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

Montana State University

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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A thesis submitted in partial fulfillment
of the requirements for the degree

of

Master of Science

in

Physical Education

MONTANA STATE UNIVERSITY
Bozeman, Montana

May 1993

APPROVAL

of a thesis submitted by

Robert Mitchell Higgs

This thesis has been read by each member of the thesis committee and has been found to be satisfactory regarding content, English usage, format, citations, bibliographic style, and consistency, and is ready for submission to the College of Graduate Studies.

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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).

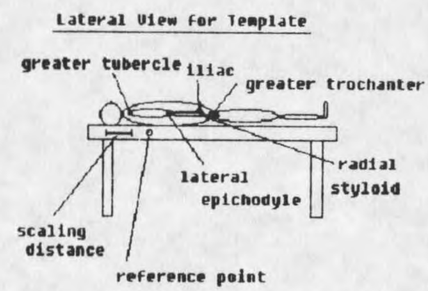
Filming Procedures

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