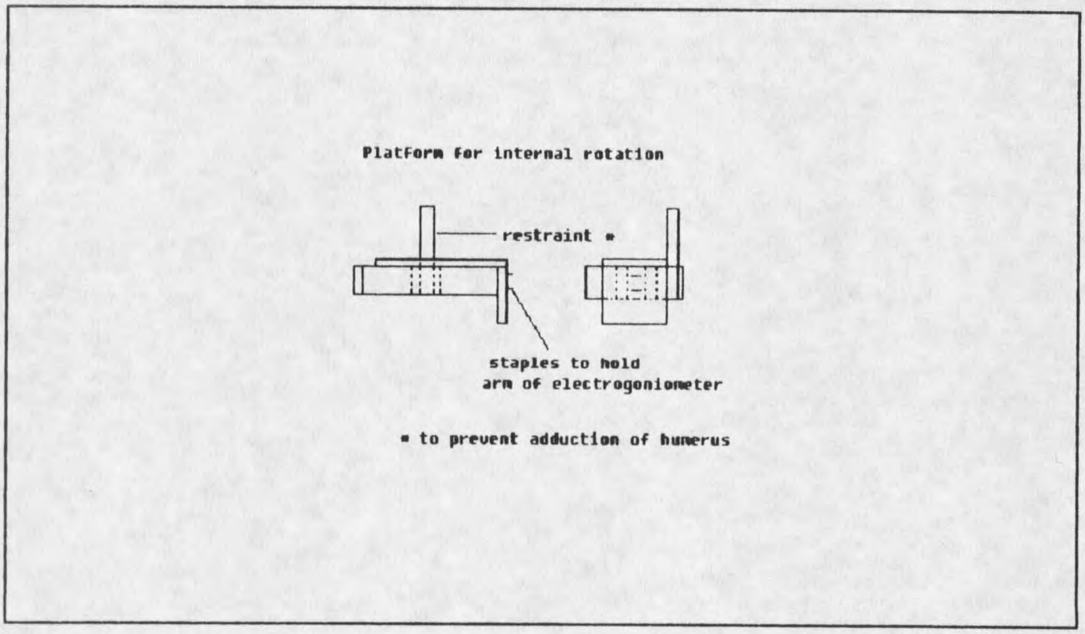
A predicted linear velocity for each system was calculated by the use of two ratios: (1) a radius of rotation ratio, $\frac{r(1)}{r(wa)}$, where r(1) is the radius of rotation of the lever system and r(wa) is the radius of rotation of the wheel-axle system and, (2) a rotational inertia ratio, $\frac{W\text{-}A\ Ia}{Lever\ Ia}$, where W-A Ia is the rotational inertia of the wheel-axle system and Lever Ia is the rotational inertia of the lever system. A predicted linear velocity was obtained by the equation $V = r\omega$, where r is the radius of rotation ratio of the systems and ω is the rotational inertia ratio of the systems. The two ratios, the radius of rotation and the rotational inertia, were thus used to represent r and ω respectively(Appendix B).

Electromyography and Electrogoniometry

All electromyographic testing was done in the Neurophysiology Lab in Lewis Hall at Montana State University. Bipolar silver surface electrodes were used to detect the electrical activity of the pectoralis major and anterior deltoid muscles during transverse flexion and the electrical activity of the pectoralis major and latissimus dorsi muscles during internal rotation. To lower the electrical impedance of the skin, a saline paste was placed on the electrode and the skin. A ground electrode was placed on the subject's nondominant wrist. Signals were fed to a Grass Instruments P5 Series A.C. Preamplifier where they were filtered at a low frequency of 30 Hz and a high frequency of 3 kHz and amplified 500 times. The signals were then fed to an Analog to Digital Converter, functioning at a sampling rate of 68 kHz, and were displayed with the use of an RC Electronics Inc. Computerscope ISC-16 software program on an IBM PC.

All subjects were placed in the same positions for internal rotation and transverse flexion as they were when being filmed. However, for internal rotation of the shoulder each subject's upper arm was positioned on a platform, which functioned to stabilize the upper arm and keep one lever arm of the electrogoniometer stationary. Attached to the platform was a vertical column that prevented the upper arm from being adducted as the subjects internally rotated their humeri(Figure 4).

Figure 4. Platform Used to Stablize Subject's Extremity During Internal Rotation.



Along with the surface electrodes, an electrogoniometer was attached to the subjects so that the axis of the goniometer was aligned with the axis of the system being tested. The electrogoniometer was positioned on the subject with velcro straps and tape(Figures 5 & 6).

Figure 5. Subject Executing Internal Rotation During Electromyography Testing.

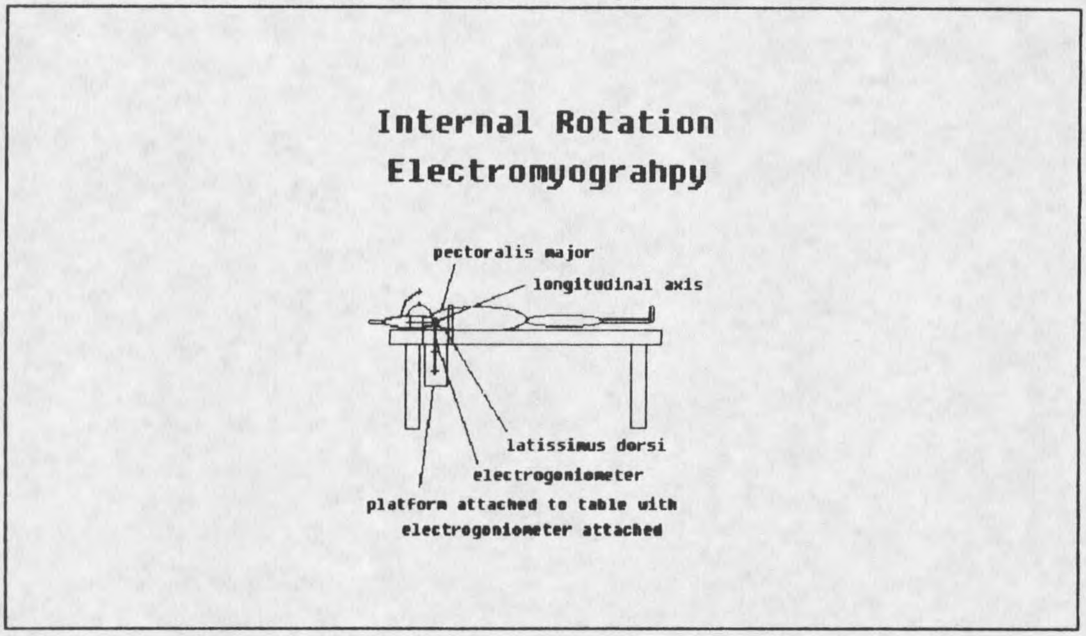
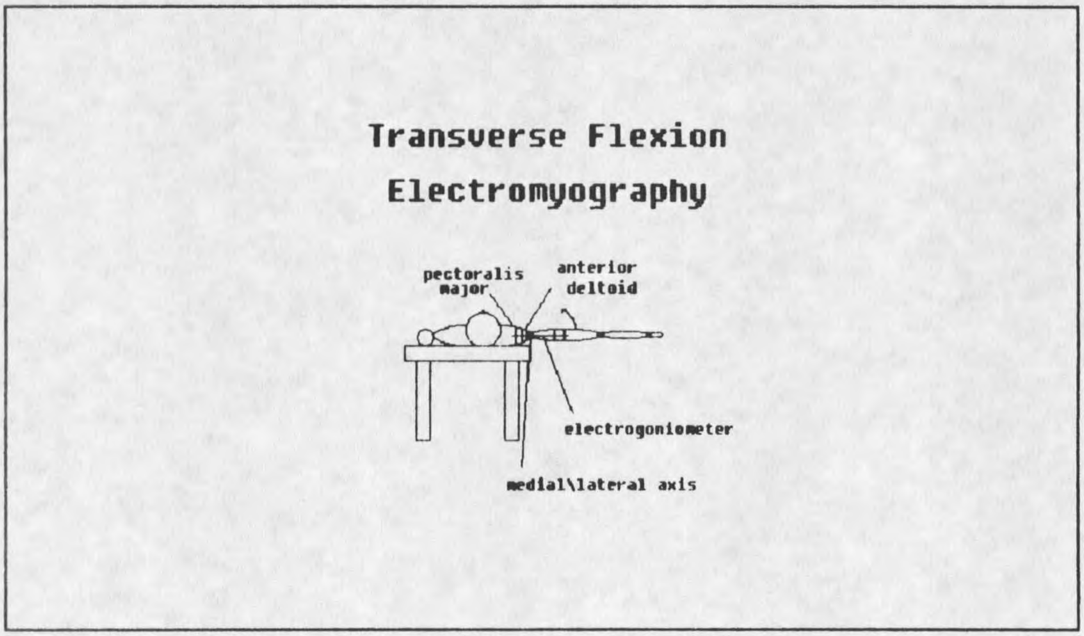


Figure 6. Subject Executing Transverse Flexion During Electromyography Testing.



To ensure that the electrogoniometer recorded the motion of the system through its full range of motion, the segment being tested was moved through its complete range of motion while the electrical activity of the electrogoniometer was monitored on an Tektronix Oscilloscope. The output from the electrogoniometer was then fed to an Analog to Digital Converter and to an RC Electronics Inc. Computerscope software program. After the electrogoniometer and the electrodes were positioned correctly, each subject was then instructed to perform the movement appropriate to the system being tested. Data from the electrodes and the electrogoniometer were saved on the computer for analysis.

Data Retrieval Procedures

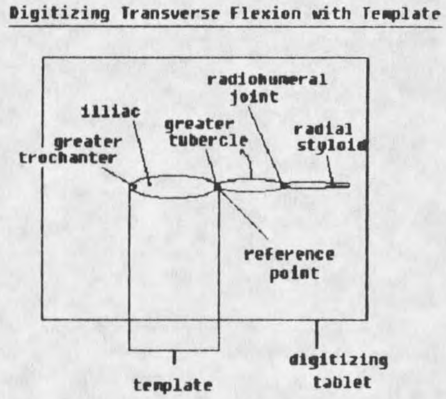
Video

The video tape was projected onto a rear projection, glass digitizing tablet by way of a Panasonic VCR, which allowed for still advancement of the video tape, and a VCR projector. A Sonar Graph Pen was used to digitize the reference points and the points of interest for each system. Every third still advanced view was digitized. Digitizing of the subject began 21 still advance views before the subject began to execute each motion and ended 21 still advance views after the subject stopped the designated motion. This was done to accommodate the smoothing procedures of the computer program.

It was determined that two measurements per subject for each system be obtained and a mean value of the kinematic and kinetic values of interest be calculated. Thus, a total of four digitized sets of data, two for internal rotation and two for transverse flexion, were calculated for each subject.

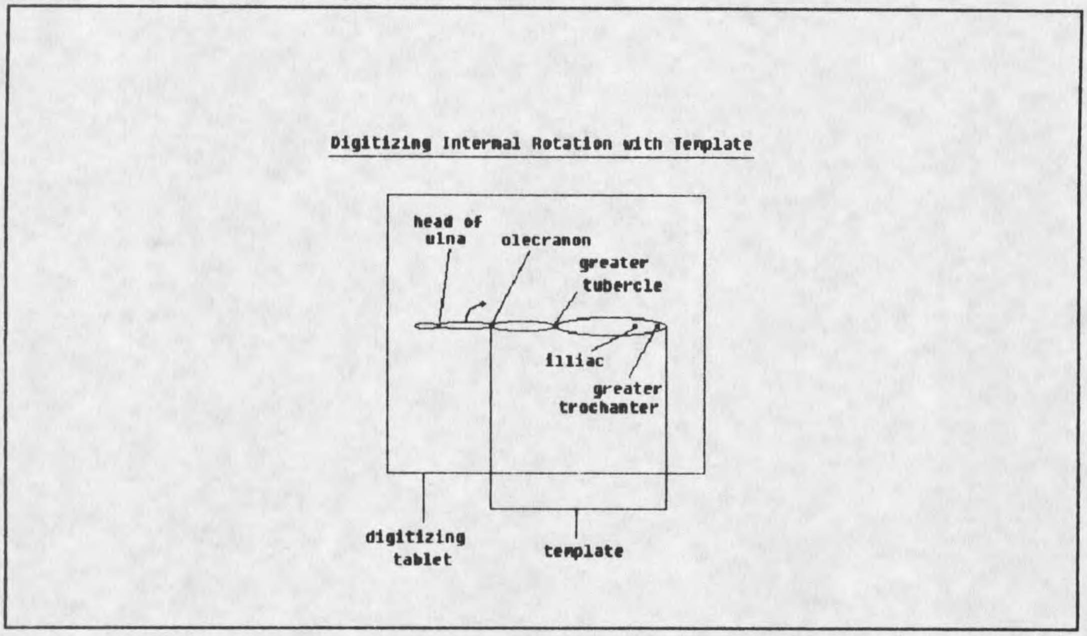
After projecting the lateral view of the subject on the digitizing tablet two templates were made. One consisted of the subject's radiohumeral joint and greater tuberosity. The second consisted of the subject's greater tuberosity, iliac, and greater trochanter. The coronal view of the subject performing transverse flexion was then projected on the digitizing tablet. The spot representing the greater tubercle of the humerus on the template, which consisted of the greater tubercle, the iliac crest, and the greater trochanter, was then positioned so that it was in accordance with the greater tubercle of the humerus from the projected image(Figure 7). Points digitized were the reference point, the radial styloid, the radiohumeral joint, the greater tubercle, the iliac, and the greater trochanter.

Figure 7. Body Points Digitized During Transverse Flexion with Template.



To digitize the subjects executing internal rotation, the view of each subject in external rotation was projected on the digitizing tablet. The two individual templates were then combined so that the points identifying the greater tubercle were connected. These two templates were combined so that the greater tuberosity was represented as one spot to be digitized. The template was then positioned such that the olecranon process of the template matched with the olecranon process of the projected image(Figure 8). The spots that were digitized for internal rotation were the head of the ulna, the olecranon, the greater tubercle, the iliac, and the greater trochanter.

Figure 8. Body Points Digitized During Internal Rotation with Template.



When the projected axis of the system being digitized did not align with the corresponding point of the template the template was repositioned through the use of a plumb line. A plumb line was used to correctly reposition the template so that it remained horizontally true.

By using a Tectronix 4025 terminal, a Vax mainframe computer, and a Filmdata software program, kinematic moments and kinematic data for the wheel & axle and lever systems were obtained. The program generated angular displacements, velocities, and accelerations about the shoulder joint and linear displacements, velocities, and accelerations of the wrist. Net moments of inertia and net forces about the shoulder were also calculated. The angular measurements for transverse flexion were determined by the change in the position of the lateral epicondyle of the humerus in relation to the position of the greater tuberosity and the iliac. The angular measurements for internal rotation were determined by the change in the position of the head of the ulna in relation to the position of the olecranon and the greater tubercle. End point linear velocity was determined from the displacement of the head of the ulna and the styloid of the radius for internal rotation and transverse flexion respectively.

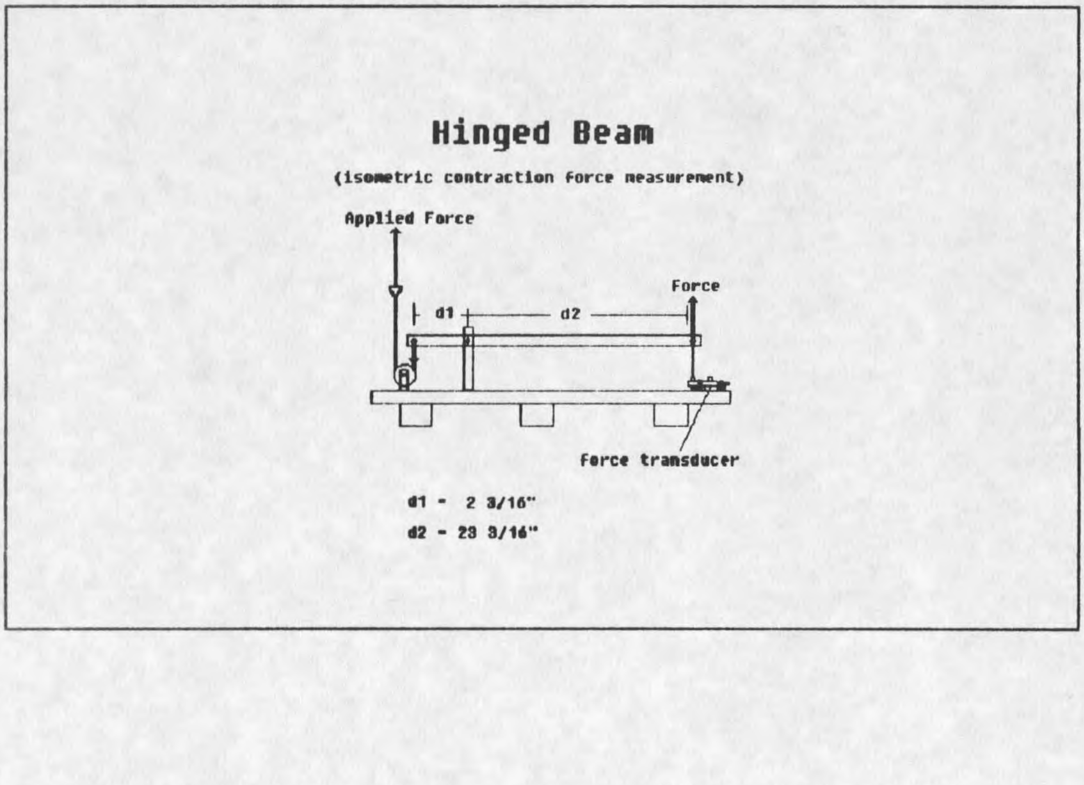
The time it took the end point of each system to achieve maximum linear velocity was also calculated. This was done by multiplying the number of frames digitized from the beginning of the movement by the time between each digitized frame until the end point of the system reached maximum linear velocity.

Electromyography

EMG data were processed using the RC Electronics Inc. Computerscope ISC-16 software package. Any offset voltage in the EMG recordings was eliminated by adjusting the baseline voltage to zero. The data were then full-wave rectified at the baseline. By integrating the area under the curve of the rectified record, an estimation of the total electrical activity was determined. Integrated values, both total and mean, were determined for the first and second halves of the movement time. The total movement time was divided in half to examine if a difference was present for the electrical activity of the muscles in terms of accelerating and deccelerating levels of activity.

After performing internal rotation or transverse flexion of the arm at the shoulder, the subjects were placed in their respective starting positions for each system and instructed to execute an isometric contraction. Resistance for each isometric contraction was provided by a cable that the subjects held in their hand. The cable was positioned at 90° to the hand and followed a pulley around where it was connected to a hinged beam. The other end of the hinged beam was attached to a Grass Instruments Force Transducer so that the applied force produced by all of the muscles internally rotating or transversely flexing the arm at the shoulder could be calculated(Figure 9).

Figure 9. Hinged Beam Used in Measuring Force During Isometric Contraction.



The pulley, hinged beam, and force transducer were attached to a plywood platform. Twelve concrete blocks were used to hold the platform stationary. The output voltage from the transducer was amplified through the Beckman R612 Dynograph Recorder and then fed to a data acquisition unit, a Tektronix's Oscilloscope, the RC Electronics Inc. software program and stored on a PC. The electrical activity of the force transducer was recorded along with the electrical activity for each muscle while performing the isometric contraction.

The magnitude of electrical activity generated during maximal isometric tension was determined by integrating the area under the full-wave rectified curve as previously described. To determine when to integrate the recorded electrical activity from the isometric contraction the recording from the force transducer was monitored. By identifying when the recorded electrical activity of the force transducer was at its greatest level the position for processing the recorded electrical activity of the muscles was determined. Two cursors, one identifying the beginning of the data to be processed and one identifying the end of the data to be processed, were positioned according to when the force transducer was at its optimal level. The time period used to process the electrical activity of the muscles during the isometric contraction, which was identified by the distance between the two cursors, was the total time taken to perform the movement as determined from the electrogoniometer during the dynamic contration.

The mean voltages for each time period of movement were expressed as a percentage of the value for the maximal isometric contraction. The percent of maximum contraction, during the first and second halves of the movement, were calculated by dividing the mean voltage values of the dynamic contractions by the mean voltage values from the isometric contraction to determine the extent to which the muscles were approaching maximum contraction. Exact Calculations may be seen in Appendix C.

Calibration

To calculate the force produced by a subject while performing the isometric contraction, the output of the force transducer was first recorded without any force on it to determine the offset voltage. The offset voltage was then subtracted from the voltage produced during the maximum contraction. This voltage was identified with a corresponding force measurement. The force amount was then multiplied by 10.60, which was the mechanical advantage of the hinged beam(Figure 9). To this value 18.7425 pounds was added to accommodate for the amount of force that was required to balance the hinged beam. The amount of force each subject produced while performing an isometric contraction for internal rotation and transverse flexion was calculated(Appendix C).

Statistical Analysis

The mean, standard deviation, and range of the following for both the wheel-axle and lever systems were obtained: the linear velocity of the end point of the system, the kinematic moment about the shoulder, the angular acceleration of the shoulder, the angular velocity of the shoulder, the force applied to the transducer during the isometric contraction, the calculated radius of rotation ratio between the two systems and the calculated rotational inertia ratio between the two systems.

Paired t-tests were applied to the observed end point linear velocities, the moments, the angular accelerations and the angular velocities about the shoulder, and the isometric force measurements applied using the two systems. Paired t-tests were also applied to the rotational inertia, radius of rotation and the predicted linear velocities of the wheel-axle and lever systems.

Scatter plots between the wheel-axle system and the lever system of the following variables were made: linear velocity, angular velocity, angular acceleration, and moments. In addition, the following scatter plots were made: linear velocity of the wheel-axle system vs. angular velocity of the wheel-axle system, linear velocity of the lever system vs. angular velocity of the lever system, moment of wheel-axle system vs. angular acceleration of wheel-axle system, moment of lever system vs. angular acceleration of lever system. Two scatter plots were produced involving ratios, whereby the value obtained for the wheel-axle system was divided by the value obtained for the lever system: the linear velocity ratio vs. angular velocity ratio and the moment ratio vs. angular acceleration ratio. Two other scatter plots were also produced. For these two plots the y-axis consisted of a predicted linear velocity ratio that was calculated by using the equation $V=r\omega$, where r is the radius of rotation ratio and ω is the rotational inertia ratio. The radius of rotation ratio was calculated by dividing the radius of rotation of the lever system by the radius of rotation of the wheel-axle system. The rotational inertia ratio was calculated by dividing the rotational inertia of the wheel-axle system by the rotational inertia of the lever system. The four scatter plots were: the predicted linear velocity ratio vs. observed velocity ratio and the predicted velocity ratio vs. angular velocity ratio. The observed velocity ratio and the angular velocity ratio for these two graphs were calculated by dividing the respective value for the wheel-axle system by the respective value for the lever system(Hamilton & Todd, 1991).

After producing the scatter plots regression analyses were performed on each set of data. The independent value for the linear regressions was the value plotted along the horizontal axis while the dependent value was that which was plotted along the verticle axis(Hamilton & Todd, 1991).

To determine if there was a significant difference between the time it took each system to reach maximum linear velocity a paired t-test was used. Mean, standard deviation, and range values were also obtained for the different time values of each system.

The mean, standard deviation, and range of the electrical activity of the muscles examined for internal rotation and transverse flexion were also obtained. These values were obtained for the first and second halves of the motion for each system tested and included the electrical activity of the anterior deltoid and pectoralis major for internal rotation and the latissimus dorsi and pectoralis major for transverse flexion. The mean, standard deviation, and range of the electrical activity of the pectoralis major for internal rotation and for transverse flexion while executing the isometric contraction were also calculated. Furthermore the mean, standard deviation, and range values for the percent of maximum contraction that occurred for the pectoralis major for internal rotation and for transverse flexion were calculated.

A total of seven paired t-tests were executed on the voltage values from the EMG data. Four paired t-tests were run to determine if there was a significant difference between the integrated value of the electrical activity of the first half of the motion and the second half of the motion for the muscles examined when performing internal rotation and transverse flexion. To determine if there was a significant difference between the electrical activity of the pectoralis major during the first half of each movement and the second half of each movement two paired t-tests were run. The final paired t-test run on the EMG data was that between the percent of maximum contraction that occurred for pectoralis major in each system.

CHAPTER 4

RESULTS

The results of this study are divided into three major areas: (1) Anthropometrics, (2) Kinematics, and (3) Kinetics.

Anthropometrics

A total of twenty male subjects were randomly selected for the testing procedures. After the filming portion of testing, one subject was excluded from further testing because of experiencing shoulder discomfort. Another subject was identified and completed the testing procedures. Subjects ranged in age from 18-50 years with a mean age of 27 years. Heights and weights for the subjects ranged from 69-75 inches and 146-250 pounds respectively with means of 71.5 inches and 182 pounds. Of the twenty subjects, sixteen were right hand dominant and four were left hand dominant. Anthropometric data for each subject are shown in Table 1.

Table 1. Anthropometric Data(age, height, weight, and dominant hand).

Age	Height(inches)	Weight(lbs.)	Dominant Hand
22	70.0	155	Left
18	75.0	175	Right
18	74.0	198	Right
24	71.0	180	Right
23	70.0	185	Right
23	70.5	170	Right
23	73.0	172	Left
21	72.0	175	Right
26	70.0	168	Left
32	69.0	146	Right
38	70.0	165	Right
22	74.0	168	Right
50	74.0	205	Right
47	69.0	250	Right
24	71.0	185	Right
24	72.0	210	Left
23	72.0	155	Right
23	72.0	200	Right
33	71.0	170	Right
31	71.0	212	Right

Kinematics

Kinematic data obtained from digitization of the subjects performing internal rotation and transverse flexion are presented in Table 2. The mean, standard deviation and range of the following parameters are listed; the linear velocity of the end point, and the angular acceleration and the angular velocity of the motion at the shoulder joint.

Table 2. Mean, Standard Deviation, and Range of Kinematic Data for Internal Rotation(W-A) and Transverse Flexion(Lever).

Linear Velocity(Meters/Sec.)

System	Mean	S.D.	Range
W-A	4.371458	0.486890	5.528103-3.644659
Lever	5.719414	0.710052	7.019200-4.433997

Angular Acceleration(Degrees/Sec./Sec.)

System	Mean	S.D.	Range
W-A	6118.00	883.438438	7791-4519
Lever	3373.15	1005.080000	6035-1685

Angular Velocity(Radians/Sec.)

System	Mean	S.D.	Range
W-A	14.6175	1.6466517	18.43-12.13
Lever	11.4545	2.0701932	16.00- 7.71

A paired t test was used as the statistical tool to analyze the data on the linear velocity of the end point, the angular acceleration and angular velocity of each system. A t-table from Thomas & Nelson (1985) was consulted to determine if there was a significant difference at $p<.05$ between the linear velocities, angular accelerations, and angular velocities of the two systems. In order for a significant difference to be present at $p<.05$, with 19 degrees of freedom, a t value of 2.093 or greater had to have been obtained. The t values obtained from the paired t tests for comparison of the linear velocities, angular accelerations, and angular velocities measurement were 9.7484286, 17.8523761, and 11.9468853, respectively. Thus, there was a significant difference at $p<.05$ between internal rotation(wheel-axle system) and transverse flexion (lever system) for these three parameters. The maximum linear velocity of the lever system was larger than the maximum linear velocity of the wheel-axle system. However, the maximum angular acceleration and the maximum angular velocity of the wheel-axle system were larger than the maximum angular acceleration and the maximum angular velocity of the lever system. Table 3 lists the t values obtained from the paired t tests performed on the maximum linear velocities of the end point of each of the systems and the angular accelerations and angular velocities of the two systems.

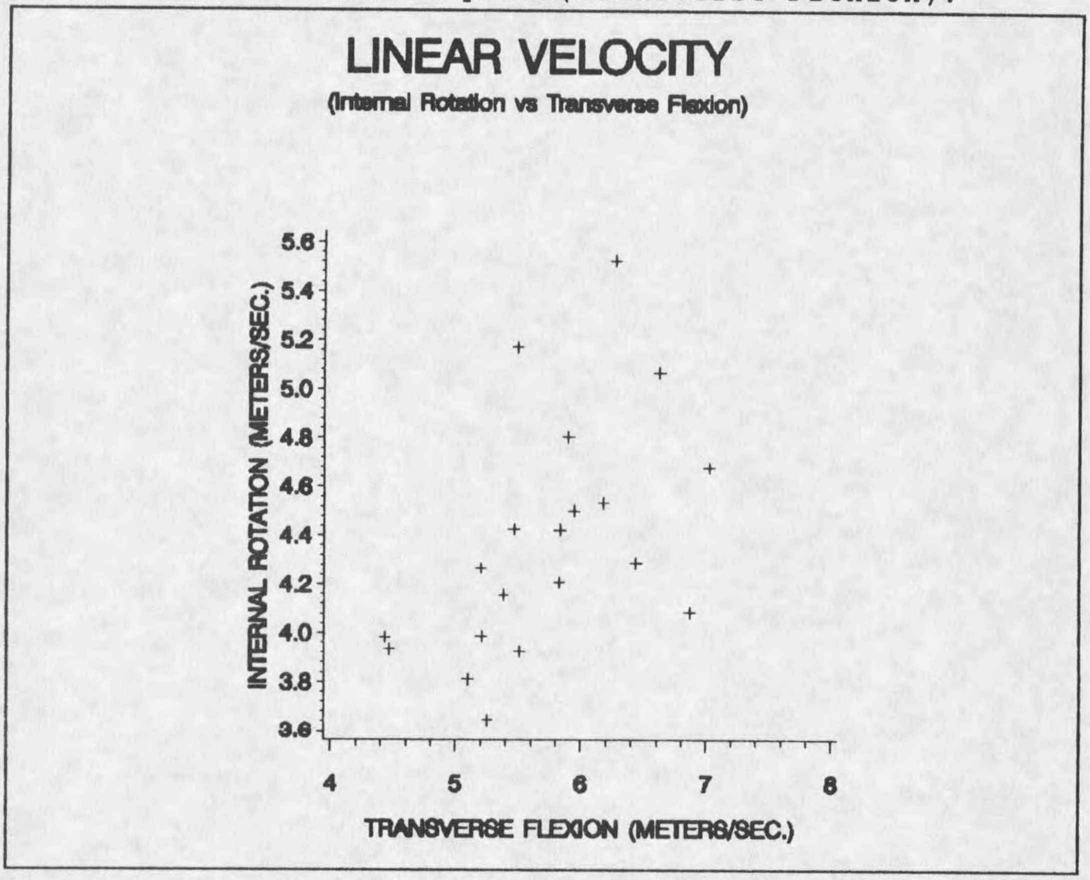
Table 3. t Values from Paired t tests for Linear Velocity, Angular Acceleration, and Angular Velocity.

Parameter	System	t-value	Prob < T
Linear Velocity	W-A - Lever	9.7484286	.001
Angular Acceleration	W-A - Lever	17.8523761	.001
Angular Velocity	W-A - Lever	11.9468853	.001

Linear regression equations were determined from the data in Figures 10, 11, and 12. To determine if a linear relationship was present between the independent and the dependent variables a t-statistic was obtained. The dependent variable was the parameter shown on the vertical axis while the independent variable was the parameter shown on the horizontal axis for the three figures.

Figure 10 is a scatter plot of the end point linear velocity of the wheel-axle system(internal rotation) and the lever system(transverse flexion).

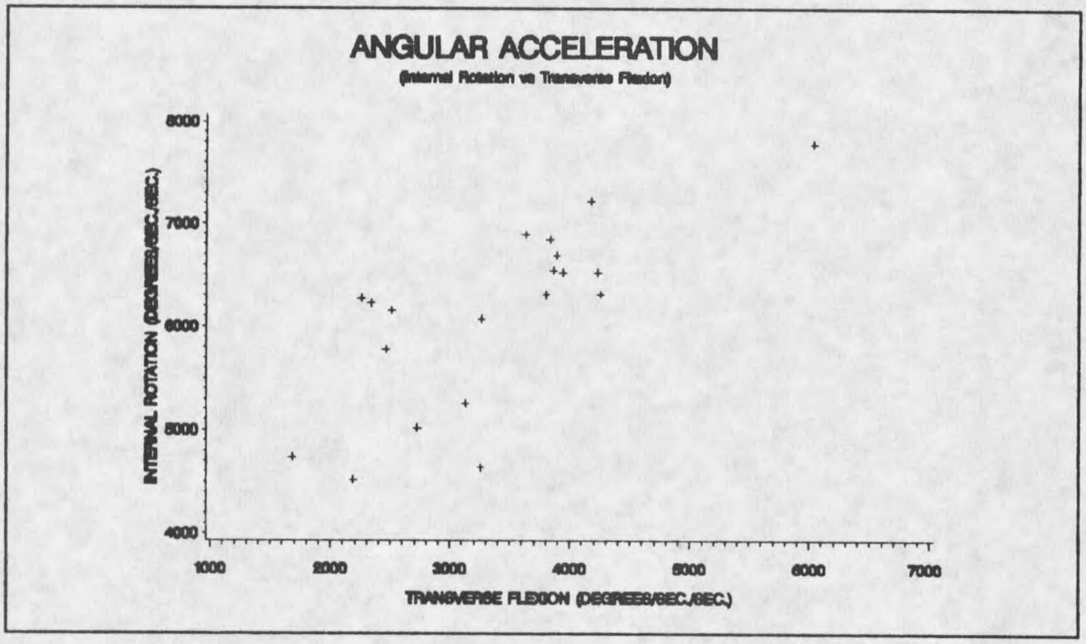
Figure 10. Scatter Plot of the Linear Velocity of the Wheel-Axle System(Internal Rotation) and the Lever System(Transverse Flexion).



The t-statistic obtained for the data in Figure 10 was 2.576. This t-statistic value is significant at p<.0190. This indicates a significant relationship is present between the dependent variable, the linear velocity of the wheel-axle system(internal rotation), and the independent variable, the linear velocity of the lever system(transverse flexion). An R-squared value of 0.2693 was also obtained. Thus 26.93% of the variability in the linear velocity of the wheel-axle system(internal rotation) can be explained by the linear velocity of the lever system(transverse flexion).

Figure 11 is a scatter plot of the angular acceleration of the wheel-axle system(internal rotation) and the lever system(transverse flexion).

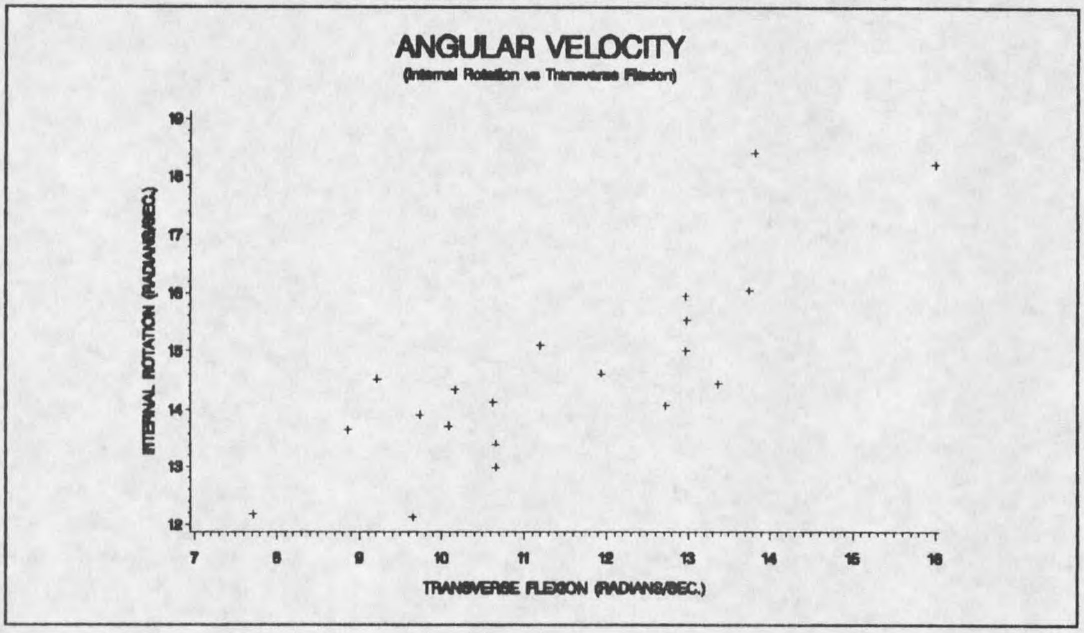
Figure 11. Scatter Plot of the Angular Acceleration of the Wheel-Axle System(Internal Rotation) and the Lever System(Transverse Flexion).



A t-statistic value of 4.697, which is significant at p<.0002, was obtained from the data in Figure 11. Thus a significant linear relationship is present between the dependent variable, the angular acceleration of the wheel-axle system(internal rotation), and the independent variable, the angular acceleration of the lever system(transverse flexion). An R-squared value of 0.5507 was also calculated, and expresses that 55.07% of the variability in the angular acceleration of the wheel-axle system(internal rotation) is explainable by the angular acceleration of the lever system(transverse flexion).

Figure 12 is a scatter plot of the angular velocity of the wheel-axle system(internal rotation) and the lever system(transverse flexion).

Figure 12. Scatter Plot of the Angular Velocity of Wheel-Axle System(Internal Rotation) and the Lever System(Transverse Flexion).

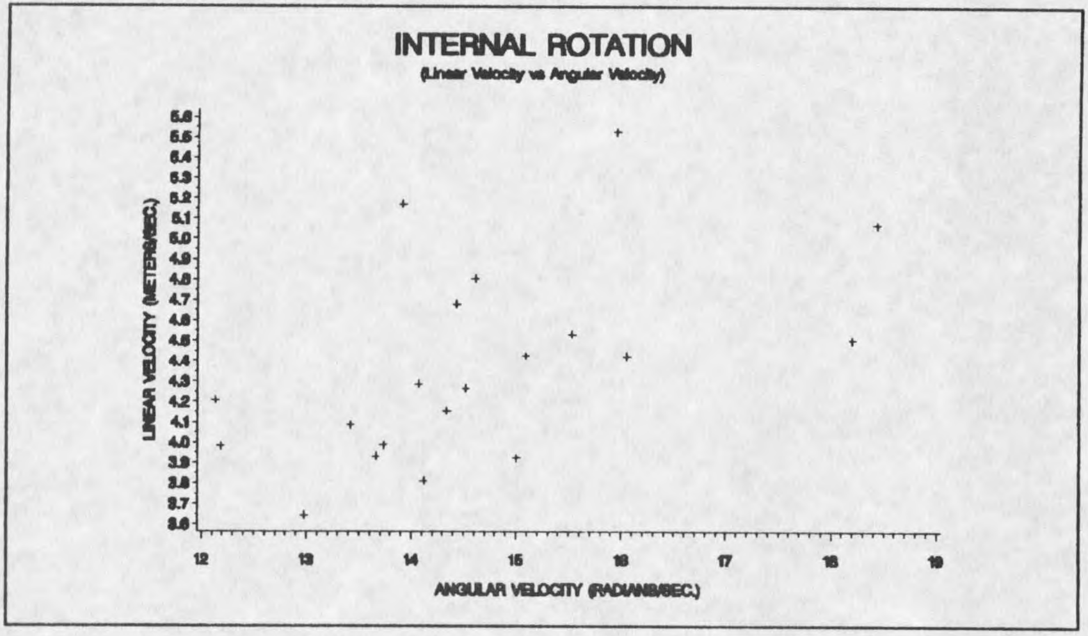


From the linear regression run on the data in Figure 12 a t-statistic value of 6.094 was obtained. This value is significant at p<.0001. A linear relationship is thus indicated between the dependent variable, the angular velocity of the wheel-axle system(internal rotation), and the independent variable, the angular velocity of the lever system(transverse flexion). An R-squared value of 0.6735 was also obtained for the data in Figure 12. Thus 67.35% of the variability in the dependent variable, the angular velocity of the wheel-axle system(internal rotation), can be explained by the independent variable, the angular velocity of the lever system(transverse flexion).

To graphically examine the linear velocity, the angular velocity, the moment, and the angular acceleration achieved by the wheel-axle system(internal rotation) and the lever system(transverse flexion) scatter plots of the linear velocity vs. angular velocity and moment vs. angular acceleration for both internal rotation and transverse flexion were produced. Figure 13 and 14 are scatter plots of linear velocity vs. angular velocity and moment vs. angular acceleration, respectively, for internal rotation. Figures 15 and 16 are scatter plots of linear velocity vs. angular velocity and moment vs. angular acceleration, respectively, for transverse flexion.

Figure 13 is a scatter plot of the linear velocity vs. the angular velocity of the wheel-axle system(internal rotation).

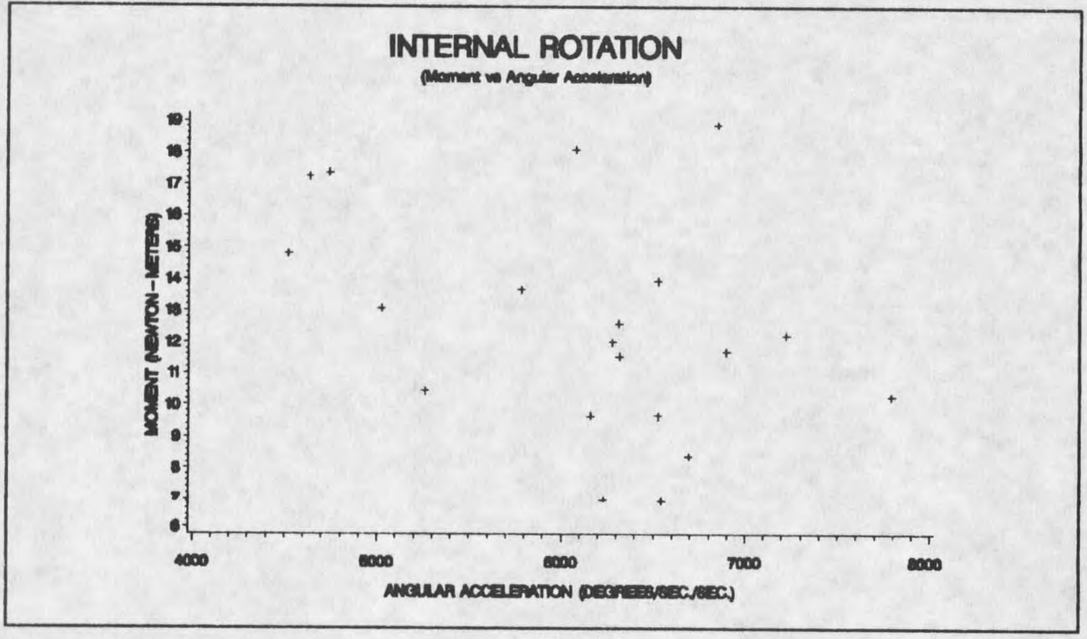
Figure 13. Scatter Plot of the Linear Velocity and the Angular Velocity of the Wheel-Axle System(Internal Rotation).



The t-statistic obtained for the data in Figure 13 was 2.695. This t-statistic value is significant at $p<.0148$. This indicates a significant relationship is present between the dependent variable, the linear velocity of the wheel-axle system and the independent variable, the angular velocity of the wheel-axle system. An R-squared value of 0.2875 was also obtained. Therefore, 28.75% of the variability in the linear velocity of the wheel-axle system can be explained by the angular velocity of the wheel-axle system.

Figure 14 is a scatter plot of the moment vs. the angular acceleration of the wheel-axle system(internal rotation).

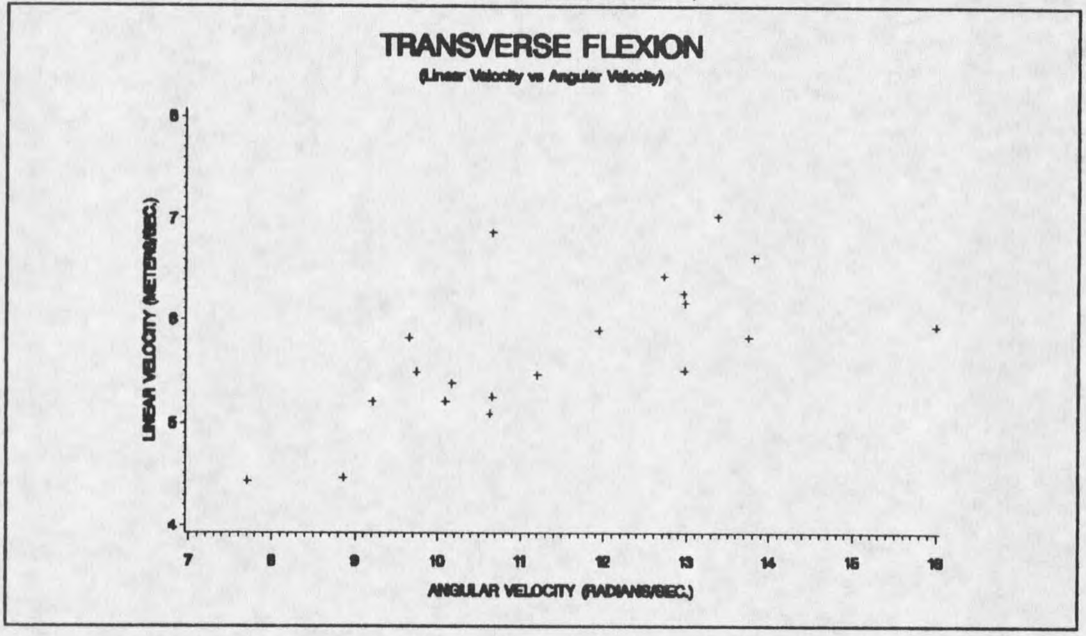
Figure 14. Scatter Plot of the Moment and the Angular Acceleration of the Wheel-Axle System(Internal Rotation).



From the linear regression determined for the data in Figure 14 a t-statistic of -1.817 was obtained and a p value of 0.0860. This t-statistic is not significant at p<.05. Thus, at a significance level of p<.05, there is not a linear relationship present between the dependent variable, the moment value of the wheel-axle system(internal rotation), and the independent variable, the angular acceleration of the wheel-axle system(internal rotation).

Figure 15 is a scatter plot of the linear velocity vs. the angular velocity of the lever system(transverse flexion).

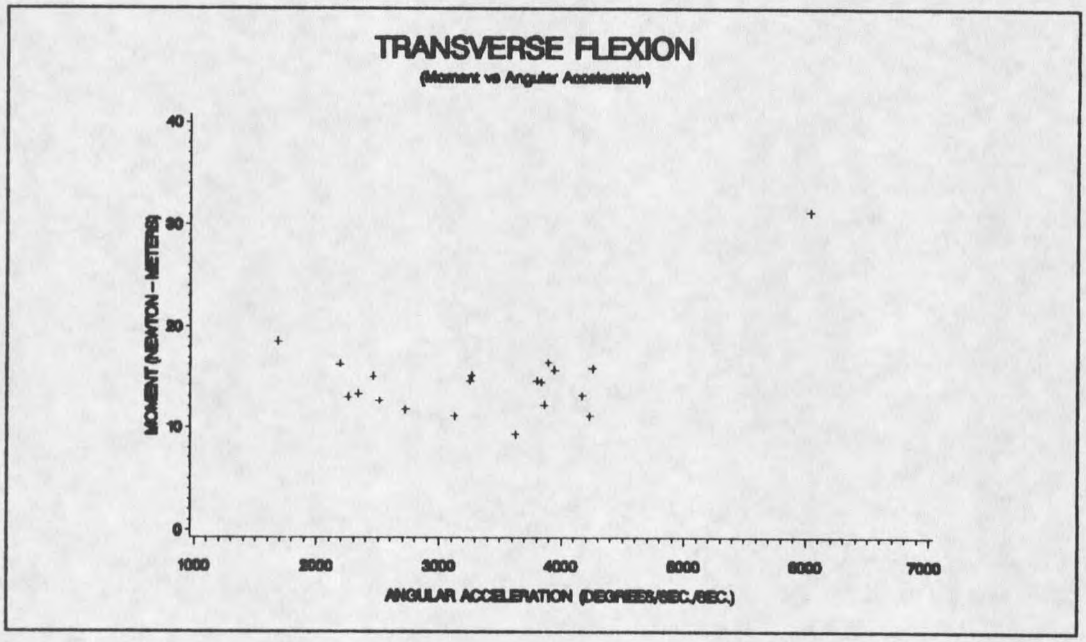
Figure 15. Scatter Plot of the Linear Velocity and the Angular Velocity of the Lever System(Transverse Flexion).



A t-statistic of 3.820 was acquired from the linear regression determined for the data in Figure 15. This value is significant at p<.0013. A relationship between the dependent variable, the linear velocity of the lever system(transverse flexion), and the independent variable, the angular velocity of the lever system(transverse flexion) is thus indicated. An R-squared value of 0.4478 was also obtained. Thus 44.78% of the variability in the dependent variable, the linear velocity of the lever system(transverse flexion), is explainable by the independent variable, the angular velocity of the lever system(transverse flexion).

Figure 16 is a scatter plot of the moment vs. the angular acceleration of the lever system(transverse flexion).

Figure 16. Scatter Plot of the Moment and the Angular Acceleration of the Lever System(Transverse Flexion).



The linear regression run on Figure 16 produced a t-statistic of 2.148. This t-statistic is significant at p<.0455. A linear relationship is thus indicated between the dependent variable and the independent variable. An R-squared value of 0.2041 was also obtained. This R-squared value indicates that 20.41% of the variability in the independent variable, the moment of the lever system(transverse flexion), can be explained by way of the independent variable, the angular acceleration of the lever system(transverse flexion).

To determine if there was a significant difference at $p<.05$ between the rotational inertia of the wheel-axle system and the lever system a paired t test was run. A paired t test was also run to determine if there was a significant difference, at $p<.05$, between the radii of rotations between the wheel-axle and lever systems. A significant difference, at $p<.05$, was found between the wheel-axle and lever systems for the rotational inertias and the radii of rotations of the two systems. The lever system had a significantly greater rotational inertia and a significantly greater radius of rotation. Table 4 shows the t values for the paired t tests run on the rotational inertias and the radii of rotations for the two systems.

Table 4. t Values from Paired t tests between the Wheel-Axle System's and the Lever System's Rotational Inertia and Radius of Rotation.

Parameter	t value	Prob < T
Rotational Inertia	25.4054626	.0001
Radius of Rotation	69.6818619	.0001

A rotational inertia ratio was calculated by dividing the calculated rotational inertia of the lever system(transverse flexion) by the calculated rotational inertia of the wheel-axle system(internal rotation). A radius of rotation ratio was calculated by dividing the radius of rotation of the lever system(transverse flexion) by the radius of rotation of the wheel-axle system(internal rotation). In order to make comparisons of the rotational inertia ratios and the radius of rotation ratios for the lever system(transverse flexion) and the wheel-axle system(internal rotation) the mean, standard deviation, and range values of the ratios were calculated and are shown in Table 5.

Table 5. Mean, Standard Deviation, and Range of Ratios for Rotational Inertia(W-A System/Lever System) and Radius of Rotation(Lever System/W-A System).

Parameter	Mean	S.D.	Range
Rotational Inertia	5.3283370	.5415783	6.224552-4.380065
Radius of Rotation	2.1128431	.0769795	2.214286-1.904762

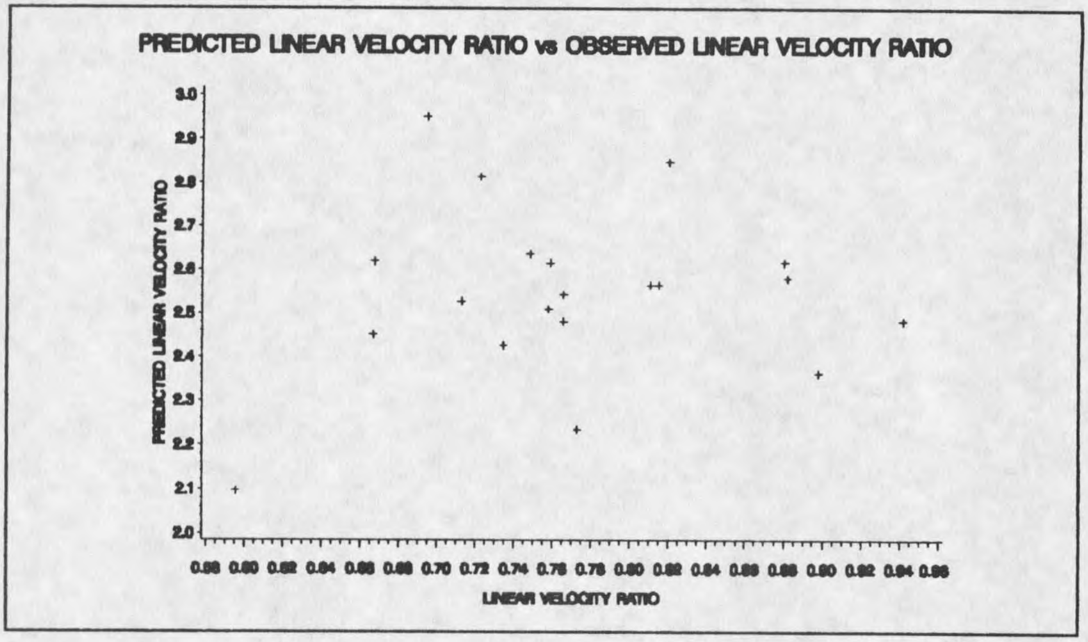
To determine if there was a significant difference, at p<.05, between the predicted linear velocities for the wheel-axle system and the lever system a paired t test was run. From this paired t test the wheel-axle system was found to have a significantly greater predicted linear velocity than the lever system. The t value from this paired t test is shown in Table 6.

Table 6. t Value from Paired t test between the Predicted Linear Velocity of the Wheel-Axle System and the Lever System.

Parameter	t value	Prob < T
Predicted Linear Velocity	30.2861252	.0001

To graphically examine if the predicted linear velocity ratio of the wheel-axle system was greater than, less than, or equal to the observed linear velocity ratio of the wheel-axle system a scatter plot was produced (Figure 17). The predicted linear velocity ratio for the wheel-axle system was calculated by using the equation: $\frac{V(wa)}{V(l)} = \frac{r(wa)\omega(wa)}{r(l)\omega(l)}$, where wa represents the wheel-axle system, and l represents the lever system; and V = Linear Velocity, r = radius of rotation, and ω = angular velocity as determined from the rotational inertia. The observed linear velocity ratio for the wheel-axle system, or the advantage the wheel-axle system would have over the lever system in terms of linear velocity, was calculated by dividing the maximum linear velocity of the end point of the wheel-axle system(internal rotation) by the maximum linear velocity of the end point of the lever system(transverse flexion). The observed linear velocity values were obtained from the film data.

Figure 17. Scatter Plot of the Predicted Linear Velocity Ratio and the Observed Linear Velocity Ratio.

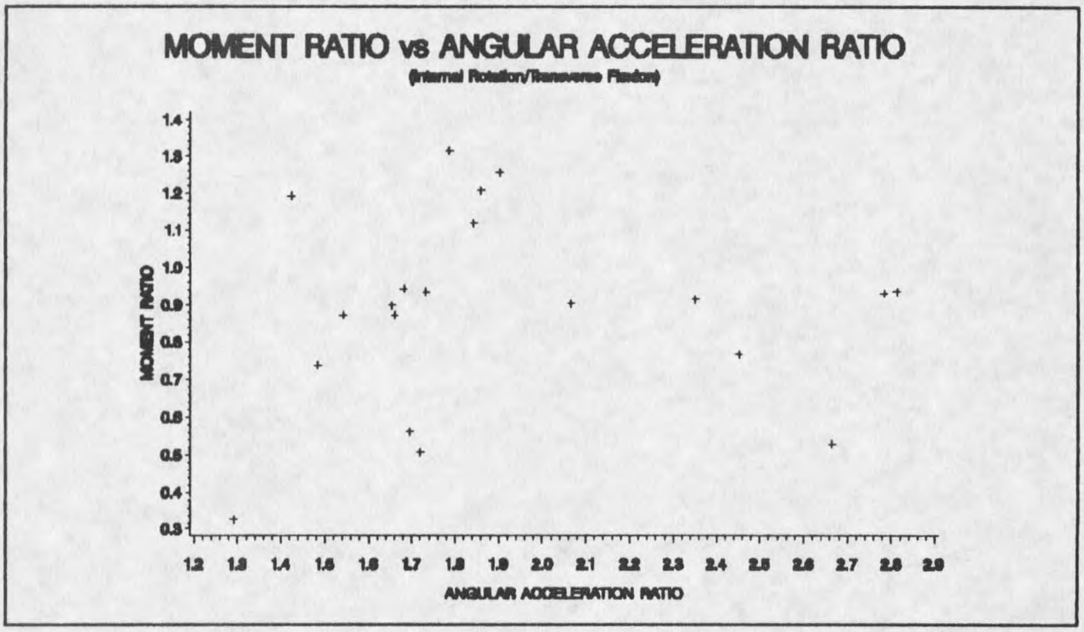


The linear regression equation determined from the data in Figure 17 produced a t-statistic of 0.447. This t-statistic is significant at $p<.6601$. Thus, a significant linear relationship between the dependent variable, the predicted linear velocity ratio, and the independent variable, the observed linear velocity ratio, was not present at $p<.05$. An R-squared value of .0110 was also determined. Thus, only 1.10% of the variability in the predicted linear velocity ratio could be explained by the observed linear velocity ratio.

Figure 18 is a scatter plot in which the moment ratios are placed on the vertical axis and the angular acceleration ratios are placed on the horizontal axis.

Each ratio was calculated by dividing the value obtained for internal rotation by the value obtained for transverse flexion(Figure 18).

Figure 18. Scatter Plot of the Moment Ratio and the Angular Acceleration Ratio.

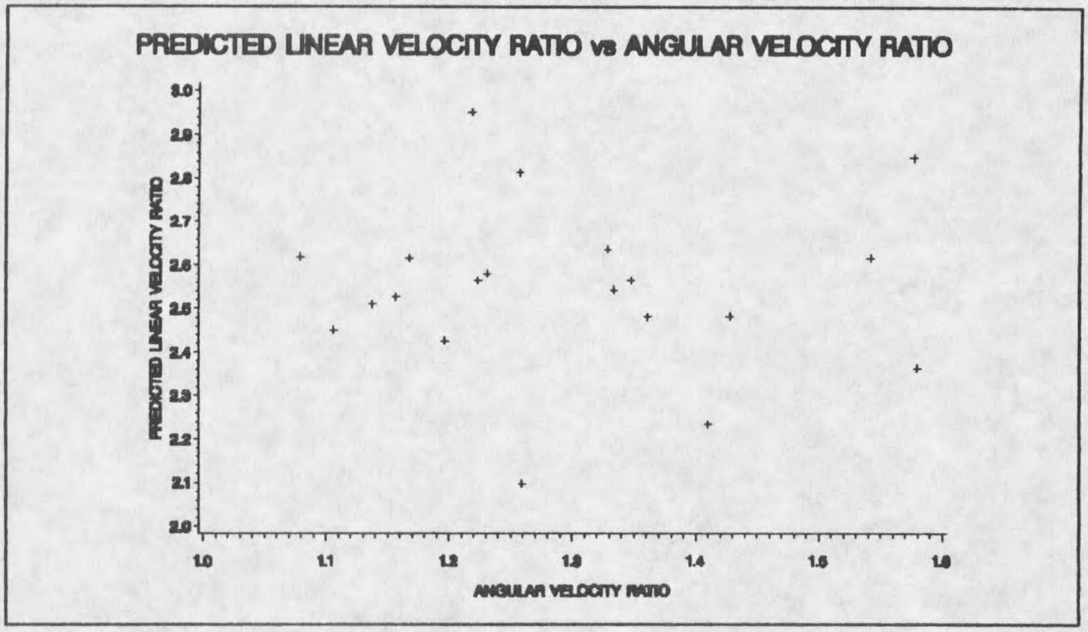


A t-statistic of .119 was obtained from the linear regression fitted to the data in Figure 18. This t-statistic is significant at p<.9069. Thus, a significant linear relationship was not present between the dependent variable, the moment ratio, and the independent variable, the angular acceleration ratio. An R-squared value of .0008 was also obtained. Thus, only .08% of the variability in the moment ratio can be explained by the angular acceleration ratio.

From this scatter plot it can be seen that the moment ratios are not equal. For the moments to have been equal a horizontal line at the moment ratio value of 1 should have been present. Furthermore, it can be seen that except for five observations the moment value of the lever system was larger than that of the wheel-axle system. Moreover, from this scatter plot it is possible to visualize that although the rotational inertia of the lever system is approximately five times greater than the wheel-axle system(Table 4), the angular acceleration ratio was not five times as great for the wheel-axle system. The maximum angular acceleration ratio was 2.82 times greater for the wheel-axle system.

Figure 19 is a scatter plot of the ratios for the predicted linear velocity and the angular velocity. The horizontal axis represents the predicted linear velocity ratio and the vertical axis represents the angular velocity ratio. The predicted linear velocity ratio was calculated by using the equation: $\frac{V(wa)}{V(l)} = \frac{r(wa)\omega(wa)}{r(l)\omega(l)}$, where wa represents the wheel-axle system and l represents the lever system; V = linear velocity, r = the radius of rotation, and ω = angular velocity as determined from the rotational inertia.

Figure 19. Scatter Plot of the Predicted Linear Velocity Ratio and the Angular Velocity Ratio.

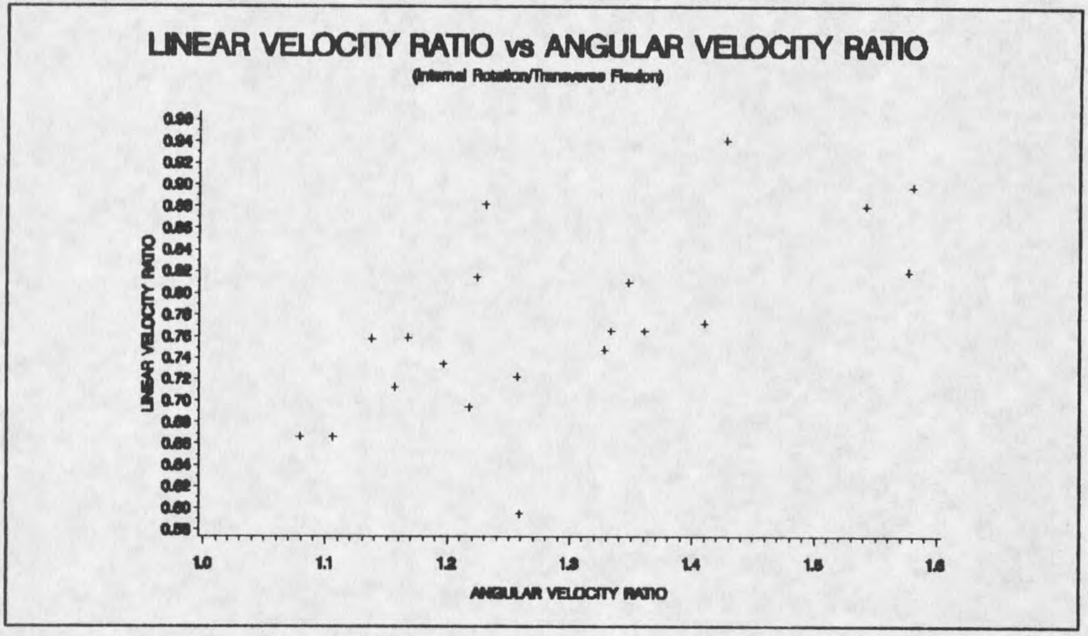


The linear regression run on Figure 19 produced a t-statistic of 0.075. This t-statistic is significant at p<.9413. A linear relationship, which was not significant at p<.05, was thus found to exist between the dependent variable and the independent variable. An R-squared value of 0.0003 was also obtained. Thus, .03% of the variability in the dependent variable, the predicted linear velocity ratio, can be explained by the independent variable, the angular velocity ratio.

From Table 5, it can be seen that the radius of rotation for the wheel-axle system is approximately one half that of the lever system and the rotational inertia of the lever system is approximately five times greater than the wheel-axle system, thus the linear velocity of the wheel-axle system should be about two and one half times greater than the lever system. The angular velocity ratio for the wheel-axle system, which would be needed to obtain the predicted linear velocity value of 2.5 times that of the lever system, and the radius of rotation of the wheel-axle system being one half that of the lever system, should be approximately five times that of the lever system. It can be seen, when referring to Figure 19, that the maximum angular velocity ratio for all the subjects for the wheel-axle system is 1.58 times that of the lever system and doesn't correspond with the values that are needed to obtain the predicted linear velocity values of the wheel-axle system.

To further examine the linear velocity and angular velocity achieved by the wheel-axle system(internal rotation) and the lever system(transverse flexion) a scatter plot consisting of two ratios for these parameters was created(Figure 20). Represented on the vertical axis in Figure 20 is a ratio consisting of the linear velocity while the ratio of the angular velocity is represented on the horizontal axis. Both ratios were calculated by dividing the value of the wheel-axle system by the value of the lever system.

Figure 20. Scatter Plot of the Linear Velocity Ratio and the Angular Velocity Ratio.



A t-statistic of 3.673 was acquired from the linear regression run on the data for Figure 20. This value is significant at $p<.0017$. A significant linear relationship is thus present between the dependent and the independent variables. An R-squared value of 0.4284 was also obtained. Therefore, 42.84% of the variability of the dependent variable, the linear velocity ratio, can be explained by the independent variable, the angular velocity ratio.

From Table 5, it can be seen that the radius of rotation for the wheel-axle system is approximately one half that of the lever system and the rotational inertia of the lever system is approximately five times greater than the wheel-axle system. Thus, from the predicted calculations, the linear velocity of the wheel-axle system should be about two and one half times greater than the lever system. It can be seen, when referring to Figure 20, that the maximum angular velocity ratio for all the subjects for the wheel-axle system is 1.58 times that of the lever system. This does not agree with the angular velocity ratio that should be achieved by the wheel-axle system as determined from the rotational inertia calculations. Furthermore, from Figure 20, it can be seen that the linear velocity ratio does not achieve a value greater than 0.95. Thus the wheel-axle system did not achieve a two and one half times greater linear velocity than the lever system.

The following table, Table 7, consists of the means, standard deviations, and ranges of the time it took the end point of the wheel-axle system(internal rotation) and the lever system(transverse flexion) to achieve maximum linear velocity.

Table 7. Mean, Standard Deviation, and Range of Time Until Maximum Linear Velocity of the End Point of the Wheel-Axle System(Internal Rotation) and Lever System(Transverse Flexion).

System	Mean(sec.)	S.D.(sec.)	Range(sec.)
Wheel-Axle	.1737500	.0348635	.250-.125
Lever	.2712500	.0514750	.400-.200

To determine if there was a significant difference, at p<.05, on the average time it took the end point of each system to achieve maximum linear velocity, a paired t test was run . Table 8 gives the t value that was obtained from this paired t test.

Table 8. t Value from Paired t test on Time to Maximum End Point Linear Velocity for the Wheel-Axle System(Internal Rotation) and the Lever System(Transverse Flexion).

Parameter	System	t value	Prob < T
Time Difference	W-A - Lever	9.0997339	.0001

A significant difference at p<.0001 was thus found between the average time it took the end point of each system to achieve maximum linear velocity. The lever system was the system that took the longer time to achieve maximum linear velocity. Thus, it took longer for the lever system to achieve a maximum linear velocity that was significantly greater than the maximum linear velocity achieved by the wheel-axle system.

Kinetics

The mean, standard deviation, and range for the force, while the subjects were executing the isometric contraction, and the maximum moment value, as determined from the kinematic data, are presented in Table 9.

Table 9. Mean, Standard Deviation, and Range of Force and Moment Values Obtained for the Wheel-Axle System(Internal Rotation) and the Lever System(Transverse Flexion).

Parameter	System	Mean	S.D.	Range
Force(Kilograms)	W-A	14.1765	4.014875	22.46-8.50
	Lever	13.1665	3.331803	20.34-8.50
Moment(Meter-Newtons)	W-A	12.4755	3.510149	18.88-6.83
	Lever	14.7140	4.467962	31.23-9.32

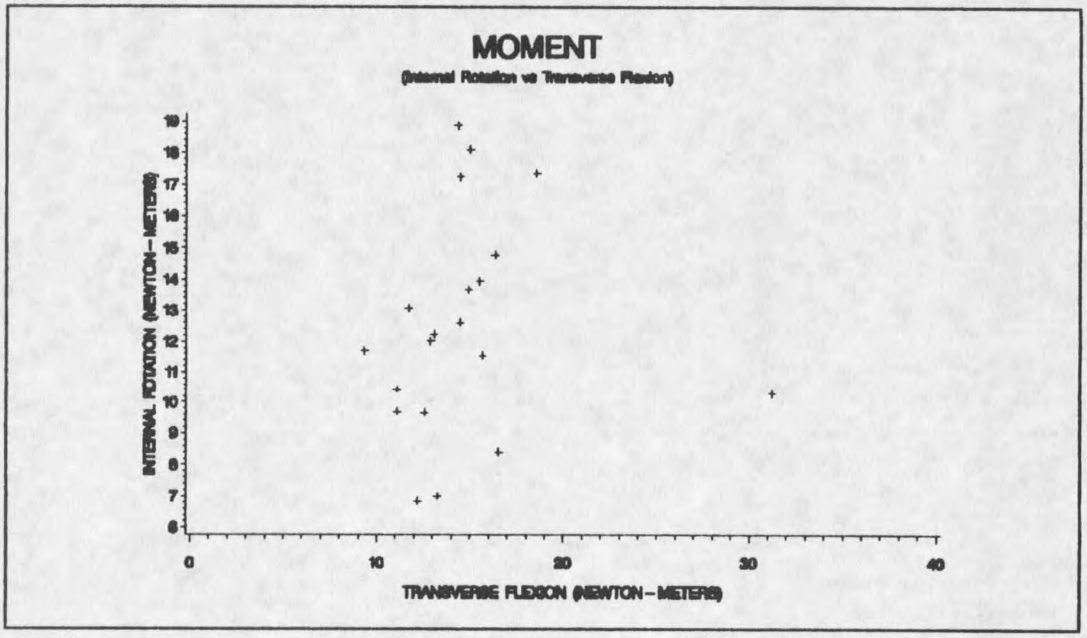
To determine if there was a significant difference, at p<.05, between the force and kinematic moment values a paired t test was executed. At 19 degrees of freedom, a t value of 2.093 or greater needed to have been obtained for a significant difference to have existed. The t values obtained from the paired t test run on the force and moment values were 1.4982077 and 1.2133441 respectively. A significant difference, at p<.05, thus was not present for either the force or the kinematic moment values between the two systems. The t values obtained from the paired t tests run on the force and kinematic moment values between the wheel-axle system and lever system are shown in Table 10.

Table 10. t Values from Paired t tests of Force and Moment Values for the Wheel-Axle and Lever Systems.

Parameter	System	t value	Prob < T
Force	W-A - Lever	1.4982077	.2637
Moment	W-A - Lever	1.8449013	.0807

To graphically examine the kinematic moment values from internal rotation and transverse flexion, a scatter plot was created(Figure 21). The vertical axis represents the kinematic moment values for internal rotation; the kinematic moment values for transverse flexion are represented on the horizontal axis.

Figure 21. Scatter Plot of the Moment of the Wheel-Axle System(Internal Rotation) and the Lever System(Transverse Flexion).



From the linear regression executed on the data in Figure 21 a t-statistic of 0.386 was determined. This value is significant at p<.7042. Thus, a significant linear relationship was not present at p<.05. An R-squared value of .0082 was also determined. The variability in the dependent variable, the moment present for the wheel-axle system(internal rotation), that can be explained by the independent variable, the moment present for the lever system(transverse flexion), is .82%.

Table 11 has the mean, standard deviation, and range of the twenty subjects for the output voltages of the muscles examined during the first and second half of the total time for internal rotation(wheel-axle system) and transverse flexion(lever system). These muscles were the anterior deltoid and pectoralis major for internal rotation(wheel-axle system) and the latissimus dorsi and pectoralis major for transverse flexion(lever system). The voltage output levels are given for the first and second half of the total time of the motions and are in microvolts.

Table 11. Mean, Standard Deviation, and Range in Microvolts of the Anterior Deltoid and Pectoralis Major(W-A System) and Latissimus Dorsi and Pectoralis Major(Lever System).

Wheel-Axle System

Latissimus Dorsi

Movement	Mean	S.D.	Range
1st	2460.19	1097.87	5024.38-201.09
2nd	1644.32	1023.89	4024.30-479.62

Pectoralis Major

Movement	Mean	S.D.	Range
1st	502.428	247.9015343	1042.98-188.72
2nd	368.465	190.2900171	836.65-151.50

Lever System

Anterior Deltoid

Movement	Mean	S.D.	Range
1st	375.9555	233.3821227	854.98-99.66
2nd	206.1865	114.2985131	467.42-58.68

Pectoralis Major

Movement	Mean	S.D.	Range
1st	1644.26	692.5016572	3967.26-969.44
2nd	1371.31	648.9943018	2823.70-601.46

To statistically examine the EMG data, several paired t tests were done. Separate paired t tests were performed on the voltage differences between the two halves of the motion examined for each muscle in the system. This was performed to determine if there was a significant difference in the voltages between each part of the movement for each muscle. Table 12 shows the paired t values obtained on the measured level of electrical activity between the first and second half of the motion for each muscle examined in the wheel-axle and lever systems. A t value of 2.093 or greater, at $p<.05$, determined a significant difference.

Table 12. t Values from Paired t test on Electrical Activity for First and Second Half of Motion for Muscles Examined in the Wheel-Axle System(Internal Rotation) and the Lever System(Transverse Flexion).

	Wheel-Axle System		
Muscle	Motion	t value	Prob < T
Latissimus Dorsi	1st - 2nd	3.7216605	.0014
Pectoralis Major	1st - 2nd	2.2590770	.0358
	Lever System		
Muscle	Motion	t value	Prob < T
Anterior Deltoid	1st - 2nd	3.6002635	.0019
Pectoralis Major	1st - 2nd	1.3109380	.2055

The paired t tests showed that there was a significant difference, at $p<.05$, for the electrical activity between the first half and second half of the motion for the latissimus dorsi and pectoralis major in the wheel-axle system and the anterior deltoid in the lever system. There was no significant difference for the electrical activity between the first half and second half of motion for the pectoralis major in the lever system.

The pectoralis major muscle was the only one measured during the movements of both systems. To determine if the measured electrical activity of the pectoralis major was significantly different, at p<.05, between the wheel-axle and lever systems for the first half of each motion and the second half of each motion two separate paired t test were done. Table 13 gives the t values from the paired t tests that compared the electrical activity of the pectoralis major during the first half of internal rotation and the first half of transverse flexion, and the second half of internal rotation and the second half of transverse flexion.

Table 13. t Values from Paired t tests between the Electrical Activity of the Pectoralis Major During the First Half of Internal Rotation(W-A) and the First Half of Transverse Flexion(Lever), and the Second Half of Internal Rotation(W-A) and the Second Half of Transverse Flexion(Lever).

Muscle	Motion	t value	Prob < T
Pectoralis Major	1st W-A - 1st Lever	7.6945655	.0001
	2nd W-A - 2nd Lever	6.2689910	.0001

A significant difference, at p<.0001, was found between the electrical activity of the pectoralis major during the first half of internal rotation and the first half of transverse flexion, and the second half of internal rotation and the second half of transverse flexion. The electrical activity of the pectoralis major during both the first half and the second half of transverse flexion was larger than the electrical activity of the pectoralis major during the first half and the second half of internal rotation.

The percent of maximum contraction that was achieved for the pectoralis major in the wheel-axle system(internal rotation) and lever the system(transverse flexion) was also examined. Table 14 gives the mean, standard deviation, and range values for the percent of maximum contraction that occurred for the pectoralis major and the latissimus dorsi in the wheel-axle(internal rotation) system and the pectoralis major and the anterior deltiod in the lever(transverse flexion) system.

Table 14. Mean, Standard Deviation, and Range of Values for Percent of Maximum Contraction for the Pectoralis Major and the Latissimus Dorsi in the Wheel-Axle System(Internal Rotation) and the Pectoralis Major and the Anterior Deltoid in the Lever System(Transverse Flexion).

	Wheel-Axle System		
Muscle	Mean	S.D.	Range
Pectoralis Major	204.25	498.5286641	2289.00 - 7.00
Latissimus Dorsi	3058.95	12328.4000000	55348.00 - 40.00
	Lever System		
Muscle	Mean	S.D.	Range
Pectoralis Major	1452.30	4615.960	20025.00 - 61.00
Anterior Deltoid	5230.00	1145.550	5230.00 - 42.00

To determine if there was a significant difference, at p<.05, between the percent of maximum contraction that occurred for the pectoralis major in the wheel-axle system(internal rotation) and the lever system(transverse flexion) a paired t test was done. No significant difference was found at p<.05 when analyzing the mean percent of maximum contraction that was present for the pectoralis major in the wheel-axle(internal rotation) and the lever system(transverse flexion). Table 15 gives the t value from this paired t test.

Table 15. t Value from Paired t test on Percent of Maximum Contraction for the Pectoralis Major between the Wheel-Axle System(Internal Rotation) and the Lever System(Transverse Flexion).

Muscle	Variable	t value	Prob < T
Pectoralis Major	%Max.W-A - %Max.Lever	1.3508841	.1926

Several factors may influence the linear velocity the end point of a system is able to achieve. These factors include the radius of rotation, the angular velocity, the angular acceleration, the torque, the rotational inertia, the force applied by the muscles in each system and the electrical activity of the muscles. Thus when determining why the endpoint linear velocity of one system is not equal to that of another system it is important to examine the individual parameters of a system, because a system which has an advantage over another other system, in terms of one parameter, may also have a disadvantage when examining a different parameter.

CHAPTER 5

DISCUSSION

It was the purpose of this study to determine if a kinetic link model for the upper limb used as a wheel-axle system and the upper limb used as a lever system predicted the relationship between the end point linear velocities produced by the two systems and to determine if there was a significant difference between the linear velocities produced at the end points of segmental links acting in a wheel-axle and a lever configuration. The results of this study indicated that there was a significant difference ($p<.001$) between the linear velocity of the end point of the upper extremity configured as a lever system(transverse flexion) and the upper extremity configured as a wheel-axle system(internal rotation). To understand why there was a significant linear velocity difference between the lever system and the wheel-axle system, and to examine whether or not the kinetic link model predicted the relationship between the linear velocities produced by the two systems several parameters were examined.

The lever system was calculated to have a two times larger radius of rotation. However, if the torque produced by the muscles involved with each system are equal, then the wheel-axle system has the capability of achieving five times the angular acceleration of the lever system, because theoretically, the wheel-axle has a five times smaller rotational inertia (Kreighbaum & Barthels, 1991).

A non dimensional relationship was expressed by considering the equation $V=r\omega$, where $r=1/2$ and $\omega=5/1$. This equation shows that if the angular velocity of the wheel-axle system is five times greater than that of the lever system and the torque in each system is equal, the wheel-axle system is capable of obtaining a linear velocity which is two and a half times larger than the linear velocity of the lever system(Kreighbaum & Barthels, 1991 pp. 612-614).

When examining the mean values for the rotational inertia and radius of rotation from the subjects in this study, the wheel-axle system had approximately a five times smaller rotational inertia and the lever system had approximately a two times larger radius of rotation. From these values the linear velocity of the wheel-axle system was hypothesized to be slightly more than two and one half times greater than that of the lever system. However, the findings of this study did not support this theory. In order to further investigate this problem other parameters were analyzed.

Two other parameters that influence the end point linear velocity are the torques applied by the muscles in each system and the resulting angular accelerations of the systems. The equation α=T/I, where α=angular acceleration, T=torque, and I=rotational inertia, demonstrates that a larger angular acceleration will be present for a system that has a smaller rotational inertia if the torque on both systems is equal.

The rotational inertia of the arm acting in a wheel-axle system(internal rotation) has approximately a five times smaller rotational inertia than the arm acting in a lever system(transverse flexion) as the wheel-axle and lever systems were defined for this study. Thus, the angular acceleration of the wheel-axle system should be about five times larger if the torques in the two systems are equal. In this study, the maximum angular acceleration value for the wheel-axle system was significantly larger than the maximum angular acceleration for the lever system. The maximum angular acceleration of the wheel-axle system was thus approximately two times the maximum angular acceleration of the lever system.

To further investigate the differences between the angular accelerations, the kinematic moment values were examined. The torque producing capabilities of the muscles used in the lever-type movement were greater than those in the wheel-axle-type movement, but they were not significantly greater. However, although the mean torque value, as calculated from the kinematics, for the lever system was larger than the torque value for the wheel-axle system, it is difficult to determine if it was large enough to account for the significantly larger linear velocity of the lever system. The kinematic moments were determined through the process of inverse dynamics.

From the moment ratios for the two systems and the angular acceleration ratios, it was seen that for fifteen of the twenty subjects, the maximum torque measured for the wheel-axle system was less than that for the lever system. Moreover, the angular acceleration of the wheel-axle system achieved a value greater than 2.5 times the angular acceleration of the lever system for only three of the twenty subjects. Furthermore, remembering that the torque values that were based on kinematic data were not significantly different at $p<.05$ and that the wheel-axle system should achieve a five times greater angular acceleration, the angular acceleration of the wheel-axle system should have been approximately five times greater than that of the lever system. Therefore, if the torque measurements were accurate, the angular acceleration achieved by each system should have been approximately equal. The force produced by the musculature in each system, during an isometric contraction and measured via a force transducer, offered some insight on this dilemma.

With the maximum angular acceleration of the wheel-axle system being approximately two times larger than that of the lever system, the angular velocity of the wheel-axle system should be larger than the angular velocity of the lever system. The mean angular velocity of the wheel-axle system was significantly greater than that of the lever system. It was theortized that the smaller rotational inertia of the wheel-axle system should allow a five times larger angular acceleration to be present and result in the linear velocity of the wheel-axle system being two and one half times that of the lever system. However, when examining the mean angular velocities of each system, the angular velocity of the wheel-axle system(internal rotation) was not two and one half times greater than that of the lever system(transverse flexion).

When examining if the nondimensional value for the predicted linear velocity of the wheel-axle system was equal to the observed linear velocity ratio for the wheel-axle system it can be seen that the advantage the wheel-axle system should have over the lever system is much greater than the value that was obtained. That is, from the predicted linear velocity ratio, the wheel-axle system should have on the average a 2.5 times greater linear velocity. However, after dividing the linear velocity of the wheel-axle system(internal rotation) by the linear velocity of the lever system(transverse flexion), the linear velocity of the wheel-axle system was never greater than the linear velocity of the lever system for any of the subjects.

Upon examination of the time it took each system to reach maximum linear velocity, it was found that there was a significant difference ($p<.05$) between the two systems. The wheel-axle system(internal rotation) achieved its maximum linear velocity earlier than that of the lever system(transverse flexion). It was found that the end point linear velocity of the lever system(transverse flexion) was significantly greater than the end point linear velocity of the wheel-axle system(internal rotation). However, while the wheel-axle system did not have the larger end point linear velocity, it did achieve its maximum linear velocity earlier than that of the lever system.

From the data on the time it took each system to achieve maximum linear velocity, a force-velocity relationship may have been influential. With the wheel-axle system achieving maximum linear velocity earlier than the lever system, and the lever system having a larger rotational inertia, it may be that the muscles acting to produce internal rotation are shortening at a rate that is too fast for them to supply any additional force. If the muscles acting to accelerate the upper extremity when it is configured as a wheel-axle type system are able to accelerate the mass such that they are not able to supply a greater force to further accelerate the extremity, the velocity the extremity is able to achieve is limited. Therefore, the lever type system may achieve a larger linear velocity because the muscles can supply a net force longer and are thus able to continue to accelerate the extremity. The muscles acting in the lever configuration to produce transverse flexion may be able to supply force to the system for a longer time, whereby a larger linear velocity for the end point of the lever system is obtained.

The paired t test on the maximum isometric force measurements of the two systems did not result in a significant difference being present. One may conclude that the systems are equal in terms of the force that each is capable of exerting during a maximal isometric contraction.

One explanation for why the mean torque value of the lever system was larger than that of the wheel-axle system and that the force measurements were not different is that the subjects may have incorporated other muscles than those tested to internally rotate the humerus while performing the maximal isometric contraction for internal rotation. The anterior deltoid and the latissimus dorsi demonstrated significantly different levels of activity for the two halves of the motion. From the mean voltage measurements, it was determined that the anterior deltoid in the wheel-axle system and the latissimus dorsi in the lever system had larger levels of activity during the first portion of internal rotation and transverse flexion. This suggests that these two muscles were recruited less during the second portion of the movement. However, when examining the data for the pectoralis major as it was used in both systems, a significant difference was not found between the voltages for the two parts of the movement for the lever system but there was a significant difference for the pectoralis major in the wheel-axle system. Thus, the pectoralis major had a smaller amount of electrical activity present when active in the wheel-axle movement than in the lever movement.

When examining the mean voltage values of the muscles for each part of the specified movement, it was determined that all the mean voltage values were smaller for the second half of the movement. However, as stated previously, the mean voltage values for the first half and second half of the anterior deltoid and the pectoralis major in the wheel-axle system and the latissimus dorsi in the lever system were significantly different. One reason why the anterior deltoid in the lever system and the latissimus dorsi and the pectoralis major in the wheel-axle system may have demonstrated significantly less activity during the second half of transverse flexion and internal rotation is that these muscles may have been recruited less to allow for deceleration of each system by way of reciprocal inhibition. The antagonistic muscles, those that oppose transverse flexion and internal rotation, may have been recruited to begin deceleration of each system with the internal rotation antagonists being recruited less because of reciprocal inhibition. This may also be the case with the decrease in activity of the pectoralis major in the lever system, but the difference was not great enough to be significant.

Furthermore, the results from a paired t test on the difference between the first and second half of the movement time for the pectoralis major in the lever system did not result in a significant difference being present. With the mean voltages for the pectoralis major being larger for both halves of transverse flexion than for internal rotation, it may be inferred that by way of recruitment, the pectoralis major is more active when transversely flexing the humerus than internally rotating it.

The two paired t tests to determine if there was a significant difference between the electrical activity of the pectoralis major for the first half of internal rotation and transverse flexion and the second half of internal rotation and transverse flexion further supported the thought that the pectoralis major was more active while transversely flexing the humerus than internally rotating it. Both t tests revealed a significant difference between the electrical activity of the pectoralis major during the first and second half of each motion. These results further support the notion that the pectoralis major demonstrated more recruitment activity while transversely flexing the humerus than while internally rotating the humerus.

The paired t test between the percent of maximum contraction that occurred for the pectoralis major in the wheel-axle system(internal rotation) and the lever system(transverse flexion) found no significant difference between the two conditions. From the t test between these two percentages, it was shown that the pectoralis major was not significantly more active in terms of percentages for one system than the other. Thus, in terms of percent of maximum contraction, the pectoralis major demonstrated similar levels of activity within each system.

CHAPTER 6

CONCLUSIONS

The following chapter is divided into three areas: (1) Summary, (2) Conclusions, and (3) Recommendations.

Summary

Kinematic and kinetic data for the wheel-axle and lever configurations were gathered by videography, electromyography, electrogoniometry, and a force transducer. Independent variables examined were; the angular velocity, the radius of rotation, the angular acceleration, the torque, and the rotational inertia of each system. Electromyographic data for three muscles; the anterior deltoid, the latissimus dorsi, and the pectoralis major were also examined, as was an isometric force measurement for each system.

The paired t test was the statistical tool used to analyze the data between the two motions examined in this study. Regression analysis was used to determine if a linear relationship was present between the data.

Based on the results of this study, the null hypothesis for the first hypothesis was accepted; the kinetic link model for the upper limb as a wheel-axle system and the upper limb as a lever system does not predict the relationship between the end point linear velocities produced by the two systems. The null hypothesis for the second hypothesis was rejected; there was a significant difference between the linear velocities produced at the end points of the segmental links acting in a wheel-axle and a lever configuration. A significant difference was found between the end point linear velocities of the wheel-axle and lever configurations.

Conclusions

With the end point of the wheel-axle system reaching maximum linear velocity earlier than the end point of the lever system, and the lever system having a significantly greater linear velocity, a force-velocity relationship may have influenced the results of this study. The wheel-axle system has a smaller rotational inertia. The muscles that acted to produce internal rotation may not have been able to contract fast enough to continue accelerating a system with a small inertial resistance. The maximum linear velocity of the wheel-axle system occurred sooner and peaked at a smaller value than the lever system. If a resistance such as a racket were placed in the hand, the muscles acting to produce internal rotation may act to accelerate the wheel-axle system over a longer time and through a greater range of motion which would result in a greater end point linear velocity.

Recommendations

The following are recommendations for further studies.

1. Conduct a similar study in which the force-velocity relationship is examined.
2. Conduct a similar study in which resistance is an independent variable.
3. Conduct a similar study using a 3-D Videographic Analysis System.
4. Conduct a similar study with force measurements being taken at 30 degree intervals while the subjects perform maximum isometric contractions.

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APPENDICES

APPENDIX A

SUBJECT CONSENT FORM

SUBJECT CONSENT FORM
FOR
PARTICIPATION IN HUMAN RESEARCH
MONTANA STATE UNIVERSITY

You are being asked to participate in a study to help determine if the wheel & axle system or the lever system produces the larger linear velocity of the end point of the system. The amount of electrical activity that can be detected from some of the muscles that produce the motions of the wheel & axle and lever systems will also be measured. The results of this study may help prove or disprove the hypothesis that the wheel & axle system allows for a larger end-point linear velocity to be achieved and that it may lead to changes in the way performers execute overarm throwlike motions so that they may be more successful. You have been identified as a subject based on your gender and your age.

If you agree to participate in this study you will be asked to perform internal rotation and transverse flexion about the shoulder while being videoed. You will also be asked to execute these same motions with surface electrodes attached so that the electrical activity of these muscles can be measured. Furthermore, you will be asked to remove your shirt for both procedures, and you will also be asked to state your weight. The total time for these procedures should take three hours.

Before beginning the videoing, six points of interest which include: the head of the ulna, the lateral epicondyle, the olecranon process, the greater tubercle of humerus, the iliac, and the greater trochanter of femur, will be identified by placing a red dot on them. At another date, which will be scheduled with your acceptance, you will be asked to perform transverse flexion and internal rotation from the same positions as with the videoing but with surface electrodes positioned on two muscles for each system and with an electrogoniometer positioned at the axis of rotation for transverse flexion and internal rotation. The final procedure you will be asked to execute is a graded static contraction against resistance at positions where your muscles demonstrated the most activity as detected by the surface electrodes and the electrogoniometer. Surface electrodes will be used to detect the electrical activity of the muscles during these static contractions. A surface electrode is a conductive piece of metal, which is approximately the size of a penny, that is attached to a lead wire which goes to an amplifier. The electrodes will be attached through the use of adhesive tape. Surface electrodes detect the electricity that is given off by your muscles when they are active. An electrogoniometer is an instrument that has two long narrow arms which rotate about an axis. This instrument records the position of the joint throughout a movement by relaying an electrical signal to a computer. The arms will be attached to you via velcro straps and\or tape such that the axis of the electrogoniometer is aligned with the axis of rotation for the system that is being examined.

The risks on your health may include a ligament or tendon strain. However, the chance of obtaining one of these injuries is minimal due to the fact you are not going to perform these movements against any more resistance other than that which is supplied by the system(arm, forearm, and hand) and that the isometric contraction will be slow and graded. Minimal discomfort may be experienced because the positioning of your arm may be one that you have not experienced before. However, it will not be painful and there should not be any discomfort after the testing procedure. The testing procedures will require approximately two separate appointments of which each will last about one hour. This study is of relatively no benefit to you. If you decline to participate another subject will be identified. There is no source of funding for this project and it is of no cost to you other than your time. You are encouraged to ask any questions you have before or during the procedures of this research.

YOUR INVESTIGATOR WILL TREAT YOUR IDENTITY WITH PROFESSIONAL STANDARDS OF CONFIDENTIALITY. THE INFORMATION OBTAINED IN THIS STUDY MAY BE PUBLISHED IN MEDICAL JOURNALS, BUT YOUR IDENTITY WILL NOT BE REVEALED.

NON-SUPPORTED RESEARCH

In the event your participation in this research directly results in injury to you, medical treatment consisting of first aid will be available but there is no compensation for such injury available. Further information about this treatment may be obtained by calling Rob Higgs at 587-5288.

AUTHORIZATION: I have read the above and understand the discomforts, inconvenience and risk of this study. I, ____, agree to participate in the research. I understand that I may later refuse to participate or that I may withdraw from the study at any time. I have received a copy of this consent form for my own records.

Signed____

Witness____

Investigator______________________________________

Date______________________________

APPENDIX B

PREDICTED CACULATIONS

PREDICTED CALCULATIONS

Subject #________ R L Age__________

Weight ________lbs. x 4.45 = ____________ Newtons
Height ________in. x .0245 = ____________ meters

Segment Lengths(from placement of dots)

lever - upper arm ________ in. x .0245 = ________m
forearm ________ in. x .0245 = ________m
hand ________ in. x .0245 = ________m

wa - forearm ________ in. x .0245 = ________m
hand ________ in. x .0245 = ________m

Mass of Segments

upper arm = $\frac{\text{\_\_\_\_\_\_\_\_ lbs.}}{2.205}$ x (.0325) =__________ kg
forearm = $\frac{\text{\_\_\_\_\_\_\_\_ lbs.}}{2.205}$ x (.0187) =__________ kg
hand = $\frac{\text{\_\_\_\_\_\_\_\_ lbs.}}{2.205}$ x (.0065) =__________ kg

Center of Gravity Location for each Segment (from proximal end)

Lever
upper arm = ________m (.436) = _________m

forearm = ________m (.43) = _________m

hand = ________m (.468) = _________m

W-A
forearm = ________m (.43) = _________m

hand = ________m (.468) = _________m

Rotational Inertia of a Segment about its own Center of Gravity

$Icg=1/2mr^2$

Lever - upper arm = ______ W-A - upper arm = ______
forearm = ______ forearm = ______
hand = ______ hand = ______

Rotational Inertia $Il = \Sigma mr^2 + Icg$

upper arm =____________________ + ________ =
forearm =____________________ + ________ =
hand =____________________ + ________ = ________ kg-m^2

$$I_{wa} = \Sigma mr^2 + I_{cg}$$

upper arm = ____________________ + ________ =

forearm = ____________________ + ________ =

hand = ____________________ + ________ = ____________ kg-m^2

Rotational Inertia Ratio

$\frac{\text{Lever Ia}}{\text{W-A Ia}}$ = ________ = ________

Radius of Rotation Ratio

$\frac{\text{Lever radius of rotation}}{\text{W-A radius of rotation}}$ = ________ = ________

Predicted relationship between Lever and W-A systems for V

(if ω is equal in both systems) (from calculations)

$V_l = r\omega$ = __________ = __________

$V_{wa} = r\omega$ = __________ = __________

Observed relationship between Lever and W-A for V.

(from digitizing)

Lever __________ + __________ /2 = __________ m/sec

W-A __________ + __________ /2 = __________ m/sec

$\frac{V_{wa}}{V_l}$ = __________ = __________

Does observed maximum V equal predicted ratio.

Compairison of maximum moments of each system.

T_{wa} = __________ + __________ /2 = __________

T_l = __________ + __________ /2 = __________

$\frac{T_{wa}}{T_l}$ = ________ Meter-Newtons

Compairison of maximum angular acceleration of each system.

α_{wa} = __________ + __________ /2 = __________

α_l = __________ + __________ /2 = __________

$\frac{\alpha_{wa}}{\alpha_l}$ = ________ Degrees/Sec.^{2}

APPENDIX C

ELECTROMYOGRAPHY AND FORCE MEASUREMENTS

ELECTROMYOGRAPHY AND FORCE MEASUREMENTS

Subject #______

EMG DATA

W-A

Mean: (v)	ch. 2	ch. 3
first half of motion	________	________
second half of motion	________	________
Max. Mean: (v)	ch. 2	ch. 3
	________	________

% of Max. Mean: (v)

	ch. 2	ch. 3
first half of motion	________	________
second half of motion	________	________

LEVER

Mean: (v)	ch. 2	ch. 3
first half of motion	________	________
second half of motion	________	________
Max. Mean: (v)	ch. 2	ch. 3
	________	________

% of Max. Mean: (v)

	ch. 2	ch. 3
first half of motion	________	________
second half of motion	________	________

FORCE PRODUCTION

W-A

voltage from channel #1 without any tension ________ (a).
voltage from max. contraction channel #1 ________ (b).
mechanical advantage $\frac{10.60}{1}$ (c).
(b) - (a) = ________ (net voltage difference) (c).
(c) ________v = ________lbs (d)(from table of voltage differences).
$\frac{10.60}{1}$ x (d) ________ + 18.7425lbs = ________ kg (force).

LEVER

voltage from channel #1 without any tension ________ (a).
voltage from max. contraction channel #1 ________ (b).

mechanical advantage $\frac{10.60}{1}$ (c).
(b) - (a) = ________ (net voltage difference) (c).
(c) ________v = ________lbs (d)(from table of voltage differences).
$\frac{10.60}{1}$ x (d) ________ + 18.7425lbs = ________ lbs (force).
18.7425lbs = constant [amount to balance lever(friction)]